

Thermal Comfort as a Climatical and Cultural Variable: a case study of Lahore, Pakistan

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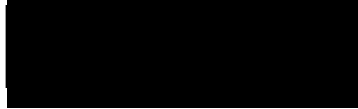
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Author's Declaration

I, Maryam Siddiq, declare that this work, submitted for the degree of Doctor of Philosophy and consisting of a thesis, meets the regulations stated in the handbook for the mode of submission selected and approved by the Research Degrees Sub-Committee.

I declare that this submission is my own work, and has not been submitted for any other academic award.

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Abstract

The initial investigations in to the field of thermal comfort focused on the physiological responses of human subjects to changes in their thermal environment. This purely objective study has progressed in recent years, undergoing several shifts in focus, to thermal comfort now being recognised as a primarily subjective entity that is dependent on numerous influencing variables to the extent that it is now often referred to as *a state of mind*.

The acceptance of thermal comfort perception being a subjective entity has not however resulted in a change to its measurement which remains established as a linear relationship between indoor comfort and the objective outdoor environmental parameters of Temperature and Relative Humidity, and few if any of the subjective influencing variables have been quantified.

The work undertaken in this thesis addresses these discrepancies in existing scholarship. The primary focus is on establishing and quantifying the variables that influence subjective thermal comfort perception as experienced by the populations of the primary case study region (developing world regions that are exposed to hot-dry climatic conditions). Extensive statistical analysis of the empirical data of the thermal environments and their occupants' thermal comfort perception and associated variables was undertaken to assess the effect of socio-economic status on one's perception of their physical environment, and in to the influence of prolonged exposure to particular physical environmental parameters on a population's expectation and consequent perception of the thermal environment.

The predictive accuracy of the traditional thermal comfort equations using both historically archived data as well as empirically collected data from the case study site is also assessed, and through a detailed statistical analysis, the best fit mathematical formula that explains thermal comfort perception with respect to the relevant outdoor environmental parameters is established.

This thesis moves the field of thermal comfort studies forward with new knowledge drawn from empirical data. The main findings of this thesis (specific to the case study area of Lahore Pakistan) are:

- Although thermal comfort is a climatically defined entity, it is also culturally specific with significant variations in thermal comfort perception existing between the different populations resident within a climatic zone.
- Previous exposure to different thermal environments has been shown to significantly influence an individuals' perception of their current thermal environment and consequently the parameters within which they perceive thermal comfort.
- Significant variation in thermal comfort perception exists between populations of different socio-economic position within a climatically and culturally specific region.

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...my everythings.**

Chapter 1

Introducing thermal comfort as a climatical and cultural variable

‘You can’t express a feeling in an equation’ –Dr. Lexi Earl -(2018)

The objective measurement or quantification of a *‘feeling’* or *emotion*, that is in essence a subjective entity, is an oxymoron in practice. It is however the *modus operandi* for assessing human need, desire, or expectation in many fields. The practice is rooted in logic, as in most instances, the human reaction(s) to physical stimuli are intrinsically tied to the objective parameters within which they are formed and influenced. In the absence of a quantifiable measurement system of the subjective entity, it is these objective parameters that are utilised to define and quantify human ‘feeling’. The definitions and formulae derived from this objective assessment of the subjective describe the subjective entity in solely objective parameters, with (one can assume), an implicit expectation that the subjective interpretation will be drawn from it to provide a holistic or well-rounded understanding of their interaction and the ‘feeling’. Without such interpretation and contextual understanding, the subjective entity: the *feeling* or *emotion*, is likely to be reduced to a numeric value that has little meaning beyond the objective.

This *express[ing] a feeling in an equation* has been both assessed and challenged in this thesis; the focus is on the field of thermal comfort studies, where the *feeling* is that of comfort within the thermal environment, which is known to be made up of many objective parameters, and their subjective interpretation, yet is measured solely by the objective environmental parameters. The study undertaken looks at the extents to which the formulaic derivations of a subjective entity through its objective parameters remains accurate, and explores the variations that exist in expectation, need, or desire within an objectively defined subjective range.

Traditionally thermal comfort has been defined through a purely rigid understanding of the physical environmental parameters and the human body’s need to maintain internal core temperature within a narrow range in order to survive. For the past five decades however, thermal comfort has been accepted as a complex entity influenced by numerous variables that affect subjective choice, and that beyond the immediate need for survival, humans desire environments that are pleasurable and induce delight (Heschong, 1979; ASHRAE, 2016). In physiological terms, the pleasure or delight experienced is known as *thermal alliesthesia*, a psychophysiological phenomenon that describes the relationship between the internal thermal state of the body with the perceived pleasure or displeasure (caused by thermal stimuli) during the process of achieving homeostasis (Cabanac, 1971; Parkinson and De Dear, 2015). The perceived pleasure or displeasure in thermal comfort studies translates to comfort and discomfort. Thus the experience of the physical objective parameters, understood to have a physiological effect on the body through the automated thermoregulatory system is described in vocabulary that is reflective of subjective choice.

Studies have shown that the thermal environments within which resident populations report comfort do vary regionally, primarily along climatic lines, such that in different climates and in different seasons within a climatic zone, people find different indoor environments comfortable (Taleghani *et al.*, 2013; Toe and Kubota, 2013). This variation can be explained through actual physical changes in the body's response to constant exposure to a thermal environment such as acclimatisation, or may be more subjective, through an expectation of a particular thermal environment due to prior experience or exposure. The prior exposure to a thermal environment may also influence the preference or desire for particular environmental conditions beyond the physiological need for survival which reflects in the thermal comfort preferences of an individual as subjective choice. Perception could therefore be said to be made up of two parts, how you perceive the environment as a physiological objective parameter, and how you perceive it based on subjective parameters. Despite this acceptance of thermal preference being both objective and subjective, the study of thermal comfort perceptions and the parameters that define it has remained within the objective realm.

The purely objective assessment of thermal comfort is reflected in the development of predictive comfort equations that are climate specific and are based on quantifying the correlation of indoor comfort parameters with outdoor prevalent conditions. These equations are required to predict a range of comfort parameters within which 80% of the local population are satisfied. The query raised by such an objective assessment is that if the evaluation of thermal comfort perception were to include an aspect of subjective influence, could the predictive power or accuracy of such equations be improved?

This is assessed in this study, by first establishing if thermal comfort is a culturally variable entity through determining the existence of variations in thermal comfort perception between different populations resident in a single climatic region. And then, through assessing the extents to which variation in thermal comfort perception occurs within a single population group based on their subjective choice.

This assessment of subjective choice of thermal comfort perception is conducted by analysing variations in perception based on an individual's (or population group's) socio-economic status. The socio-economic position, particularly within the developing world scenario is a good indicator of access to different thermal environments, the exposure to which may influence thermal comfort perception. The lines of investigation examined in this thesis thus include the effect of socio-economic position on thermal comfort perception, and the effect of exposure to different thermal environments on the expectation and preference of thermal comfort parameters. The case study site of Lahore in Pakistan is selected as a typical developing world urban region, which due to its hot-dry summer season, diverse socio-economic population, and consequent variation in thermal environments available to its residents, is expected to provide robust data for analysis.

The primary objective of this thesis is to establish the extent of influence of subjective parameters on thermal comfort perception.

It is possible that the inclusion of subjective parameters in the measurement and assessment of thermal environments may lead to improved understanding of thermal comfort, accuracy in predictions, and improved evidence-based design processes as well as more appropriate and inclusive policy documents through including reference to and acknowledging subjective

influence. This investigation in to establishing the interactions between comfort and socio-economic status is particularly relevant in the current political and ecological crisis that sees climate change and increasing social and economic inequity across the world, with potential devastating effects in the global south.

Summary of the thesis

Both the existing literature and practice of thermal comfort perception focus solely on the physical environmental variables and by implication overlook the subjective aspects of thermal comfort perception. This gap in knowledge is examined and addressed in this thesis by assessing the influence of socio-economic status of an individual on their thermal comfort perception.

The question raised through this investigation examines differences in thermal comfort perceptions of a single population due to variations in their socio-economic position, as well as the effect of exposure to different thermal environments on a population's thermal comfort perception.

To this end, this thesis is presented in 3 parts. The first 3 chapters comprises of the literature review that lay the groundwork of existing scholarship and tie the two subjects of thermal comfort and socio-economic status together. The second part of the thesis comprises of 2 chapters that present the research methodology and situate the research within the context of the case study site. The third section of the thesis is made up of a further 3 chapters; two analysis chapters that present various aspects of the investigation and a discussion chapter that provides an in-depth interpretation of the analyses locating the findings within the context of the study. These three parts are bookended by the introduction and conclusion which (respectively) introduce the study, and provide a contextual understanding of the implications of the findings within the larger body of work in the field as well as its contribution towards future research.

A brief outline of the chapters is presented below:

Chapter 2, 3 and 4 are literature review chapters.

Chapter 2 – provides an in-depth understanding of the field of thermal comfort studies. The development of the field is listed chronologically, with the two main methodological formats of thermal comfort studies, the steady state or laboratory based, and the field study methodology explained along with their relative strengths and weaknesses. The chapter lists the contributions to scholarship by both methodologies, and also provides a comprehensive description of the popular scales of measurement of thermal comfort. The recent trends in the research in the field are presented through accounts of recent literature with particular focus on those that acknowledge the subjective influencers of thermal comfort perception. The chapter highlights the gap in scholarship where the subjective influences on thermal comfort perception have not been appropriately quantified, and conjectures that such subjective influence could be empirically measured from an assessment of socio-economic status.

Chapter 3 – presents a discussion on socio-economic position. This chapter provides an explanation of the term, as well as the difference in socio-economic status, socio-economic position, and social class, and discusses their manifestation in different societies. The main

signifying parameters of socio-economic position are presented, and the complex interactions between these indicators that together form the socio-economic identity of an individual is explained. The manifestation of socio-economic position in the physical urban form is also discussed along with the effects of belonging to a particular socio-economic position and the relative difference in the available services and infrastructure, their quality and reliability, and its effect on social mobility. The differences in the meaning of socio-economic position between the developed and developing world (with respect to the parameters that define it) are presented and through this, the socio-economic position of an individual or population group is shown to be a relative and contextual entity that is largely based on subjective assessment. The criteria for the ranking of socio-economic position and the popular scales for subjective assessments are also presented.

Chapter 4 – focusses on the interactions between thermal comfort perception and socio-economic position as reported in the literature. The instances in recent literature where the main identifiers of socio-economic position have been linked with thermal comfort or thermal environments are described. The manifestation of thermal comfort and socio-economic status within the architectural form are discussed with reference to the cases presented in literature, as well as anecdotal reference of affordability of materials, land and urban density etc. which clarifies the interconnected nature of these three entities. The chapter highlights the gap in scholarship regarding the subjective influence of socio-economic position on thermal comfort perception.

Chapters 5 and 6 present the research design and the local context of the case-study site.

Chapter 5 – encompasses the research design and the methods deployed by this thesis. It presents two distinct lines of enquiry which need to be undertaken to address the research questions in their entirety. The first intends to establish the regional specificity of thermal comfort parameters, and the second to determine the influence of socio-economic position on thermal comfort perception. The methodological format for these two investigations is also discussed along with the modes of analysis proposed. The chapter also includes an introduction to the equipment used for data collection, the methodology through which data collection was undertaken, and a description of the two sets of questionnaires (one for physical environmental parameters and the other for subjective choice). The chapter also provides an outline of the selection method of participants along with a summary of their demographic information to ensure the sampling process is representative of the population of the selected case study region.

Chapter 6 – provides an in-depth introduction to the case study site of Lahore Pakistan and its suitability to the study. The chapter includes an overview of the geographic and climatic classification of the city and also includes a description of the urban character, the infrastructure and population demographics. The environmental sensitivity of the urban form, and both traditional buildings and modern buildings, is discussed with respect to their thermal properties. A socio-economic portrait of the residents is provided in the chapter as well as a description of the thermal comfort practices of the local population.

Chapters 7, 8 and 9 present the analysis and its discussion.

Chapters 7 and 8 – present the statistical analysis undertaken. Chapter 7 focuses on the physical environmental parameters of thermal comfort, establishing thermal comfort as a

climatic variable. The analysis determines the temporal and geographic extents to which a comfort equation developed for a particular geographic region could provide accurate predictions for other regions, and may establish the most appropriate means of assessing and predicting thermal comfort within the context of objective parameters. The analysis presented in Chapter 8 focuses on the subjective influences on thermal comfort perception through assessing the influence of socio-economic position on thermal comfort perception.

Chapter 9 – provides an in-depth discussion and interpretation of the analysis presented in chapters 7 and 8. The chapter reviews the hypotheses and their propositions presented in chapter 5, and concludes that the hypotheses hold true and that thermal comfort is indeed both a climatical and cultural variable.

Both socio-economic position and variations in exposure to different thermal environments have been shown to influence thermal comfort perception. The chapter discusses the limitations and weaknesses of the study and situates the results and findings of this thesis within the larger body of scholarship in the field of thermal comfort studies and shows how an original contribution to knowledge has been made.

Chapter 10 – is the concluding chapter of this thesis. The chapter provides an overview of the thesis, discusses the original contribution to knowledge, and provides a contextual understanding of the work within the field. The possible extrapolation of the findings to other fields is also indicated and through this the external validity of the research and findings is established.

Chapter 2

Thermal Comfort

This thesis presents an enquiry into the entity of thermal comfort with the intention to further the scholarship of the field through original empirical research. To this end, this chapter presents an overview of the field of thermal comfort studies.

2.1 Introduction

The term thermal comfort traditionally applies to the physiological satisfaction one feels within the environment and includes within it a significant element of psychological comfort or satisfaction with the thermal environment. Most modern definitions regard the psychological satisfaction with the thermal environment as the primary determining factor in achieving thermal comfort with the most popular definition of comfort reflecting this as it states: ‘that condition of the mind that expresses satisfaction with the thermal environment’ (ASHRAE/ISO 7730). This has led to the understanding that thermal comfort is not a steady-state entity and is rather a subjective assessment of the environmental conditions that is influenced by the perceptions and expectations of each individual. Fountain (1996, p. 182) goes further and describes thermal comfort as ‘not a physiological condition but a state of mind’, this is a recognition that physiological comfort, the *thermal sensation* is an objective measure (Hensen, 1991) and is regulated through an independently managed system and that the condition of thermal comfort or discomfort is a complex state that involves the balance of multiple variables which include the physiological and psychological as well as cultural influences thus being a subjective measure.

Enquiries into understanding thermal comfort and establishing the variables that comprise a comfortable environment date back over a century, with the earliest recorded undertaken by a British physician in 1774 (Taleghani *et al.*, 2013). These initial enquires were primarily conducted by physicians and engineers, and focused on the physiological response of the human body to changes in the thermal environment. Such investigations were conducted in controlled environments where the environmental variables could be maintained or modified by the researcher as required. These laboratory-based studies were later complimented with field studies which were undertaken within the more natural environment with little or no control over environmental factors. Both of these comfort study typologies have provided a strong understanding of the underlying need for maintaining thermal comfort, while also clarifying the extent to which human survival is dependent on a comfortable environment. Of late there has occurred a consensus amongst thermal comfort researchers regarding the relative advantages of applicability and comprehensiveness of field over laboratory-based studies as well as the acknowledgement that studies undertaken in a controlled environment are more experimental and hence do not reflect real life, leading to a focus on field study methodology. Nevertheless it must be acknowledged that the extent of understanding achieved today in the field of thermal comfort has only been possible due to the substantial work undertaken by the researchers who laid the foundations of this field through the steady state studies.

The proceeding sections of this chapter will review the existing literature and highlight the respective contributions made by both the laboratory-based and field-study approaches to the field thermal comfort studies. Through this, a comprehensive understanding of the physiological and psychological influences on the perception of comfort will be established, as well as highlighting the variables of comfort not yet explored. The chapter will thus provide a solid understanding of the contextual nature of thermal comfort perception and lay the groundwork for establishing further lines of enquiry in to the respective influence of climatic, regional, social, and cultural differences on thermal comfort perception.

2.2 Thermal comfort: the physical & psychological aspects

In order to maintain optimum function, the inner core temperature of the human body has to be maintained within a narrow range ($37^{\circ}\text{C} \pm 1^{\circ}\text{C}$) (Epstein and Moran, 2006). This is managed through an automated system, the thermal regulatory system (Figure 2.1), where the body functions as a thermodynamic machine by regulating the heat produced through metabolic process and exchanging it through the skin surfaces with the environment. The system's responses are dependent on the environmental conditions and in order to dissipate excess heat or to raise core temperature automated processes such as vasodilation, vasoconstriction, sweat production, and shivering occur (Hensen 1991). These automated responses are augmented by conscious decisions of *behavioural adjustments* or adaptations whereby clothing or the environment is modified to bring the thermal sensation to a more desirable level, for example through the wearing of a sweater or the opening of a window and also through technological adjustments where the environmental conditions are manipulated through the use of mechanical means such as turning on a fan or air-conditioning unit (Fountain, Brager and de Dear, 1996; Djongyang, Tchinda and Njomo, 2010). While these adaptations facilitate the achieving and maintaining of inner core temperatures they are often not essential to human survival as the thermoregulatory system is resilient and effective, and able to create heat balance within wide limits of the environmental variables, even when conditions not conducive to comfort (Fanger, 1970). The purpose of these adjustments then, is to provide a level of comfort that goes beyond the requirements of fulfilling bodily function.

The sensations evoked by thermal stimulation can thus be divided into two categories, temperature or *thermal sensation*, which is a measurable and hence predictable entity, and *thermal comfort* or *discomfort*, which is an interpretation of an individual's *perception* of the thermal environment and is based on their *acclimatization* to the climate and *expectation* of the thermal environment (Hensen, 1991; Goldstein, B and Brockmole, J, 2015).

Thermal sensation

Sensation is the detection of environmental stimuli by the human (or animal) body, it 'involves the elementary processes of detection at the beginning of the sensory system' without any interpretation to the meaning of the stimuli (Goldstein, B and Brockmole, J, 2015, p. 5). The sensations pertaining to changes in the thermal environment are part of the somatosensory system which detects changes to one's skin or within one's body and is known as thermal sensation.

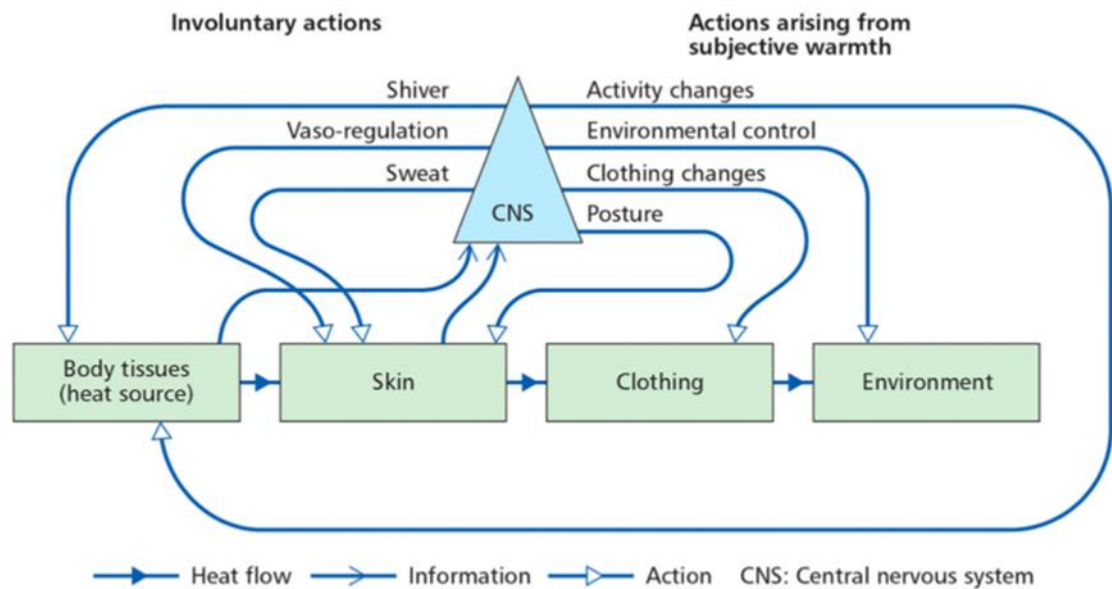


Figure 2-1

Thermal regulatory system (Nicol & Humphreys 1973 cited in (Nicol and Roaf, 2017))

Thermal sensation is affected by six factors of which four are physical variables: air temperature, air velocity, relative humidity, mean radiant temperature, and two personal variables: clothing insulation, and activity level (which translates to metabolic rate). Through the methodological control of specific climatic parameters, steady state experiments have provided an in-depth understanding of their individual influence on thermal comfort; however the effect of their relative combinations that together compromise thermal comfort has not yet been defined. The personal variables influencing thermal comfort are considerably more difficult to define as the relationships between the variables are complex and non-linear (Hensen, 1991). Furthermore, variations between different individual's metabolisms exist due to variations in their physical attributes, however an individual's metabolism is also not a static entity and has a propensity to change due to physical and mental exertion (van Hoof, 2008), as such considerable variations in thermal sensation would be recorded for the same climatic conditions for an individual, making the determination of thermal comfort parameters all the more difficult for a group of people.

This is reinforced by the understanding that several other physical factors such as the location of a person within a room, age and gender, along with regional, cultural and seasonal changes. have all been shown to influence comfort parameters (Givoni, 1992; van Hoof, 2008; Nicol, Humphreys and Roaf, 2012). Further factors influencing thermal comfort sensation have also been identified including odour, lighting, and noise, however the different interactions and combinations of these parameters and their collective influence on thermal perception has not been thoroughly investigated as yet (de Dear, 2004).

Thermal perception

Perception is the interpretation of the sensations detected by the body and involves 'higher-order mechanisms such as interpretation and memory that involve activity in the brain' (Goldstein, B and Brockmole, J, 2015, p. 5). Thermal perception thus involves the interpretation of the thermal sensation based on the existing knowledge and prior experience of thermal conditions. The previous exposure to thermal environments results in the

expectation of specific environmental parameters and this informs the ‘interpretation and memory’ that makes up perception.

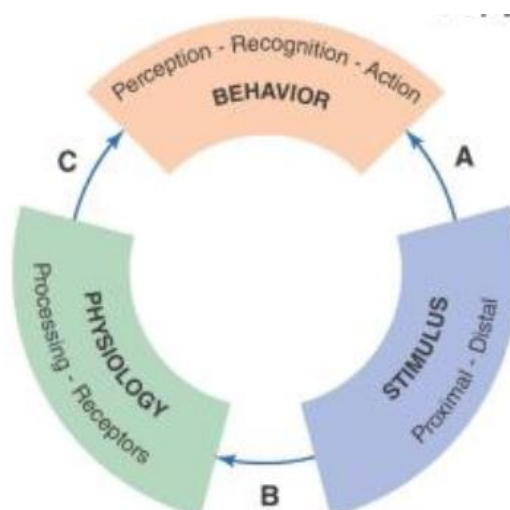


Figure 2-2

Simplified perceptual process showing the relationship between the three major components of the seven-step perceptual process: Stimuli (1 and 2), Physiology (3 and 4) and Behavioural response (5,6, and 7). (Goldstein, B and Brockmole, J, 2015, p. 11)

Expectation is thus a psychological response to the frequent exposure of varying environmental conditions that leads to a degree of acceptance (of these varying conditions) and often results in anticipatory adaption to them through behavioural or technological measures or both. This experience of exposure to the same regular variations in thermal environment (possibly due to diurnal or seasonal variations) will over time become routine and hence the adaption of it will become less conscious, more habitual and anticipatory (Fountain, Brager and de Dear, 1996; Chun *et al.*, 2008).

In other words, perception is dependent on expectation informed by previous experience. This is reinforced through studies that show that the indoor temperature regarded as most comfortable is higher in warmer climatic regions and decreases in colder climatic regions (de Dear, 2004). Furthermore, within the same climatic context, differences in reported comfortable temperatures between users of air-conditioned and free-running buildings has been recorded (de Dear and Auliciems, 1988; Chun *et al.*, 2008; van Hoof, 2008) with de Dear reporting that occupants of air conditioned buildings are twice as sensitive to changes in temperature compared to occupants of free-running buildings (de Dear 1997 in van Hoof 2008). Additionally, anecdotal and empirical evidence has been collated showing that people adapt to their environments both behaviourally and psychologically to achieve acceptable comfort conditions (Givoni, 1992; de Dear and Brager, 2002; Cândido *et al.*, 2010).

Acclimatization

Acclimatization is the physiological response to a prolonged exposure of environmental conditions which results in adaptations that optimise the functioning of the body's automated regulatory systems within the parameters of that climatic environment. The residents of a particular climatic environment or altitude are thus acclimatized to it, and people who are exposed to a new or different climatic environment or altitude become acclimatized to it over time and through constant exposure; the process of acclimatization can take from 1-3days in

the case of altitude acclimatization, and up to 5-7weeks for heat acclimatization. (Périard, Racinais and Sawka, 2015).

Acclimatization includes a process of physiological adaption through a *habituation* of the body to the particular environmental stresses the new climate imposes, examples of the adaptive processes the human body undertakes in conditions of heat acclimatization are listed in Table 2.1.

Adaptation	Consequence	Adaptation	Consequence
Core temperature	Reduced	Cardiovascular stability	Improved
Rest (temperate) – decreased		Heart rate – lowered	
Exercise – decreased		Stroke volume – increased	
Sweating	Improved	Cardiac output – better sustained	
Onset threshold – decreased		Blood pressure – better defended	
Rate – increased		Myocardial compliance – increased	
Sensitivity – increased		Myocardial efficiency – increased	
Skin temperature	Reduced	Cardioprotection – improved	
Skin blood flow	Improved	Skeletal muscle metabolism	Improved
Onset threshold – decreased		Muscle glycogen – spared	
Sensitivity – increased		Lactate threshold – increased	
Rate (tropical) – increased		Muscle and plasma lactate – lowered	
Fluid balance	Improved	Muscle force production – increased	
Thirst – improved		Whole-body metabolic rate	Lowered
Electrolyte losses – reduced		Acquired thermal tolerance	Increased
Total body water – increased		Heat shock proteins expression – increased	
Plasma volume – Increased		Cytoprotection – improved	

Table 2.1 - Physiological adaptations (automated) and their functional consequences that are associated with the heat acclimatization that results in improved thermal comfort. (Périard, Racinais and Sawka, 2015, p. 21)

2.3 Thermal comfort as a contextual entity

Recent definitions of thermal comfort have recognised the complex relationship of indoor comfort to outdoor climatic conditions (elaborated in Section 2.2), simultaneously the effect of cultural influence and personal expectation has been acknowledged within literature however it has not yet been substantiated or quantified. A persuasive argument thus exists for research in thermal comfort parameters to be conducted in the context in which they are to be applied as this will ensure the climatic, cultural, and social influences will be factored into the outputs of the research. This aspect of thermal comfort studies falls into the realm of environmental psychology, a field that deals with the often symbiotic relationship between individuals and their surroundings. Of particular interest to thermal comfort studies is the sub-discipline of the Gestalt school of thought within the field of environmental psychology. In this, the perceptual process and organization of stimuli are explained as well as an understanding of the *perceptual grouping* through which disparate stimuli are perceived together to provide a specific experience (Ehrenstien, 2001), and includes aspects of memory and prior experience in the creation of perception (Ehrenstien, 2001; Nilsson, 2001).

Within the context of thermal comfort, this translates to the relationships between parameters, (the physical environmental as well as cultural and behavioural etc.) being as important as the effect of the individual parameters in determining thermal comfort (de Dear, 2004). As the gestalt philosophy recognises that the effects of contextual perception where the occupant's perception of the space is simultaneously effected by the physical environmental conditions of the space and the psychological environment of the occupant experiencing those conditions, the physical environmental conditions are thus tinted with the pre-conceived notions of experience and expectation and cognition of the occupant. This may go toward explaining the

variations of comfort perception for members of the same population exposed to the same environmental conditions, or even the differences in comfort reported by the same people between air-conditioned and naturally ventilated spaces.

Thermal comfort is thus a contextual entity and it would appear that in order to garner a holistic understanding of thermal perception the collection of accurate data regarding person-environment relationships, which retain integrity and applicability, that studies be undertaken within the natural contexts is imperative.

2.3.1 The social context

The perception of the thermal state is a psychosomatic condition, affected not only by physical environmental variables but also the state of mind of the subject. Despite the acknowledgement of thermal comfort being region specific, current standards, guidelines, and indeed studies continue to address the notion of comfort as a function of the physical environment largely disjoint from the cultural and social aspects of the region. The few studies undertaken to understand these influences are yet to quantify their significance.

Variations in thermal comfort range have been explained due to cultural variations in clothing between different regions, seasonal changes to clothing within the same location which varies between the genders with females generally dressing more appropriately to climatic changes than males, and due to variations in clothing due to employed position with executives generally being more restricted in their clothing choices than lower subordinate staff and thus less able to adapt (Fountain, Brager and de Dear, 1996; de Dear and Brager, 2002).

Givoni (1992) referenced studies undertaken in developing countries that indicated the residents of such regions have a slightly different perception of thermal comfort from residents of the developed regions of the world and proposed a modification in the comfort range as an offset in acceptable temperature and wind speed in order to accommodate this variation. The difference in perception can be explained to a large extent through acclimatization as the prevalent climatic conditions in most developing countries are warmer than those of the developed world, however it is significant that Givoni also attributed the variation on the 'standard of living' of the developing world which references the cultural, social and economic parameters effecting lifestyle (Givoni, 1992, p. 13).

Traditionally, regional variations in environmental conditions were dealt with through cultural and social adaptations to lifestyle that included the design of buildings, the materials used in construction, the opening of windows at cooler times of the day, night time ventilation, clothing, day-time siestas et cetera (Nicol, Humphreys and Roaf, 2012). However recent trends influenced by globalization has resulted in a homogenization of the urban form and its consequent lifestyle that has in many instances done away with regional traditional adaptations and increased the reliance on mechanical conditioning of indoor spaces (Healy, 2008). While traditional methods were neither class nor social status dependent, in the case of mechanically conditioned spaces, the exposure to such environments is dependent on both the availability and affordability of the technology which, in developing regions of the world is not uniform.

2.4 Thermal scale: quantifying variations in preference

The attitudes towards, and preferences of, thermal comfort are traditionally quantified through a 7-point Likert-type scale. These attitude measurement scales are bipolar with the opposing extremes of comfort at the ends (hot vs cold) and neutral in the center with a typical Likert Scale comprising of 5 points. Most psycho-physical studies indicate recognition of the human ability to easily differentiate between a maximum of 7 sensations and thus use a 7-point Likert-type scale. This position is supported by the consensus amongst thermal comfort researchers that longer or more detailed scales do not add value or clarity to the study (Nicol, Humphreys and Roaf, 2012). Two of the more popularly used thermal comfort scales used in field studies, the ASHRAE¹ and Bedford scales are presented in Table 2.2.

ASHRAE Scale		Bedford Scale	
Hot	+3	Much too warm	7
Warm	+2	Too warm	6
Slightly warm	+1	Comfortably warm	5
Neutral	0	Comfortable –neither warm nor cold	4
Slightly cool	- 1	Comfortably cool	3
Cool	- 2	Too cool	2
Cold	- 3	Much too cool	1

Table 2.2 - 7-Point Likert-type scales traditionally used in thermal comfort studies

The initial steady-state models considered thermal neutrality (where the heat exchange of the body with the environment is maintained at essential core temperature without triggering any thermoregulation processes) as the ideal condition for thermal comfort which equated to a central vote of '0' on the scale. However the recognition that thermal comfort is a contextual entity such that people in cold environments may prefer conditions of warmth rather than neutrality and similarly occupants of hot climates may prefer conditions to be cooler, has led to the central three options on the scales from comfortably warm-to-neutral-to-comfortably cool (Bedford Scale) (in ASHRAE slightly warm-to-neutral-to-slightly cool) to be considered acceptable comfort votes. The scales can then function as a 5-point scale which is particularly suitable in that it provides the condition of nuance in subjective variation within the comfort ranges for respondents.

Both the ASHRAE and Bedford Scales are similar except for a slight difference in their wording wherein ASHRAE scale refers to thermal condition of the space and the Bedford scale refers to the thermal sensation perceived by the subject thus including the concept of comfort. However field study experience has shown that both lists are interpreted in the same way by participants in the research, and therefore the language used by the researcher in explaining the questions is significant to the participants understanding of it (Nicol, Humphreys and Roaf, 2012). The inclusion of additional scale points or supplementary questions in order to formally include the psychological aspect of thermal comfort had been proposed as early as the 1970s (McIntyre, 1978b; Schweiker *et al.*, 2017). These questions focus on the *preferences* of the respondents with regards to the thermal environment therefore incorporating thermal desire in the reporting of thermal comfort. Table 2.3 provides an overview of a representative sample of a subjective judgment scale that can be utilized to include a more complete indication of thermal preference.

¹ American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

Type of judgement	Perceptual	Affective evaluation	Thermal preference	Personal acceptability	Personal Tolerance
Subject under judgement	Personal thermal state			Thermal ambience	
Wording	How do you feel (at this precise moment)?	Do you find it ...?	Please state how you would prefer to be now	How do you judge this environment on a personal level	Is it ...?

Table 2.3 - Overview of judgement scales to be used as supplement to the thermal sensation scales. (Adopted from ISO 10551 (1995) cited in (Schweiker *et al.*, 2017)).

Another point of contention is that both scales assume a linearity of thermal comfort perception; however the change in environmental parameters and the physiological response to them is not necessarily linear and may not be the same between each unit on the scale. In fact, non-equidistant reading of the scale points by respondents has been shown to be a particular problem in Likert-type scales, where in examples such as the ASHRAE and Bedford Scales, in which each point is diagrammatically presented, respondents tend to see the central values of the scale as further apart than the scale points near the ends (Lantz, 2013). This means that respondents would perceive the distance between *comfortable* and *comfortably cool* to be greater than between *too cool* and *much too cool* with the end points being closer together. The use of a linear scale is also of concern as the hot and cold discomfort are presented as polar opposites; however the physical environmental parameters due to which discomfort is reported are different in their relative combinations for both hot and cold discomfort, as are the means of achieving comfort in both hot and cold conditions. It is imperative therefore that these scales are used as a means of recording subject response to the thermal environment and not read off as a numeric description of the comfort value of the thermal environment as this may be problematic for the interpretation of responses and analysis (Lantz, 2013; Schweiker *et al.*, 2017).

Despite these recommendations, the ASHRAE scale remains the most popularly used thermal scale in field studies since 2000, however this is often supplemented with additional comfort scales (Schweiker *et al.*, 2017).

2.5 The physical environmental parameters defining thermal comfort perception

The effects and interactions of the various parameters that determine thermal comfort perception have been shown (in the previous section 2.3) to vary depending on the particular individual circumstance and physical context of each individual and within the larger climatic and cultural context of their particular population group. It is necessary therefore to establish our understanding of these parameters within the social and environmental context as well as within the regional and climatic that they are usually defined by. In this section, the physical environmental parameters that have been found to define thermal sensation and perception are discussed, as well as an indication of their respective contributions to thermal comfort perception and an outline of their current position within the field of comfort scholarship.

Of the six primary factors that form the basis of our understanding of thermal sensation, air temperature, relative humidity, and wind speed (air movement) have been highlighted through a review of literature as the main influencers of thermal comfort perception.

Air temperature:

Air temperature has been the primary environmental parameter that is used as a measure of thermal comfort within the indoor and outdoor environments. This is generally measured with the dry-bulb temperature (which does not vary with changes in humidity levels). Surface and radiative temperatures are also known to have an effect on thermal comfort but are significantly more difficult to measure in real life situations such as in the field study scenario, and the dry-bulb temperature has been found to provide a reasonable measure against which thermal comfort values can be measured.

In indoor spaces that are not sealed from the outdoor environment such as in the buildings that are not highly insulated, or that are naturally ventilated, the influence of outdoor environmental conditions, particularly outdoor temperature, has been found to have a significant influence on the indoor environment. The correlation of the indoor comfort temperatures and outdoor temperatures has been well defined in existing scholarship (Humphreys, 1978; Halawa and Hoof, 2012; Humphreys, 2016; Humphreys, Nicol and Roaf, 2016). This has been diagrammatically represented in Figure 2.4 where it is seen that this relationship of indoor comfort temperature and outdoor temperature is largely linear except for at extreme temperatures and that variations in indoor desirable temperature appear to occur due to changes in outdoor conditions. Acceptable comfort temperature ranges therefore vary regionally as well as seasonally.

Indoor air temperatures in conditioned environments are also influenced by prevalent outdoor temperatures, however to a much smaller extent than in free-running or naturally ventilated buildings (de Dear and Brager, 1998; Taleghani *et al.*, 2013). The primary reason is the time-lag with which the indoor environment is exposed to variations in the outdoor conditions and is based on the insulative value of the building envelope (Nicol, Humphreys and Roaf, 2012; Qureshi, 2015). The thermal comfort temperatures for occupants of conditioned spaces have been found to have a complex relationship with outdoor temperature, in part because of the time lag associated with the building envelope, but also because their perception of comfort temperatures is heavily influenced by their expectation of a uniform conditioned environment (de Dear and Brager, 1998; Healy, 2008; Taleghani *et al.*, 2013).

Outdoor air temperature has been established as the main influencer of thermal comfort perception within indoor environments for both conditioned and unconditioned (free-running or naturally ventilated) environments (van Hoof, 2008; Nicol, Humphreys and Roaf, 2012; Humphreys, Nicol and Roaf, 2016), and is thus often taken to be the defining property of thermal comfort sensation and used in predictive thermal equations (discussed in detail in Section 2.6).

Relative Humidity:

Relative humidity is a measure of the water vapour present in the air, it is expressed as a percentage of the amount needed for saturation at the same temperature, and is one of the environmental parameters associated with thermal comfort perception.

The contribution of relative humidity to comfort is highly reliant on the air temperature and the human body's thermo-regulatory system; The higher the relative humidity the more difficult it is for the body to lose its excess heat through the evaporation of sweat thus

resulting in lower comfort levels. Consequently low humidity levels at high temperatures are more conducive to thermal comfort as there is no hindrance of the humidity on sweat evaporation, however humidity is not reported by occupants as providing thermal comfort in such conditions and does not factor into calculations of thermal comfort sensation (Nicol, Humphreys and Roaf, 2012). The use of air movement to assist in the evaporation of sweat is a common practice in regions of high temperatures, and in hot-dry climatic conditions, the forced increase of water vapour through the use of desert coolers or misted fans has also been a traditional conditioning method where the increased humidity level results in skin wettedness and cools the human body through *evaporative cooling* to improve comfort levels as an assist to sweat evaporation (Farnham *et al.*, 2017). This is however only effective in well ventilated spaces and if care is taken that humidity levels do not become uncomfortably high.

In cold conditions, relative humidity levels are not considered relevant to thermal comfort perception, however increased skin wettedness through high humidity levels results in a lowering of body temperature and an increased reporting of discomfort.

The relationship between temperature and relative humidity based on human thermal comfort perception was shown by Givoni (1992) to start at humidity levels of more than 50% and that temperature and relative humidity are interrelated with an increase in humidity level resulting in a decrease in the acceptable temperature. Givoni also states that the upper limit of relative humidity within which thermal comfort may be achieved is 80% in still air conditions which can be increased to 90% with the use of air movement of up to 2m/s. It is clear from this that the relationship between thermal comfort perception and humidity is not simple and that the influence of humidity is within the context of the air temperature and, to a lesser extent, the wind speed.

Wind speed:

Indoor air movement often referred to as *wind speed* is one of the primary environmental parameters that effects indoor thermal comfort.

In many areas that are climatically classified as hot or hot-dry, residents adapt by using the cooling aspect of air movement (Givoni, 1992; Fountain and Arens, 1993; Baker and Steemers, 2000; Nicol, Humphreys and Roaf, 2012). This beneficial effect of air movement has been well documented with Olgay's bioclimatic chart showing a significant increase in acceptable temperature due to increase in air speed particularly at high humidity levels (Koenisberger *et al.*, 1978), similarly Givoni (1992) has also determined air movement to be beneficial in achieving thermal comfort in high humidity environments (described in the preceding section). This effect has been both theoretically and experimentally confirmed; Fanger's comfort equation (1970) describes that an increase in temperature of 2.5°C can be compensated for by an increase in wind speed by 1m/s, while McIntyre's (1978a) practical experiments determined the upper limit of temperature at which wind speed was beneficial to be 28°C, later studies claimed a beneficial effect of wind speed of 1m/s at temperatures up to 31°C (Fountain and Arens, 1993).

Despite this positive influence of air movement, ASHRAE guidelines have limited indoor air speeds to 0.8m/s determining the *turbulent* effects of higher speeds as negating any benefits in thermal comfort sensation (Givoni, 1992). Field studies have established however that higher wind speeds of 1m/s have been reported as 'pleasant' with 'the turbulence of the air flow a

beneficial aspect' to thermal comfort (Fountain and Arens, 1993, p. 27). Similarly Baker et al (2000) discussed the effect of air speeds between 0.5m/s and 3m/s as reducing the effective temperature and determined an upper limit to acceptable wind speed to 1.5m/s after which the 'nuisance factor' (of papers etc. moving) would negate any benefits. Similar studies conducted by Tanabe showed Japanese subjects preferred windspeeds of 1.6m/s at 31°C (at 50% humidity) and by McIntyre (1978a) where subjects in a 30°C environment and with access to controls setting desired wind speed preferred 2m/s. In fact, the use of air movement as a means of achieving thermal comfort and instances of exposure to wind speeds of up to 4m/s have been recorded with no reported discomfort (Givoni, 1992).

In conditions where relative humidity is less than 100%, *evaporative cooling* can take place whereby the sweat or water on the skin surface evaporates leading to a reduction in body heat. Increased air movement facilitates evaporative cooling by moving the saturated air away from the surface of the skin more quickly resulting in an increased rate of cooling. The use of air movement in this way has been shown to increase the upper limit of relative humidity within which thermal comfort may be achieved from 80% in still air conditions to 90% with the use of air movement of up to 2m/s (Givoni, 1992).

The success of high speeds of air movement in improving thermal comfort in hot climatic conditions may also be due to the turbulence that has been considered its distracting factor in lab-based studies (Fountain and Arens, 1993; Baker and Steemers, 2000). Thermal comfort is time dependent with more recent changes in environmental conditions having more bearing on comfort perception (Nicol, Humphreys and Roaf, 2012), and as turbulence caused by air movement results in consistent unpredictable changes in the immediate environment this ensures the occupants are not exposed to, and thus do not acclimatize to a uniform environment (Fountain and Arens, 1993; Humphreys, Rijal and Nicol, 2010). Furthermore it has been well established that different parts of the human body have varying thermal comfort requirements (Fountain and Arens, 1993; Nakamura *et al.*, 2008, 2013) which means that while the non-uniform environment provided by air movement provides spot relief to only a particular part of the occupant but the perception of overall thermal comfort may still be achieved.

Further benefits of air movement include the perception of improved air quality, that is, occupants find the environment to be fresher with stale air recirculation, and perceive a decrease in temperature as wind speed is elevated (de Dear and Brager, 2002; van Hoof, 2008). There is no doubt that increased air movement has a beneficial effect in reducing the temperature perceived especially in hot climatic conditions, and it is for this reason that one of the primary modes of adaption in such regions is the use of mechanical fans for the recirculation of indoor air. It would appear logical therefore to include a reference of air movement (or the potential for it) in calculations of thermal comfort standards for such regions along with the afore-mentioned parameters of temperature and humidity.

Thermal comfort is not a purely physical entity however it continues to be predominantly defined with the physical environmental parameters that have been discussed in this section.

The relative contributions of each environmental parameter, and the contribution of their interactions with other parameters on thermal comfort have been established (as discussed in

this section) and based on this, predictive definitions of thermal comfort have been developed, predominantly in the form of predictive thermal equations (discussed in Sections 2.6.1 and 2.6.2). These predictive equations, and the standards developed through thermal comfort studies, do not however include reference to all the indices that have been developed and that address the contributions of the environmental and personal variables that are known to influence thermal comfort. The predictive equations can therefore be considered to be somewhat simplistic representing thermal comfort in terms that only refer to the primary environmental parameters or restricting the use of the equations to within set limits of environment, clothing or activity (as is done in lab-based studies).

It can be argued that there are in simple terms, too many variables to be practically catered for, both in terms of accurately measuring personal variables of clothing insulation or metabolic rate, or even radiant temperature, and also in the representation of these within predictive equations. Furthermore not all interactions or indices carry equal weight and influence on thermal comfort perception, and the inclusion of them may detract from the variable nature of thermal comfort, limiting comfort perception to a rigid binary format.

It is essential that work into thermal comfort perception and the numerous parameters that influence it is continued in order to provide a holistic understanding of the entity of thermal comfort, which may lead to the improved design and use of indoor environments to be more conducive to achieving thermally comfortable environments.

2.6 A concise account of thermal comfort studies – the salient features

Early research in the field of thermal comfort studies was largely experimental in nature and focused on understanding the physical processes of heat exchange, the effect of exposure to extreme environments and developing an understanding of the thermoregulatory system (Taleghani *et al.*, 2013). These varied experiments led to the development of indices that either form our current vocabulary of comfort studies or have been an essential development in our understanding of the field. Appendix 2.1 lists the main indices in chronological order of development.

The academic value of any research is based on its applicability to real life situations. In the case of thermal comfort studies, the application of research in practice is through the development of thermal comfort standards that act as guidelines and feed in to legislature. Two methodological formats have dominated this research, the *deterministic lab-based steady-state* methodology which has underpinned most of the established comfort standards the world over, and the *holistic person-environment centric field-study* methodology (de Dear, 2004; Nicol, Humphreys and Roaf, 2012). While the steady-state studies have been successful in providing a solid foundation of thermal comfort, the field studies have brought the study to context and enabled the link between theory and practical applicability of the knowledge.

Inter-individual and intra-individual variations in thermal perception in a population mean that it is not possible to provide acceptable thermal conditions for every occupant all of the time. Thermal comfort standards therefore aim to achieve a satisfaction level of at least 80%, with standards prepared for controlled environments striving for a higher satisfaction level of up to 90% (de Dear and Brager, 2002; de Dear, 2004; Nicol, Humphreys and Roaf, 2012).

2.6.1 Understanding the steady-state scenario

Of these early models, the most comprehensive work into understanding thermal sensation is undoubtedly the work of P.O. Fanger published in 1970. Based on a series of steady-state experiments, Fanger's study was centered on the theory of heat balance but differed from earlier work in that it combined the effects of all the six variables that affect thermal sensation (four physical and two personal), adjusted to the activity levels of the individual (as measured through mean skin temperature and sweat secretion) and provided a 'comfort equation' that could indicate the particular combinations of thermal comfort parameters that would create an optimal thermal comfort environment (Fanger, 1970). Fanger further provided an index known as the *Predicted Mean Vote (PMV)* by which the percentage of individuals satisfied with a particular environment could be predicted. Consequently the percentage of dissatisfied persons within a particular environment, known as the *Predicted Percentage of Dissatisfied (PPD)* was established. Fanger established that at a mean PMV of neutral (0), the PMD reaches a maximum of 5%, which increases to 77% when the mean sensation is reported at warm (+2) or cool (-2) (Berglund, 1979). Through this an estimation of how well a particular environment could be modified through an increase or decrease of temperature to provide thermal comfort the highest percentage of occupants known as the *Lowest Possible Percentage of Dissatisfied (LPPD)* was also provided (Fanger, 1970, pp. 16–17).

The data used to formulate the model was collected from a rather narrow sample set of college-aged students in two developed regions of the world in the northern hemisphere. The subjects, who were paid for their participation, were exposed to steady-state conditions in laboratory settings (a climate chamber) for 3-hour periods, wore standardised clothing, and were advised to carry out various near-sedentary activities during the experiment (Fanger, 1970). The resulting comfort equation is therefore quite limited in its application with Fanger acknowledging that the model is only applicable to healthy adults and cannot be applied to children, older adults, or the disabled without corrections. Fanger also acknowledged that the study was conducted with the intention of being applied by the heating and air-conditioning industry and is therefore not appropriate for use in unconditioned spaces (Fanger, 1970; de Dear and Brager, 2002; van Hoof, 2008). Furthermore, it was the author's opinion that the model was suited for conditions in temperate zones and that it could, dependent on further research, be applied to tropical conditions however it was unlikely that appropriate adjustments could be made for the model to be accurate in extreme environmental conditions (van Hoof, 2008).

It is worth noting that the research that led to the PMV-PPD model was driven by the increasing popularity of air conditioned environments and the recognition that people in urban environments spend (and would continue to spend) most of their lives in conditioned climatic environments (Fanger, 1970). Investigations into the success of the model have brought several issues to light that are primarily related to the research being undertaken in isolation from any context. These include errors in estimation of clothing insulation (clo values) and inaccurate metabolic rates and activity levels of subjects. Another aspect of thermal comfort dealt with unsatisfactorily by the model is the inability to account for short term variations in climate and to deal with the psychological aspects of thermal comfort perception including acclimatization and adaption (Humphreys and Nicol, 2002; Taleghani *et al.*, 2013).

Despite these issues, the PMV-PPD model has informed the development of several international thermal standards and guidelines including ISO²-7730 and ASHRAE Standard 55 and CEN³ CR 1752 (van Hoof, 2008; Taleghani *et al.*, 2013). The model has become the internationally accepted descriptor of the predicted mean thermal perception of occupants of a building and as a result is used to gauge the successful design of both conditioned and unconditioned indoor spaces (van Hoof, 2008).

Numerous reviews of the PMV model have been made during the past 50 years addressing its use and applicability, along with attempts to optimize its use through improvements to the model and to expanding its domain. An extension to the model was proposed by Fanger and Toftum (2002) to adjust it for use in free-running buildings in warm climates. This involved including a factor of expectancy (*e*) that is based on previous thermal experiences of the users and also adjusting for a reduced activity level based on empirical evidence suggesting people tend to slow down in hot environments (Fanger and Toftum, 2002). Several researchers have attempted to modify the PMV for use in hot climates with less success, these include the PMV_{new} proposed by Humphreys and Nicol (1986), Sherman and Federspiel's simplified linear iterations (1985 and 1992), and adjustments made through the use of Fuzzy logics (which are programmable mechanical interventions) to the indoor environmental conditions based on the imprecise and vague information that human decisions often entail (van Hoof, 2008). However the most successful of these has been Fanger and Toftum's extension for free-running buildings.

The indices used to assess the indoor environments in these models, the PMV, ET* (effective temperature in PMV*) and SET (standard effective temperature in ASHRAE Standard 55) were developed within uniform and steady state environments. Fanger believed that a uniform conditioned environment that provided thermostatic control to the user would be a more satisfactory thermal environment than one that provided control through openable windows and had a non-uniform environment (Fanger and Toftum, 2002) thus the PMV model has not been designed for use in naturally ventilated buildings. Zhang & Zhao's 2006 climate chamber experiments that sought to assess the relationship between thermal sensation, acceptability, and comfort in both uniform and non-uniform conditions proved that the PMV model lost much of its predictive ability in non-uniform environments (Zhang and Zhao, 2008) which is possibly due to the PMV model being based on studies undertaken in uniform environments and is not able to accurately predict the comfort perceptions of occupants of variable thermal environments. The same conclusion was also made through field study analysis of naturally ventilated buildings with openable windows (that consequently do not have a uniform indoor environment) (de Dear and Brager, 2001).

One of the core concerns of the laboratory based methodology has been the disjoint between the thermal environments experienced by participants in real life conditions and those within the climate chamber. Although precautions were taken to limit outside influence on the participants in order to achieve accurate measurements of their thermal perception responses,

² International Organization for Standardisation (ISO) is an independent (non-government) organization with a membership of 162 countries that share knowledge and develop international standards to support innovation provide solutions to global challenges (ISO, 2016).

³ European Committee for Standardization (CEN) is an association that brings together the National Standardization Bodies of 33 European Countries, recognized by the European Union it is responsible for developing and defining voluntary standards at European level.

the controlled conditions and restrictive behavioral requirements of this could itself cause the participants to react in non-normal ways to the thermal environment. One (somewhat extreme) example of this influence is highlighted through the image below (Figure 2.3) where female participants of a climate chamber experiment are shown in the standardised clothing specific to a particular thermal study. Such an outfit would provide a similar clo value for the researchers enabling the researchers to disregard the effect of clothing insulation however, especially in this particular example, this would undoubtedly inhibit the participants' natural response to the thermal environment and thus provide an inaccurate representation of thermal perception.

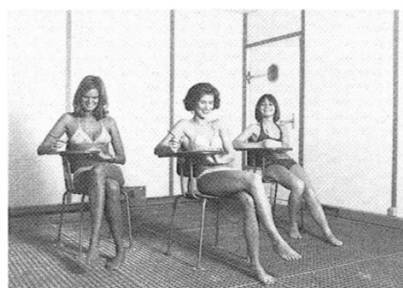


Figure 2-3

An image of participants during a climate chamber experiment taken by B.W. Olesen (from Fabbri 2015).

2.6.2 Adaptive method as complement

While the PMV model allowed for some adjustment through behavioural adaption (de Dear and Brager, 1998; Fanger and Toftum, 2002; van Hoof, 2008) the lack of contextual (location, outdoor climatic conditions) and psychological influences (based on previous experiences and expectations) led to dissatisfaction with the steady state model (Fountain, Brager and de Dear, 1996; Brager and Dear, 1998; de Dear and Brager, 1998). A solution to this was the development of the adaptive theory at the heart of which is the idea that control of both personal and environmental parameters is central to achieving thermal comfort (Brager and Dear, 1998). The adaptive theory was developed from the observation and analysis of thermal comfort practices and preferences in the field, and hypothesizes: 'If a change occurs such as to produce discomfort, people will react in ways which tend to restore their comfort' (Nicol, Humphreys and Roaf, 2012, p. 8).

The adaptive method is rooted in empirical field study methodology where data is collected on-site and with minimal intervention to participant behavior and control of the thermal environment, thus enabling a holistic approach to understanding the local environment, preferred climate, and the various methods of adaption undertaken by different populations. The results of field study data, compiled and collated into meta-datasets have been distilled through meta-analysis to understand the relationships between the environmental variables and to develop formulae of these relationships to potentially predict thermal preferences. The key meta-datasets and adaptive formulae developed are as below.

One of the earliest such analysis was undertaken by Humphreys (1975; 1978) based on a meta-analysis of approximately 30 field study surveys undertaken between 1930 and 1975 and comprising over 200,000 observations. The analysis highlighted the link between indoor comfort temperatures, prevalent indoor temperatures and outdoor temperatures, showing a significant correlation between the three. A linear relationship between indoor comfort and

outdoor temperature for free-running buildings was shown to exist as shown in Figure 2.4. Based on this, Humphreys proposed the monthly mean outdoor temperature of the region used in a linear model would predict the indoor comfort range for occupants in free-running buildings (in which no energy is expended in the heating or cooling of the indoor environment) (Humphreys, 1976; M. A. Humphreys, 1978). This led to the development of the Equation 2-1.

$$T_n = 0.534 T_o + 11.9 \quad \text{Equation 2-1}$$

Equation 2-1

Where T_n is the indoor neutral temperature and T_o is the prevailing outdoor temperature

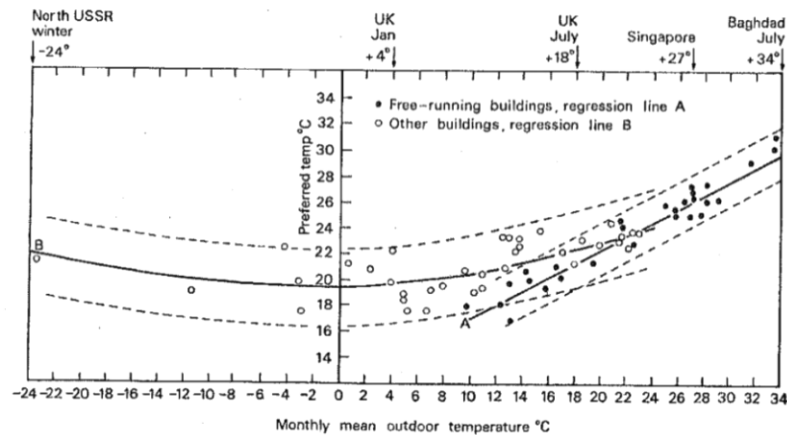


Figure 2-4

Humphrey's graph (1978) showing mean indoor preferred temperature variation with monthly mean outdoor temperature.

Free running buildings = solid circles;
 heated/cooled buildings = empty circles.
 Continuous lines = average of values;
 Dashed lines = boundary indicating 95% of values

Auliciems (1981; 1989) reworked the same dataset with the inclusion of new studies and the exclusion of those he felt were incompatible, thus inadvertently restricting the dataset to field study sites that had mean monthly outdoor temperatures to above 0°C. The study was further different from Humphreys in that Auliciems' dataset included both free-running and conditioned buildings (heated and/or cooled). Auliciems' analysis resulted in a revised formula to calculate indoor neutral temperature which included a factor of indoor mean temperature as well as the outdoor mean temperature (Humphreys, Rijal and Nicol, 2010). The use of the prevalent indoor temperature in this calculation is redundant in cases of optimum comfort as in such conditions the indoor mean temperature would equal the neutral temperature. The use of such circular logic as well as the treatment of free-running and conditioned buildings in the same dataset mean that these formulae are not adequately sensitive nor representative of the adaptive model.

In the mid-1990s, ASHRAE funded the compilation of existing field studies into a database known as the RP-884. A meta-analysis of these studies was conducted with the aim to develop an adaptive counterpart to the PMV model. This Adaptive Comfort Standard (ACS) was incorporated into the internationally accepted ASHRAE Standard 55 guidelines (de Dear and Brager, 2002).

The Adaptive Model was developed through the perusal and analysis of this extensive dataset comprising of 21,000 readings taken from 160 buildings from various different geographic and climatic locations ranging across 4 continents. In order to assemble a robust dataset a strict selecting process was undertaken whereby only projects that used a standardized (or similar) protocol in data collection methodology (measurement techniques, type of data collected, and database structure) were selected. The data was then further standardised by using uniform data processing techniques for clo calculations and comfort indices. Included in the RP-884 are a full range of thermal perception responses, estimated clothing and metabolic values as well as indoor and concurrent outdoor temperatures (de Dear and Brager, 1998, 2002).

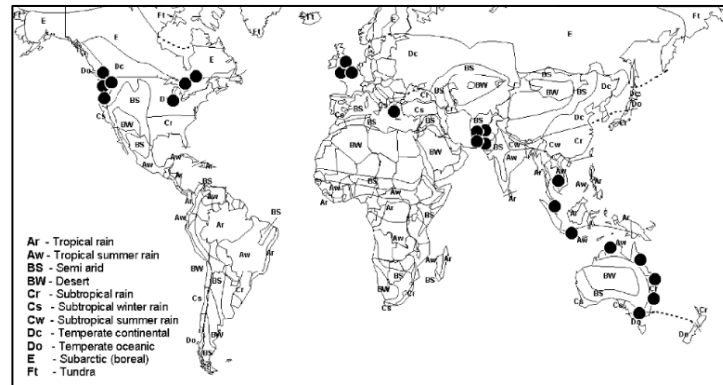


Figure 2-5

World map indicating extent of initial field study sites comprising RP-884 and indication of primary climatic classification of each region (de Dear and Brager, 2002)

In order to make the Standard easy to use, especially for the non-specialist engineer, the accurate ET^* was replaced in the second iteration of the model, and indoor comfort temperature was computed through a regression based on the mean monthly outdoor temperatures, the resulting relationship is shown in Equation 2-2

$$T_{\text{comf}} = 17.8 + 0.31T_{\text{mmout}} \quad \text{Equation 2-2}$$

Equation 2-2

Where T_{comf} is the indoor comfort temperature and T_{mmout} is the monthly mean outdoor dry bulb temperature (de Dear and Brager, 2002)

Initial studies of the database showed a significant difference in comfort temperatures between naturally ventilated buildings and conditioned buildings which was hypothesized to be due to the effect of psychological adaption (de Dear and Brager, 2002).

The ACS gives a comfort range of between 5°C -to- 7°C (at 90% and 80% acceptability respectively), and is taken in the ASHRAE Standard 55 to be reliable for conditions occupants of naturally ventilated buildings who are involved in near-sedentary activities and where mean outdoor temperature is between 10°C -to- 33°C. For conditions above 33°C the only available recourse (according to ASHRAE) is the PMV model (de Dear and Brager, 2002; van Hoof, 2008). The most recent version is the ASHRAE Standard 55-2013 which includes an allowance for the cooling effect of air movement in the calculation of comfort in naturally conditioned spaces and also provides a predictive model for occupant clothing behavior (ASHRAE, 2016).

The RP-884 was divided along climatic lines by Toe & Kabota (2013) based on the Koppen-Geiger climate classification to produce three groups representing hot-humid, hot-dry, and moderate (which included the winter readings of the RP-884). The datasets thus achieved were checked for consistency and thermal equations were developed for each climatic zone:

$$T_{\text{comf}} = 13.8 + 0.57T_{\text{dmout}} \quad \text{Hot-humid} \quad \text{Equation 2-3}$$

$$T_{\text{comf}} = 13.7 + 0.58T_{\text{dmout}} \quad \text{Hot-dry} \quad \text{Equation 2-4}$$

$$T_{\text{comf}} = 18.6 + 0.22T_{\text{dmout}} \quad \text{Moderate} \quad \text{Equation 2-5}$$

Equation 2-3, Equation 2-4, Equation 2-5

Where T_{comf} is the indoor comfort temperature, and T_{dmout} is the daily mean outdoor temperature (Toe and Kubota, 2013)

Two further region-specific adaptive guidelines have been developed along the lines of the ACS. These were the Adaptive Temperature Limits guideline (ATG), and the EN15251. The ATG was developed in the Netherlands in 2004 as a replacement to the previous standards that were based on the PMV model. This standard dealt with naturally ventilated buildings and mechanically conditioned buildings as separate cases (alpha and beta buildings respectively), where for naturally ventilated buildings its computation is similar to Humphreys' adaptive algorithm such that the indoor comfort temperature is defined with reference to the running mean outdoor temperature (a weighted composite of the average temperature of the last 4 days). The ATG provided the upper and lower limits of comfort temperature for 90%, 80% and 65% acceptability levels through variations in the algorithms for each level. Additional research has developed the guideline further for residential buildings by dividing the buildings into zones dependent on activity level, the comfort level for each zone was then predicted through a modified algorithm that incorporated the metabolic rate, clothing etc. (Peeters *et al.*, 2009; Taleghani *et al.*, 2013), however this may be too specific to be incorporated in to working guidelines.

The EN15251 is a European standard that was developed from a CEN³ (European Committee for Standardisation) funded Smart Control and Thermal Comfort project (SCATs). The project focused on naturally ventilated, non-industrial buildings (including residential houses, apartments, offices, educational buildings), and involved data collected from 26 European buildings from 5 different countries. A comfort equation was developed for each country in which the indoor comfort temperature was defined as a function of the weighted mean running outdoor temperature of the previous 7 days. Along with this, appropriate range of comfort temperature, and the acceptable degrees of deviation from this range were specified based on the various building types (Taleghani *et al.*, 2013).

Adaptive equations and the variations in reference temperature

The relationship between indoor and outdoor temperatures in the field study data has been predominantly found to be linear between indoor preference temperature and prevalent outdoor temperatures (Humphreys, Rijal and Nicol, 2010). The outdoor reference temperatures used in the various iterations of the adaptive equations described in the preceding paragraphs has been of different temporal qualities ranging from monthly mean to historical averages. These outdoor reference temperatures are largely dependent on the availability from local meteorological stations and is therefore most often the outdoor mean of the previous month. Although the monthly mean outdoor temperature by and large provides

an indication of prevalent climatic conditions, the adaptive theory recognises that significant variations can occur in outdoor climatic conditions within shorter timespans (days or weeks) that can affect the indoor comfort parameters. The use of the different outdoor reference temperatures and their relative accuracy in predicting indoor comfort temperatures has been examined and consequently a modified formula was proposed to provide a more accurate prediction of indoor comfort temperature by using an exponentially weighted running mean outdoor temperature (Equation 2-6) (Mccartney and Nicol, 2002; Nicol and Humphreys, 2002; Humphreys, Rijal and Nicol, 2010; Humphreys, Nicol and Roaf, 2016). This has enabled the effect of more recent environmental conditions on the thermal comfort perception to be included in the prediction.

$${}_nT_{rm} = (1-\alpha)T_{od-1} + \alpha {}_{n-1}T_{rm} \quad \text{Equation 2-6}$$

Equation 2-6

Where ${}_nT_{rm}$ is the running mean temperature for day n, and ${}_{n-1}T_{rm}$ is the mean running temperature for the previous day. α is a constant between 0 and 1 and governs how quickly the running mean responds to the outdoor temperature. α is a constant between 0 and 1 and governs how quickly the running mean responds to the outdoor temperature (and would be based on the thermal mass, insulative values etc.). (Nicol, Humphreys and Roaf, 2012, p. 38).

The use of large composite datasets comprising thermal comfort studies from cross-sections of populations of varied climatic and cultural backgrounds has reinforced our understanding of thermal comfort perception as an inherently subjective entity that cannot be replicated within the laboratory environment. The studies undertaken with datasets that have focused on single climatic regions have built on the earlier composite studies to show that the link between prevalent outdoor conditions and indoor thermal comfort is not a static linear relationship across different climates and is influenced by regional differences in thermal preferences and adaptations across the different cultural populations of each climatic region. Based on these conclusions, the potential for the indoor thermal comfort temperature of a single climatic region to be predicted to a more precise range than has currently been attempted, exists. The increased accuracy of predictive equations may, however, also result in a decrease in their applicability to real world scenarios.

Further to the possibility of establishing the regional variations in thermal comfort perception between different populations exposed to a single climate, these thermal comfort field studies have also laid the ground for investigating the existence and extent of variations in thermal comfort perception between different members of a regional population, such as due to variation in work environments (office, conditioned environment, factory worker etc.) or due to thermal comfort practices available (such as due to variations in socio-economic position). Previous studies based on these composite datasets have touched upon the different variables that comprise the subjective influence of thermal comfort perception within a population, however little if any effort has gone to quantifying these influences. The thermal comfort field studies have brought our understanding of thermal comfort perception to the point from where we may begin to quantify the relative influence of these subjective variables for different strata of the population.

2.6.3 The steady-state and adaptive model: weaknesses, concerns, and new solutions

Both the steady-state and adaptive models of thermal comfort have contributed to the current scholarship in the field, affecting both policy changes and influencing advances in technology to the extent that much of the changes in lifestyle across the world including the reliance on technological conditioning methods has been seen to have been influenced by them. However the methods of data collection and analysis through which these thermal models have been developed, and indeed the models themselves, have not been without criticism. With the view that, as with all design, recognizing the weaknesses clears the path from making the design stronger, the core concerns of both models are discussed in this section.

One of the core concerns of the laboratory based thermal studies has been the narrow sample set from which the participant groups were sourced. For example, the experiments conducted by Fanger relied almost exclusively on use of young college aged students which means that their age, social status (based on ability to afford college), and general health and metabolic rate could not have been representative of the population. This is further amplified by the disjoint between the thermal environments experienced by the participants in real life conditions and those within the climate chamber; even where the climate was representative of the outdoor environment, the participants being required to remain sedentary during the study, and to wear standardized clothing. Such enforced behavior and clothing choices that do not reflect the participants' normal practice would necessarily result in thermal comfort perception that would vary significantly from that normally experienced, and thus provide inaccurate data.

The field survey method of data collection addresses the disparity between laboratory and real world environments by collecting and measuring thermal data and occupant's perception within their normal thermal environment and with minimal intervention to the activity, lifestyle and clothing. It is not, however without its own weaknesses. The main argument against the field study methodology has been the increased possibility of human error in the recording of data, the collection of physical parameters, and the recording of the subjective response. This is compounded by the fact that indoor environments in the real world are rarely uniform which may result in the measured environmental parameters being different from those experienced by the participant. Furthermore, the uncontrolled aspect of field studies makes it difficult to estimate the metabolic rate, the insulative value of the clothing of the participants and other parameters that may influence their thermal perception such as lighting, proximity to apertures, or the hierarchical dynamic with respect to the control of the environment. Given these variables, it is unlikely that a thermal model based on the field study method will provide an infallible guide to thermal perception. On the other hand however, it is for precisely these reasons that advocates of the adaptive method have argued that its being more context centered provides more genuine and true-to-life reflections of thermal comfort perception that recognise thermal comfort as a dynamic non-static entity that cannot be replicated within a controlled environment.

The steady-state model, despite its disregard for the social and psychological dimension of thermal perception, has provided a strong foundational understanding of thermal sensation and the physiological reactions to changes in the thermal environment, and to an extent to our understanding of thermal perception. The field study method on the other hand, has its

weaknesses, but provides more of an opportunity to incorporate the behavioural and adaptive aspects to thermal comfort and as such has become the preferred method for thermal comfort researchers (Cole, Brown and McKay, 2010; Nicol and Roaf, 2017). Nevertheless, the PMV index developed from the steady-state studies is often used as an indicative measure of acceptable thermal conditions in both types of studies.

Over the years there have been several attempts to marry the two empirical approaches through permitting behavioural changes or adaptations in laboratory-based studies and limiting adaptations and activities in field studies. These experiments have resulted in a large collection of indices that focus on improving the predictive power thermal equations by incorporating adaptive factors to the PMV. These indices along with a brief description are provided in Appendix 2.1. These indices range from a coefficient of expectation for the PMV to the development of the adaptive thermal heat balance (ATHB) model which seeks to combine the adaptive comfort approach with existing heat balance models by assessing predictive equations for the three adaptive processes (behavioural, physiological and psychological) and incorporating the clothing insulative value and metabolic rates of the PMV calculations (Schweiker and Wagner, 2015, 2017; Enescu, 2017).

2.7 Current trends in the field of thermal comfort research

This section provides a brief outline of the current trends of research in the field of thermal comfort studies. This is not an exhaustive list or description, the purpose is to provide an indication of the wide range of topics that are under examination within the field.

The past few decades have seen an extensive body of research undertaken on the indoor thermal environment and the parameters that define desirable thermal conditions. These studies continue to range from understanding the *physiological* effects of changes to the thermal environment to the *psychological* variables that influence perception of the environment, and to the *built form* in determining the indoor environmental conditions that are, or should be, to ensure desirable thermal conditions. These three lines of enquiry have been influenced by current issues that include climate change, lowering energy-use and carbon footprint as well as an increased awareness and acceptance of the adaptive nature of thermal comfort. (Enescu, 2017; Nicol and Roaf, 2017).

One area of enquiry in current thermal research has focused on furthering our understanding of the physiological processes that take place as part of achieving a thermal balance and in achieving comfort. These studies have included large scale investigations to examine the processes of acclimatization and include assessing the thermo-physiological adaptations that occur due to the regular exposure to mildly warm environments (Pallubinsky *et al.*, 2017), exploring the links between thermal experience and adapting to new climates (Amin, Teli and James, 2018), as well as the effect of forced heat stress for acclimatizing of army personnel and for improving the performance of athletes (Périard, Racinais and Sawka, 2015). This line of research has led to the possibility that regular thermal discomfort has beneficial effects on health by varying energy expenditure and effecting metabolic rates (Lichtenbelt *et al.*, 2017), and may thus have a positive influence on managing of metabolic disorders such as Type 2 Diabetes. The effect of the indoor thermal environment on health has also been a focus of recent research especially for the elderly and vulnerable population with regards to fuel

poverty and residents of social housing (Healy and Clinch, 2002; Walker and Day, 2012; Rosenthal, Kinney and Metzger, 2014).

These investigations link closely with related studies that look in to the energy use and social characteristics and consequent thermal practices of various populations (Andamon, Williamson and Soebarto, 2006; Santamouris, Kapsis, *et al.*, 2007; Yun and Steemers, 2011). This has included research focusing on understanding and improving building energy standards that can enable the achieving and maintaining of appropriate indoor environmental conditions and thus reducing the energy expenditure on artificial conditioning (Yang, Yan and Lam, 2014). The role of building energy standards has also been debated thoroughly in recent years, bringing light to the inadequacies of existing standards and also questioning who the beneficiaries of energy standards are and who should be; for example, improved building design resulting in decreased energy expenditure to achieve and maintain thermal comfort would benefit the occupant (space user) and lead toward a sustainable environment, however if the standards cater to achieving thermal conditions that are not reflective of occupant's desires and result in an increased dependence on artificial conditioning then they are guilty of serving the agencies and owners of the conditioning companies (Chappells and Shove, 2005; Cass and Shove, 2018; Shove, 2018). Shove (2018) has further queried the call to be more efficient in thermal comfort studies and whether the term is used with regards to efficient in energy use, or efficient in maintaining thermal comfort. This line of questioning has included enquiries into the influence of the bodies funding thermal comfort research, and also highlights concern for newer trends of controlled and sealed indoor environments such as in the passivhaus system that are not respective of adaptive methods of thermal control.

The concern with occupant control over the indoor environment is actually divided into two camps, the technology-centric which disregards direct human input in the achieving of desired comfort variables having described occupant control as 'a risk that could diminish building system optimization and increase building owners' and management's economic and labour costs ... [through] uninformed and thus wasteful decisions' (Cole *et al.*, 2008, p. 326; Cole, Brown and McKay, 2010); and the people-centric (though not entirely technology-agnostic) approach that promotes occupant control. This is based on empirical field research that has shown that an element of control over the environmental conditions results in greater satisfaction with the thermal environment, and occupants with access to control are accepting of a larger range of environmental conditions and are less critical of uncomfortable conditions (Cole *et al.*, 2008). This behaviour is not limited to naturally ventilated or unconditioned environments and has been observed in air-conditioned environments where occupants have been provided thermostatic control over their immediate surroundings or have the option of adaption through the use of fans. The effect of control has been shown to go beyond the improved thermal comfort conditions with evidence linking improved energy efficiency due to occupants only using the energy required to achieve thermal comfort and only conditioning the parts of the building that are occupied (Hawkes in de Dear and Brager, 2002). Other studies in the same publication found that control also led to fewer building-related ill health conditions reported and to greater productivity. The potential to increase the percentage of satisfied users therefore exists by providing individual control to occupants within conditioned spaces (Fountain, Brager and de Dear, 1996; Cole *et al.*, 2008; van Hoof, 2008).

Studies have also revolved around understanding thermal preferences in many different parts of the world with numerous field studies being undertaken in developing world regions. Most

field studies have focused on the urban built form and are often defined by their focus on a building type or use (office, hospital, residential etc.), several detailed reviews of these studies have been undertaken (Djongyang, Tchinda and Njomo, 2010; Mishra and Ramgopal, 2013; Taleghani *et al.*, 2013; Enescu, 2017). Studies have also focused on thermal environment, comfort, and perception in specific spaces within the built environment such as transition and lobby spaces (Jitkhajornwanich and Pitts, 2002; Vargas, Lawrence and Stevenson, 2017). Similarly investigations into the effect of transitioning from a thermal environment to another on ones' thermal perception have also been undertaken (Wu and Mahdavi, 2014) (Jitkhajornwanich and Pitts, 2002). Of these, the study by Palma & Stevenson (2015) is particularly interesting as it discusses the effect of prior thermal exposure (thermal history) on comfort perception and reports that people in thermal comfort are more accepting of larger changes in the thermal environment than those reporting discomfort.

A study that stands out from the standard format of thermal comfort field studies is the Pakistan Study undertaken by Nicol *et al* (1999) in which the thermal data collected was not restricted to a building type and the focus was on recording the full spectrum of thermal environments that participants experienced during the course of their normal day. This involved the participants carrying the environmental data recording devices and recording their thermal responses themselves.

These field studies and their analysis have informed research into assessing the capabilities and limitations of thermal models especially with respect to the new challenges of climate change and sustainable design, as well as establishing the parameters of desired thermal and environmental conditions, which in turn inform the development of thermal comfort standards (Jones, 2002). This has involved the revamping of existing thermal models to include new indices of measurement (summarized in Appendix 2.1) (Humphreys and Nicol, 2002; Charles, 2003; Schweiker and Wagner, 2015; Manu *et al.*, 2016), as well as developing potential new or improved passive techniques that may contribute to improved indoor conditions by bringing indoor parameters closer to acceptable thermal conditions. Examples of such passive conditioning methods include those aimed at low-income housing outlined by Santamouris *et al* (2007) as well as assessments of the effect of ventilation in environments with chilled ceilings (Loveday *et al.*, 2002), the use of solar panels to restrict heat gain (Maneewan and Hirunlabh, 2005) and the effect of evaporative cooling through misting fans (Farnham *et al.*, 2017). Additionally, the effect of localised variations in environmental conditions such as the cooling or heating of the face, neck, or torso have also been investigated by Nakamura *et al* (2008, 2013) and Zhang & Zhao (2008), and show that the face is more sensitive to changes in thermal environment and a targeted heating or cooling of the face results in an increased response from the thermoregulatory system. This, and similar research may potentially be used to develop or promote spot conditioning of the environment to achieve thermal comfort.

Comfort research has also looked in to differences in thermal perception between the genders, with women found to be more sensitive to variations in temperature, preferring higher room temperatures than men and being more dissatisfied in both very hot and very cold conditions (Fanger, 1970; Nakano, Tanabe and Kimura, 2002; Karjalainen, 2012). Similarly low levels of light have been shown to effect thermal comfort perception making subjects feel cooler, while wooden furnishings, carpets and soft lights instill the feelings of warmth. A similar change in

thermal comfort perception was found to occur in occupants on the basis of information (both true and false) regarding environmental parameters (van Hoof, 2008).

In recent years, research into thermal comfort parameters has included a significant focus on establishing and understanding the psychological variables that make up thermal comfort perception. This includes looking in to the notion of comfort as a negotiable socio-cultural construct (Chappells and Shove, 2005; Shove, Walker and Brown, 2014), that it is formed of psychological adaptations that include expectation, environmental stimulation, time of exposure (extents), past experience and perceived control (Shooshtarian, 2015, p. 48). Several studies focus on different psychological factors effecting thermal comfort perception (Liu *et al.*, 2014; Amin, Teli and James, 2018), while others have looked towards establishing the relation between energy use and social characteristics of occupants (Santamouris, Kapsis, *et al.*, 2007). The effect of the thermal environment on user behavior has also been investigated (Gomez-Azpeitia *et al.*, 2005), as has the influence of socio-economic status on the thermal environment experienced.

Research topics and trends in thermal comfort studies, particularly those undertaken through the field study method, reflect the complex nature of human behavior and the many different variables that include physical environmental and subjective measures that effect the thermal preferences and adaptive practices of an individual or population group. The brief outline of research in the field provided in this section is therefore not an exhaustive summary of the current work, and is presented here as an indication of the various research branches within the field.

2.8 Conclusion

This chapter has provided an overview of the field of thermal studies, tracing a chronological development of the field from initial laboratory studies that attempted to understand the human body's physiological response to thermal prompts undertaken in the 17th century, to our current understanding of thermal comfort perception as a primarily psychological state of satisfaction. This has also provided an understanding of the systems of measurement of the physiological and psychological parameters that define thermal comfort perception.

The discussion within the chapter has identified through a perusal of existing literature that though the traditional definition of thermal comfort has evolved from a balance equation to a subjective choice, the primary method of quantifying thermal comfort perception remains a rigid mathematical connection between outdoor prevalent climatic conditions (temperature within a range of relative humidity) and indoor comfort (again measured as temperature). However the move from the deterministic laboratory-based steady-state methodology which has underpinned most of the established comfort standards toward the holistic person-environment centric field-study methodology has brought with it a greater understanding of the subjective aspects of thermal comfort perception. These include in particular the quality of thermal comfort perception as a non-static entity that is dynamic and influenced by variations in climate and potentially also by regional variations in cultural norms and adaptive practices. The field study methodology has been central to this shift in the understanding of thermal comfort perception, significant in which has been the influence of the large collated datasets such as the RP-884. The study of these datasets has led to the increased sensitivity of thermal

comfort researchers to the variations within the acceptable thermal comfort ranges for the different populations of a particular climatic zone. These studies have also provided a basis for identifying, and possibly quantifying the variables that inform the subjective choice of thermal comfort perception.

In this regard, the discussion within the chapter recognized that a population's thermal perception as described through the adaptive equations is based on its collective expectation of the thermal environment, yet there may exist significant differences in thermal perception between individuals of the same population due to differences in previous exposure. This would be particularly pronounced in regions of large social and economic inequity where stark differences in standard of living and availability of adaptive technologies between members of the same population exist.

The study of thermal comfort has come a long way from the days when the definition of comfort was a heat balance equation between the physical environment and the thermoregulatory system of the human body. The inclusion of psychological satisfaction with the thermal environment to its definition has not however translated to the calculation. We find that while the current predictive formulae may provide accurate data for the developed world scenario within which much of the initial data was collected, our current knowledge of the field is not adequate to provide a holistic understanding that is applicable to the rest of the world. There remains a gulf between the study of thermal comfort as a precise calculable entity and how the thermal environment is perceived in real life.

It would appear that in order to bridge this gap any new enquiry has to be directed into establishing the parameters that influence thermal comfort perception within the field, acknowledging the real life practices, and the variations that exist within a population. To this end, an assessment of how thermal comfort perception varies within a specific climatic and cultural population is required, through which the granularity of comfort perception and consequently predictive equations can be determined. Such research will determine if the present focus of thermal comfort researchers and practitioners at the climatic level where they take thermal comfort as a regional entity needs to be reassessed. It is also possible that enquiry into the thermal comfort preferences of individual population groups may provide a more precise definition and increased accuracy for predictive equations for such groups thus reducing the currently accepted accuracy rate where only 80% of the population have to report comfort.

The literature review presented in this chapter has thus led the thesis to understand that the mechanics of thermal comfort sensation and to an extent its perception both have been well researched, but the overall picture surrounding thermal comfort is still blurred with more work required in order to understand the multiple variables that influence and define it.

Chapter 3

Socio-economic Position and its manifestation in the built environment

This thesis looks toward furthering the knowledge around thermal comfort with a focus on the subjective aspect of thermal comfort perception. The literature reviewed in the preceding chapter has led to a recognition of a gap in the scholarship of the subject where the variations in comfort perception between the various populations resident in a single climatic and cultural zone have been acknowledged yet not quantified. In an attempt to determine if such variations are significant along population lines, this thesis presents the investigation in to variations in thermal comfort perception along socio-economic position in society. To this end, this chapter provides an overview of the field of socio-economic position, as well as an understanding of the manifestation of socio-economic position in architecture and the built form. This chapter will thus lay the groundwork for further enquiry into the intersections in scholarship that address thermal comfort and socio-economic position as presented in the proceeding chapter.

3.1 Introduction

This chapter aims at defining socio-economic position with a view to further our understanding of the construct; how it is developed and measured. And through this, to determine how the socio-economic position of a person or family within a community effects their movement throughout their life in regards to the opportunities afforded them and in particular how it may affect their perception of their selves, their worth, and of their environment. The chapter furthers this understanding of socio-economic position being influenced by and influencing the built environment, the infrastructure, open spaces, and the buildings and architectural form. A conversation is thus developed around the associations of the built form and socio-economic position.

The explanation of socio-economic position is undertaken through a description of the habitus through which the character traits of individuals within their society or community groups are developed. This includes the elements that give them their sense of belonging and ownership, and those that control and guide their behaviour and choices within the confines and guidelines of society rules. This is achieved through developing an understanding of what makes up a society, the particular hierarchical systems through which individuals, groups, and families are given a place, recognised, and often kept and controlled within it: their social class and their socio-economic status.

The measures of social class and socio-economic position are based on interactions between an individual's social, cultural, and economic backgrounds and their perceived status within society. They are thus both similar in their description of positioning an individual in a system of social stratification within the larger construct of society, and are often taken to be synonymous, however they refer to distinctly separate constructs and are measured in different ways. The *socio-economic position* of an individual (or group) refers to their social and

economic capital that affords them a certain societal value and lifestyle, it is a measure of their current societal worth that is not fixed and may change with time and circumstance. The *social class* on the other hand, refers to an individual's socio-cultural background that affords them a particular position and identity within their society, and is a more stable construct, not easily influenced by changes in capital, that reflects class position across generations (Rubin *et al.*, 2014). The discussion in this chapter also covers the systems through which the social class and socio-economic statuses are gauged, including an assessment of the value of the *subjective social status*. This is a measure of the social position of an individual gained through a system of self-assessment of their own societal worth and that includes contextual information regarding their social position that may not be available or obvious through the objective measures of income, education, and occupation (Adler and Stewart, 2007; Rubin *et al.*, 2014). The importance of subjective assessment is discussed in this chapter relative to the objective measures which provides clarity as to the objective identifiers comparative contribution in creating social position.

The discussion provided in the proceeding sections is an overview of the social stratification systems that are popularly and successfully used in different fields of study, and within different environments that include both the developed and developing world. The chapter is laid out with each of the objective and subjective identifiers of social class identified along with the means of their measurement. The terms *social status*, *socio-economic status* (or position), and *subjective social status* are defined and expanded upon. The discussion also includes an introduction to the expression of the socio-economic position in the built environment.

Through this, the importance of the study of such stratification systems that illustrate the implications of social class and socio-economic status on the decisions that one makes during the course of a day and across a lifetime is established. Thus laying the groundwork for understanding the specific influencing variables in the decisions and preferences in achieving and maintaining thermal comfort parameters.

3.2 Understanding socio-economic position

Several social and economic factors and their interactions influence the position of individuals (or groups) in the structure of society, creating what we commonly refer to as their socio-economic position or status (Oxford, 2016). The two terms, socio-economic status and socio-economic position, are often used interchangeably, however understanding the nuance in the meanings is essential to the text of this thesis: the word *status* invokes a sense of increased significance of privilege over the material resources such as income, education, and wealth (which are some of the primary determinants of socio-economic position) (Krieger, 2002; Galobardes *et al.*, 2006a). The term socio-economic position is therefore preferred, however in certain situations, the word status has been used, particularly when a comparative discussion of power and importance due to the social and economic capital is discussed.

The socio-economic position of a person or group is not a stand-alone description and is used in reference to the particular social structure to which they belong, and as such is context-specific. In this regard, a person of lower socio-economic position in a developing country cannot be directly compared with an individual of low socio-economic position within a developed country as the social and economic worth of both individuals is linked to the

amenities and opportunities available to them. Similarly the markers used have different strengths and limitations, and even different meanings dependent on their context. The factors included in determining socio-economic position thus have to be regionally specific and relevant to the research.

The socio-economic position is a complex construct with numerous interrelated and independent indices that relate to exposures, resources, and susceptibilities of individuals and groups. These include both resource-based factors that include markers for wealth and poverty or deprivation (income, education, property ownership, occupation etc.) and prestige-based factors which are based on the perceived social class (relative to the rest of society) that the individual belongs to. These resource-based factors are also time-dependent with different indices being more relevant for socio-economic position assessment than others during the lifetime of an individual. Figure 3.1 shows an example of such variations.

Socio-economic position is traditionally measured through indicators of *Education, Occupation, and Economic status*. These measures are interrelated and when assessed together provide an indicator of a person or social group's socio-economic status at a particular instance in time. Each of these factors represents distinctive aspects of the social position and are therefore not interchangeable, the factors also do not exist or work in isolation and are influenced by variables such as race, gender and each other (Galobardes *et al.*, 2006a, 2006b; UCSF, 2008) reflecting the complex construct that is human society.

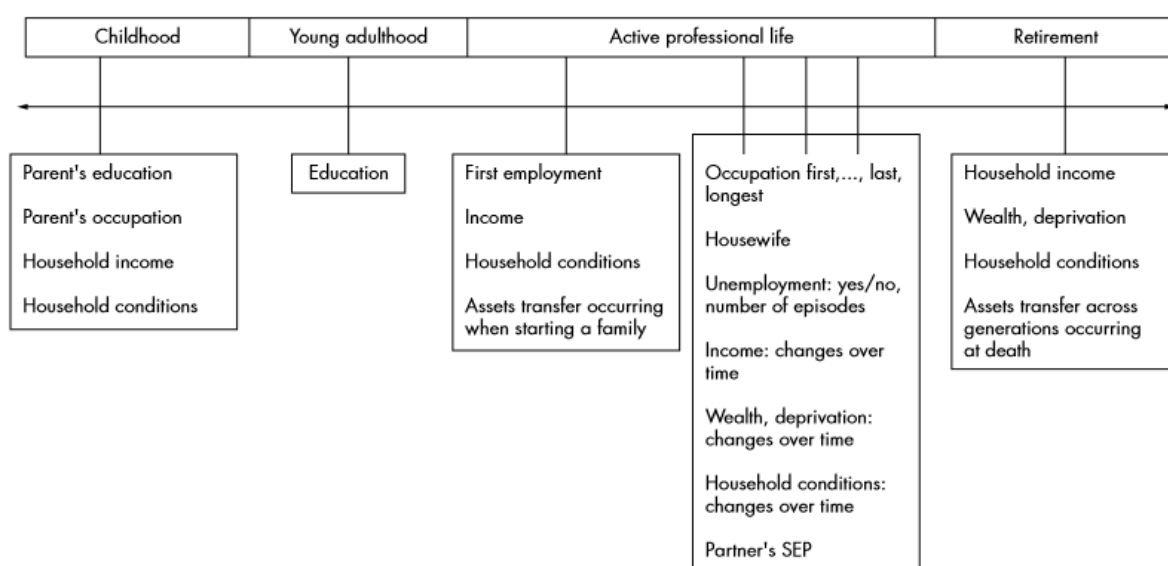


Figure 3-1

Examples of indicators measuring life course socio-economic status. (Galobardes *et al.*, 2006a).

A person's socio-economic factors are personal and often considered private which can make the collection of accurate data difficult. The main source of such information is often from the point of contact of the person being assessed, and may therefore be subject to interpretation or exaggeration. The ease with which data is available depends on its nature as well, so while the number of years spent in formal education may be easy to ascertain (though a less educated person might resist providing the information for fear of being judged by his peers), gathering data with the accurate income of a person may be more difficult.

3.2.1 Educational status

The level of one's education often translated to how many years of formal education (or lack of) is used as a measure of socio-economic position of an individual. Educational attainment is often used as a stand-alone indicator of socio-economic position being preferred over the other common markers such as occupation and economic status as it is easy to determine and reliable as not all persons have an occupation or an income. In the health sciences education is preferred over other factors as most problems that may hinder a person's economic position or occupational activities such as health impediments, usually occur in adulthood after the age at which formal education is completed. Educational attainment therefore provides a reliable indicator of socio-economic position that is not prone to contamination of reverse causation that is inherent in the other measures. (Elo & Preston (1996) cited in Stewart (2009b).

Krieger & Fee (1994) argue against the use of educational attainment as the sole indicator of socio-economic position citing that accurate representation requires information of individual, household, and neighbourhood markers of social class. There are multiple reasons for this including that educational attainment is largely dependent on the socio-economic status and especially the education level and attitudes dictated by the other members of the household. Educational attainment also has a gendered bias with the same amount of education having different social meanings for women and men. Similar variations in the social value of educational attainment has also been reported across generations which are attributed to shifts in the levels of education attainments between different birth cohorts which necessitates the taking into account in the measuring of individual socio-economic status. (Krieger and Fee, 1994; Stewart, 2009b).

For the purposes of gauging socio-economic position, educational attainment can be measured through either the years spent in formal education or through a listing of the highest credentials earned (often the highest degree is recorded with the assumption that it trumps those before it). Both methods of measurement are used in research, however the outcomes of educational attainment are not linear which means that though there may be a year's worth of education between a high school graduate and a subject who dropped out in their final year the possible attainable potential of the two is vastly different with regards to occupational and economic potential. The non-linearity of the effect of educational attainment is also visible at the higher end of the measure with there being less variation in economic status due to greater education achieved, and also for persons who reside below the poverty line as it appears that the effects of such material deprivation cannot be mediated through education. (Krieger and Fee, 1994; Galobardes *et al.*, 2006a).

The level of education garners a high response rate from subjects, however, this in isolation is not an accurate measure of the social position of a person, as it does not relate the quality of the education nor be translated directly to employability (Galobardes *et al.*, 2006a). Furthermore, as with all the socio-economic indicators, the level of education is only relevant in context, so in a society where a large percentage of the population have a college degree, the value of a high school diploma will be less than in a region where few people graduate high school.

3.2.2 Occupational status

Occupation is a 'reflection of a person's place in society related to their social standing, income and intellect' (Galobardes *et al.*, 2006a, p. 10) and is thus traditionally associated with prestige-based factors and is a strong indicator of socio-economic position.

Occupational status is used as a measure of socio-economic position as it is often a direct result of the educational level attained and is responsible for (at least part of) the economic status of the individual thus providing a somewhat rounded picture of their socio-economic position. The use of occupational status as the sole indicator of socio-economic position works well for adults in employment, and also provides a better indication of income over a longer period of time as opposed to the recording of income levels at a single point in time that may not be indicative of the full earning power of the individual over the course of his life (Williams and Collins, 1995). Occupational status can be used as the sole representative of socio-economic position as it provides information about life quality through job characteristics that include the environment, working conditions, and associated lifestyle such as the individual agency and decision-making latitude as well as psychological demands of the job that lend themselves to social status outside of the job environment. (Burgard, Stewart and Schwartz, 2003).

Traditional occupational status is often ranked with respect to the speciality of the skills required (unskilled worker, day labourer, skilled worker, data entry officer etc.) with *higher* occupations being linked with educational attainment. Non-traditional occupations cannot as easily be prescribed to these ranks, and people who are unemployed or homemakers (non-salaried spouses) whose socio-economic position is largely dependent on other members of their family are not accurately represented. Similarly landed gentry, persons who have illegal incomes, children, and retired folk all have non-traditional occupations that do not translate easily into comparable scales (Krieger, Williams and Moss, 1997) and may therefore have to be ranked according to the occupation status of the 'head of the household' or the 'highest status occupation in the household' (Galobardes *et al.*, 2006a, p. 10). The ranking systems of occupational status have largely been developed from studies of mainly white male populations and therefore do not provide as accurate results for non-white workers within the same occupational background. Similarly the ranking of women is also problematic with their social position associated with their spouses not being reflected, as well as a lack of sensitivity of the dynamics that dictate their career choices. Furthermore, the prestige and status rankings of different occupations vary across different cultures and even across generations making the comparison of cross-cultural or cross-generational ranking of socio-economic status through occupation inaccurate (Berkman and Macintyre, 1997; Burgard, Stewart and Schwartz, 2003). The use of occupational status as the sole indicator of socio-economic position has therefore been found to give an inaccurate representation of the social dynamic that exists between people due to their positions within society.

In many cultures, the hierarchical position of a person within society is dependent upon their economic interactions with others as an indicator of power and prestige; a ranking system based on this power will provide a stronger indication of socio-economic position than an individual's personal characteristics (such as occupation) alone, combinations of occupational status that include the control due to supervisory or managerial powers therefore provide a better indicator of socio-economic position. The necessity of sensitivity toward socio-

economic ranking across cultural, ethnic and demographic differences has been acknowledged as well as the understanding that the socio-economic aspects that are based on individual, environmental, or ecological measures have different strengths, possibly reflecting different aspects of social class. (Berkman and Macintyre, 1997; Burgard, Stewart and Schwartz, 2003).

3.2.3 Economic status

The Economic status of an individual is often used as an indicator of their socio-economic position within that society. This is widely measured through a linear ranking of income to represent economic status, with the most common income-based measure being a household's total cash income over the course of a month or year. This provides an indicator of the economic power that corresponds to the affordances of amenities including education and access to healthcare that are reflective of position within society, which is often cited as the reason for economic status to be the strongest and most robust indicator of socio-economic position. (Stewart, 2009a).

Economic status is also measured through an assessment of wealth that includes variables such as inherited wealth, employment benefits, car, house or land ownership and savings. This provides an indication of the economic status at a given point in time as opposed to income which reflects cash flow and may therefore be more variable across the lifespan of a person. Wealth of a family is often shared, making it a robust indicator of economic status reflecting the facilities and amenities that were accessible before personal income was generated, and also provides a reflection of their economic security as their ability to withstand hardship such as loss in income or ability to afford treatment for illness et cetera. The assessment of household wealth is more difficult to undertake than ascertaining household income as it extends to an assessment of material assets and may include size of house, type of residence, whether rented or owned, land ownership, and within rural or agricultural settings, type of residence and ownership of assets such as land, cattle, televisions, washing machines etc., or infrastructure availability such as source of potable water, sanitation facility etc. (Krieger, Williams and Moss, 1997; Galobardes *et al.*, 2006a; Vyas and Kumaranayake, 2006; Stewart, 2009a).

A positive correlation exists between wealth and income however they are not interchangeable and signify different aspects of economic status (Stewart, 2009a). The relevance of using wealth as an indicator of socio-economic position varies between different population groups such as amongst elderly or retired folk who may have a relatively small disposable income or pension but are wealthy through an assessment of their assets. Similarly in the case of populations residing in social states such as Sweden, individuals or families may have relatively little wealth but have a social welfare system to rely on in case of loss in income. (Galobardes *et al.*, 2006a; Stewart, 2009a).

The socio-economic position of a person or family is not a fixed status and is prone to variation over the years and even within a short time span as loss in income can translate to bigger differences in their buying power affecting economic status and lifestyle. This precarity of socio-economic position is more severe for people of lower economic ranking, however they may have access to support available through their community or government-led income support programs. Similarly people from higher-economic groups often have recourse to support through their accumulated assets that can make up for loss in income. Middle

income persons however do not have access to either of these support systems and are therefore most affected by, and often unable to overcome loss in income. (K. Newman 1998 cited in Stewart (2009a).

The signifiers of economic status such as income and expenditure are often considered private and are therefore difficult to ascertain accurately. The recording of such data can be further compromised in some situations where the income of a person is seasonal or for poorer members of society who may be paid in kind, and is thus less quantifiable. Often, a measure of the assets available or owned is used to replace income, however this may result in inaccurate information regarding the socio-economic position as the quality or age of material circumstance may vary significantly but quantify equally on the same wealth scale (Vyas and Kumaranayake, 2006). On occasion, the calculation of wealth can be replaced by a poverty index which essentially measures the deprivation of the population in terms of *have-not*, such as: unemployment, lone-parent households, household with occupant of long-term illness etc.

3.2.4 Variations in socio-economic status assessment

The construct of socio-economic status can be used to describe individuals as well as groups of people at the societal, community, and neighbourhood level (APA, 2018). When looking at socio-economic status at a level different from the micro or individual level, we find that the three primary indicators of education, occupation, and income, may need to be complimented with additional indicators to provide a more comprehensive impression of socio-economic status. Socio-economic position does not conform to a standard formulaic definition, it is therefore the particular nature of the study or research question, and to an extent, the methods through which the question is addressed that determine which indicators are most appropriate to the assessment of socio-economic status (Galobardes *et al.*, 2006a). As an explanation of this, a few of the more popularly used indicators are summarised below:

3.2.4.1 Family size

Family size and demographic composition are often recorded as complimentary information to the economic identifier of socio-economic position as it provides an indication of the poverty scale of the family unit. Large families are often linked to lower economic stability with less income stretched to accommodate more people. It is worth noting however that large family units can also mean a pooling of income resources where there are fewer dependents and in the case of blended or composite *joint* family systems in which several families live together (elderly parents, adult children possibly with spouses and dependents). This identifier is often culturally specific as social customs including family size and living arrangements vary in different cultures (APA, 2018).

An extension of this indicator is the measurement of overcrowding. This is calculated by the number of people divided by the number of rooms (excluding kitchen and toilets), and is considered to be high if the number is above a pre-determined number (often 2persons/room). Overcrowding reflects on the economic conditions of the unit with the assumption that resources of space, amenities, food etc. are stretched (Galobardes *et al.*, 2006a).

3.2.4.2 Housing: size, tenure, amenities, conditions

Housing characteristics such as size, tenure, and condition can be used to measure the material aspects of socio-economic conditions of a person or family group. Such information provides insight in to their economic status and incorporates both wealth and income aspects.

The type of tenure: whether a residence is rented, mortgaged, or owned, is a useful identifier in assessing socio-economic status as it reflects on the economic stability and security of the individual or family group. This is often complimented with information regarding the type of residence: detached, semi-detached etc., along with a measure of the size of property that may either be in area (square footage/meters) or as a record of the number of bedrooms or bathrooms, or the presence of a garden. Such identifiers help to establish the quality of life and reflect on the social standing of the occupants.

In certain studies, the availability of amenities may also be found to be useful indicators. These include items such as running water, the availability of both hot and cold water, indoor toilets etc. These indicators are of particular relevance to studies in developing world regions and also to studies looking at health and disease. The relevance of amenities is therefore not universal and their inclusion should be dependent on context and relevance to the study; for example, car access is an amenity that has been found useful for the assessment of socio-economic status in the urban UK context where existing public transport provisions mean that car access is not a necessity and hence is a luxury item, on the other hand, in many other countries and in rural settings within the UK where public transport systems are not as developed, car ownership is often a necessity and may not be a sign of excess disposable income. A measure of conditions of housing such as the presence of mould or broken windows etc. can also provide relevant information about the socio-economic position, this is particularly relevant in the middle classes as this is the most heterogeneous of the socio-economic classes that may not be as accurately represented through the traditional measures of income, education, and occupation.

Information regarding housing characteristics, amenities, and conditions is relatively easy to collect and may provide an in-depth understanding of socio-economic position, however, it should be noted that these indicators vary along both cultural and temporal lines and as such cannot be used across different geographic and generational studies (Galobardes *et al.*, 2006a).

3.2.4.3 Perspective of study = Level of focus

The perspective through which society is viewed for a particular study, whether at the individual, family, or community level determines the level of socio-economic position that are to be assessed and which indicators would be most suited to its assessment. At the individual or familial level the trio of income, occupation, and education are often adequate for purpose providing a wholesome reflection of status however at the communal and societal level, the assessment of socio-economic position becomes more intersectional with an understanding of historic and current policy, infrastructure and amenities becoming an essential part of the assessment.

Due to the iniquitous distribution of public wealth through policy, the infrastructures and amenities that are available to different localities and their resident populations within a single geographic region are not of similar quality. This includes services and access to infrastructure

such as access to public parks, health care, and quality education. A person born into an impoverished area will therefore have experiences throughout childhood and adolescence that are drastically different from someone from the same region that is a resident of a more enriched community. The discrepancies in experience and opportunity are unfortunately a self-reinforcing process that severely limits social mobility, reinforcing the position of a person of lower socio-economic background within that status throughout their life.

These discrepancies exist at each tier of societal hierarchy, with differences in infrastructure existing between different parts of the same town or city, and with large differences between different cities. The local government funding and earning provisions also often result in differences between different councils and provinces of countries which leads to a variation in higher-level definition of the socio-economic positions of the local populations, as the description of lower, middle, and upper socio-economic classes may differ between each region. It is therefore necessary that all studies that address issues involving socio-economic status, and particularly those that address more than one geographic region, take in to consideration these geographic and temporal definitions and influences of the indicators that are chosen for socio-economic positions of those studied.

3.2.4.4 Socio-economic status through proxy indicators

In certain instances where direct measures of socio-economic position are not available, proxy indicators can be used. These proxy indicators are not true indicators of socio-economic position but are items or measures that are strongly correlated with the socio-economic indicators within the population under study. Proxy indicators are therefore not standardised and vary between enquiries, and are also therefore population and context specific.

Proxy indicators have often been used in the field of health studies such as, for example due to the positive correlation between the number of siblings and respiratory infections in lower socio-economic populations, the number of siblings has been used as a proxy indicator for socio-economic status in other studies within the same population group. In recording the socio-economic status for regional or country level data, infant and maternal mortality rates have been used to indicate socio-economic position, as well as maternal marital status: single mother, illegitimacy et cetera, as these could lead to hardship due inability to get a (flexible) job, and social ostracisation (Galobardes *et al.*, 2006b). Similarly, being an orphan, the loss of one or both parents at an early age, or having separated or divorced parents have been used to signify socio-economic status particularly within the developing world, and have been used in several health studies for this purpose. When using proxy indicators it is essential to keep in mind the possibility of confounding factors or the existence of factors associated with the proxy indicator but unrelated to the socio-economic status, as for example, increased infant or maternal mortality rate may be due to a high incidence of infectious disease due to climate change instead of socio-economic status (Galobardes *et al.*, 2006b)

The use of proxy indicators must be undertaken with caution as there may be undocumented relationships between the proxy indicator and the other factors in the study which may distort the results. Caution must also be taken as proxy indicators may vary in strength and even meaning depending on their context (Galobardes *et al.*, 2006b). In studies where socio-economic position is not a main factor and may only be a confounding variable, several factors such as those discussed above may be combined into a composite indicator of socio-

economic position. Composite indicators are specific to the study and are often formulated based on available socio-economic position factors (Galobardes *et al.*, 2006b).

3.3 Social class

Social class is a subjective assessment of social status that is based on the material conditions and assets that have been described as socio-economic indicators (Section 3.2) and also includes an intuitive reference to social standing and power or prestige. This assessment is embodied as the establishment of a social stratification system where people are ranked in to sets of tiered or hierarchical social categories (Grant, 2001). Social class is thus intrinsically linked with the socio-economic status of an individual, with the power and prestige often taken to be relative to the economic position and wealth of the individual within society.

Typically the gradations of class are broadly divided in to three: upper, middle, and lower⁴. With each group being further subdivided in to more precise classifications through which the inner hierarchy of a single social class is labelled. The particular social and economic conditions into which an individual is born have a significant influence on the earning potential, quality of life with regards to access to health care etc., and their potential of socio-economic mobility in adulthood. However in certain instances, such as due to being in a position of power as a leader or due to managerial power, or even by virtue of physical strength, social class can be considered to be disjoint from economic value and is based solely on perceived power.

In a theoretic model the demarcations of the social classes would be clear cut with homogenous populations of similar social and economic position within each one, however in reality the boundaries of social classes are not as easy to define. The economic and lifestyle factors on which social class is assessed are non-linear, and people occupy different grades of these factors during their lifecycle due to changes in income or occupation and even in power due to familial or social position. Social class has been assessed through theoretical models; most notably the conceptualisations presented by Marx and Weber have led the way to our understanding of structural functionalism. These theories have been intersected with a number of sociological perspectives leading to variation in definitions of class that are informed by the fields of anthropology, psychology, and economics. Social class is therefore contextual to the society it is made of and also the view or perspective through which it is being assessed.

Marxist and Weberian conceptual theories hold economic power as central to the formation of a social class structure, which reinforces the use of the economic worth of an individual or population group to identify their social standing. The recognition of power and prestige is also incorporated to this understanding and is juxtaposed with the understanding of belonging through shared values, ideals, and fashions etc. (Grant, 2001; Leander, 2001). These theories thus incorporate the subjective assessment of social position within a hierarchical class system.

⁴ There has been the emergence of a fourth social class of *super-rich* that comprise the richest 1% of the world's population. This is both an economic characterisation and also a very small population group and does not therefore have a bearing on the study of socio-economic position presented in this chapter. For the purposes of this study the super-rich is considered an outlier and the focus is on the remaining socio-economic construct of the population.

Of particular interest to this study are the concepts of habitus and field introduced by Bourdieu through which he explained social class as being made up of the interplay between an individual's economic, social and cultural capital⁵ (Navarro, 2006).

The theory of habitus describes the formation of cultural capital and the power and position associated with it as the largely natural, unconsciously acquired (hence habitual) way of behaviour and mannerisms that each member of a social group possesses. People of similar backgrounds such as religion, nationality, social class, educational experience etc. share the characteristics of habitus. Habitus are the ingrained habits, skills and behaviours that are acquired through imitation and familiarity, such as in the way a child picks up the mannerisms of their parents or one picks up an accent. Habitus are formed through social interactions and are as such the result of a social rather than individual process, that is not stagnant and changes under different conditions, and even collectively over an extended period of time. The theory of the habitus also includes an explanation of the *Hexis* that is the physical and mental attributes an individual possesses. The physical attributes include one's accent, way of walking, holding themselves, their assertiveness, etc. while the mental attributes are more abstract being the mental habits, ways of thinking, perception, wittiness, and feelings: tastes and moral intuitions, that can be recognised as gut intuition of a person, and was often referred to by Bourdieu as 'the feel for the game' (Navarro, 2006; Routledge, 2016).

Habitus could be said to be the embodiment of the society in the person. This is supported by Bourdieu's claim that the cultural tastes of a society that are reflected in the tastes in art, food, etc. are due to the populations' exposure to those items and practices from a young age, and through a generational additive accumulation, they form an integral part of the habitus through which cultural identity is formed. (Bourdieu and R.Nixon, 1977; UoSussex, 2018).

The understanding of habitus also involves the concept of *field*, which are the physical and cultural environment within which the habitus is developed. Thus the arena or field of art, religion, education, all contribute to different parts of an individual's habitus, with each being distinct and autonomous from the other. Each field has its own positions and status that may or may not reflect or carry through in to the other, as for example a subordinate officer may also be the head of an extended household. The fields can thus contribute either complimentary or opposing attributes to a person, and it has been observed that individuals occupying different fields can behave in drastically conflicting ways depending on the field that they are occupying. (Navarro, 2006; UoSussex, 2018).

The measurement and ranking of social class as an empirical undertaking has been a recent development in social class studies. (Galobardes *et al.*, 2006b).

⁵ **Economic capital** refers to the economic security and consequent power an individual has by dint of his income and wealth (money, assets, property etc.)

Social capital refers to the social position within a society a person occupies and experiences through the networks between different people and groups that are based on shared values of interpersonal relationships, identity, trust and belonging.

Cultural capital is similar to the Weberian concept of status where through an individual's knowledge and intellectual skills they enjoy a particular status of position within the society which is embodied through the presentation of characteristics that other members of the society recognise.

3.3.1 Cultural class analysis

Recently, empirical investigations in to class structures and stratification systems have been driven by the awareness of increasing class inequalities as represented by economic inequity (assessed through wealth and income), along with the numerous regional and indicators of social inequity including mortality, education attained, quality and type of residence etc. (as described in the preceding sections). These studies have been heavily influenced by Pierre Bourdieu's conceptual theories, with the approach to modelling social class undertaken in a manner that is sensitive to the interplay of social, economic, and cultural capital, and forming a multi-dimensional understanding of social class that is not based solely on the identifiers of occupation or income. This approach, and the studies undertaken with it are known as *cultural class analysis* (Savage *et al.*, 2013).

In this respect, the most notable of the empirical investigation of the past decade has been the BBC's **Great British Class Survey** undertaken in 2011 which was designed to include questions through which detailed measures of economic, social, and cultural capitals could be developed. This study based on the data from two complimentary surveys provided unusually detailed data 'on the link between class and specific occupational, educational and geographical profiles which offer unparalleled insights into the organisation of class inequality in 2011-2012 [in the United Kingdom]' (Savage *et al.*, 2013, pp. 220–221). The questions regarding cultural capital included both conservative and popular measures in leisure means, musical tastes, food preferences, use of media etc., which enabled a comprehensive class analysis that is complex and nuanced and provides a reflection of the influence of cross-generational cultural capital on social class. This is discussed further in Section 3.5.

Cultural class analyses thus provide comprehensive models for stratifying social class that make up a society into the multi-faceted inter-connected complex entity it is. The analysis also provided the framework along which the types of questions can be easily modified to address particular class characterisations in different population groups and for different types of focus. The methodology developed and successfully used in the Great British Class Survey where two complimentary surveys are run is particularly relevant for the study presented in this thesis.

3.4 Subjective Social Status

The Subjective Social Status measures include a persons' own perception of their social standing within the larger construct of society. This differs from previously described models and measuring systems for social class and socio-economic status as it does not rely on a standardised methodology or bench marks for assessment. Rather, the individuals themselves provide the context through their interactions and knowledge of their society and their own relative societal and economic worth (Rubin *et al.*, 2014; APA, 2018).

Subjective assessments of social status as such provide information that is not available through objective measurements, and often adds significant value to the understanding of the social status by being both relevant to, and sensitive of, the intersections within status indicators and not prone to the biases and preconceptions that colour objective interpretations. For example, a member of an ethnic minority group may be ranked of low status in measures standardised to the rest of the population, but may be relatively well off and

ranked highly within their minority group. The use of the individual's subjective assessment of their socio-economic status (with respect to the relative population) and of their social status (with respect to their social group) would provide better understanding of the precise nature of their position within, and contribution to, society (Adler and Stewart, 2007; Rubin *et al.*, 2014). Similarly, in the context of social groups that are uniformly classified on the basis of objective assessment there may be differences in habitus that effect their comfort or discomfort within an environment that in turn effects their ability to thrive. An example of this is in the standard classification of college students as a uniform social group which is not true as there may be stark differences in the habitus of students from well-to-do families who will be familiar with the expectations of college life and of 1st generation college students who lack the vocabulary of prior experience and the lack of a supportive peer group as new entrants to college. Self-assessment also does away with the accuracy, or indeed the knowledge, required of parental occupation or income, and makes assessments of non-typical situations such as the case of an orphan, widow, widower, or care-leaver, or in the case of mature student etc. easier to classify (Rubin *et al.*, 2014).

The use of subjective self-definition of social class alongside the objective measurements of social class and socio-economic position has been shown to provide a more comprehensive impression of social status than objective measures alone; in fact, in certain cases such as in education research, subjective measures have been shown to be stronger predictors than objective measures (Adler and Stewart, 2007; Rubin *et al.*, 2014, p. 199). The schemes of measurement through which subjective assessment is popularly undertaken are discussed in detail in the proceeding section.

The use of subjective social status in the assessment of social class or socio-economic position provides a reflection of the intersectional nature of social status and society in general. It thus highlights the imprecise nature of objective measuring systems unsuited to gauge a construct that is itself not a precise objective entity.

3.5 Scales of Measurement

The scales of measurement through which social status was assessed did not initially differentiate between the status due to socio-economic means and status achieved through social position. Furthermore, the indices used to define social status were often limited to the objective indicators of socio-economic position and although the selection of indicators used in a study was primarily based on their relevance to that particular study, in many instances, the choice of indices used was restricted by the limited availability of data.

Most of today's popular scales were developed within the health industry in the developed world (Galobardes *et al.*, 2006a) and as such their focus is on the indices that fulfil the objective of class distinctions and amenities that reflect their access to healthcare. Many of these scales provide a classification system for social class that is based on an objective assessment of their social position, these are often hierarchical in nature and are developed on the basis of occupation. However, more recently, the inclusion of subjective assessments of social status especially in the fields of social psychology and education has led to the development of scales of measurement that provide a more holistic representation of the complex and intersectional nature of social status. Both types of scales are described as under.

Scales for objective assessment:

The various classification schemes that assess social class objectively, predominantly use the parameter of occupation and its associated traits of prestige, skills, and power balances through working relations and variations in lifestyle etc. due to social distance in their ranking. These indicators and their theoretical basis and group allocation are outlined in Table 3.1.

Prestige, skills	Working relations	Social distance (in lifestyle, social interactions, resources)	Property of means of production and class relations—social class
Registrar general's social class	Erikson and Goldthorpe class scheme	Cambridge Scale	Wright
I Professional	I Higher grade professionals, administrators and officials; managers in large industrial establishments; large proprietors	Continuous scale, can be arbitrarily grouped	1 Capitalist
II Intermediate	II Lower grade professionals, administrators and officials; higher grade technicians; managers in small industrial establishments; supervisors of non-manual employees		2 Small employer
III-N Skilled non-manual	IIIa Routine non-manual: higher		3 Petty bourgeoisie
III-M Skilled manual	IIIb Routine non-manual: lower	I Least advantaged	4 Expert manager
IV Partly skilled	IVa Small proprietors with employees	II	5 Skilled manager
V Unskilled	IVb Self employed without employees	III	6 Non-skilled manager
VI Armed forces	IVc Farmers/smallholders	IV	7 Expert supervisor
	V Foremen and technicians	... Most advantaged	8 Skilled supervisor
	VI Skilled manual		9 Non-skilled supervisor
	VIIa Semi and unskilled manual		10 Experts
	VIIb Agricultural workers		11 Skilled workers
			12 Non-skilled workers
Education and income			
American census classification	UK National Statistics classification (NS-SEC)		Lombardi, <i>et al</i>
I Managerial and professional	1 Higher managerial and professional employers		Underproletariat (unemployed and seasonal workers)
II Technical, sales and administrative support	2 Lower managerial and professional		Typical proletariat (unskilled and semiskilled workers in manual occupations)
III Service occupations	3 Intermediate employees		Atypical proletariat (unskilled and semiskilled in commerce and services)
IV Farming, forestry, fishing	4 Small employers and own account workers		Traditional small bourgeoisie (self employed, small business owners)
V Precision production, craft, repair	5 Lower supervisory, craft and related employees		New small bourgeoisie (university-trained professionals)
VI	6 Employees in semi-routine occupations		Bourgeoisie (large business owners)
	7 Employees in routine occupations		
	8 Never worked and long term unemployed		

Table 3.1 - Occupational based socioeconomic indicators: theoretical basis and group allocation (Galobardes *et al.*, 2006b, p. 96)

Initial classification was along the lines of *prestige and skills*, which focussed on a hierarchical classification of occupation and the prestige and social standing accorded to a particular occupation in society. Examples of this were the Registrar General's Social Class developed in Britain and used from 1911 to 1990, the UK National Statistics socio-economic classification of 2000, and the American census classification system which is similar but is based on a combination of the education and income level required for each occupation.

Classifications developed along similar lines of occupation but focussing on *working relations* have also been a popularly used means of assessing social class (Galobardes *et al.*, 2006b). These are often in the form of non-hierarchical listing of occupation types that provide an indication of social power and position through the relationships between the different categories such as those in managerial positions and their subordinates etc. This scheme has been used in several international comparisons of socio-economic position, however due to the nature of occupation and job changes, the working relations between occupation and individuals is not stagnant and so the scheme requires regular updating.

A modern iteration of the social interaction and stratification scale similar to those that identify social class through ranking prestige and skills is the Cambridge Scale that classifies

social status through assessing the *social distances* between various occupations. The premise being that the distance in interactions is defined by similarities in lifestyle, social relations, and available resources that are shared across different occupation groups. This scale provides a more socially accurate classification than previously used scales as its derivation is based on the existing social network rather than perceived status of occupation, however, this also means that the development of the scale is specific to each study (or socio-cultural region). Such scales have to be revised regularly to remain abreast of social developments and remain relevant.

A very comprehensive classification system that takes in to account both employment and social circumstances is the Wright classification that was developed based on on *Marx's theories of class and exploitation* (Galobardes *et al.*, 2006b; Wright, 2015). The scheme classifies people based on the interaction of their (i) ownership of capital assets, (ii) control of organisational assets and, (iii) possessions of skills or credential assets, which results in 12 ranks as indicated in Table 3.1. These ranks could be classified into a 5 classes of people from the capitalist (1 and 2), the petty bourgeoisie (self-employed) (3), the contradictory class (where people are simultaneously capitalist and of the working class) (ranks 4 through 10), and the working class (11 and 12). This classification scheme is robust and has been used widely with modifications made to it based on the requirements of each study undertaken and the availability of data.

Wright developed several permutations of this system, such as in assessing the American class structure, he modified the system to 8 ranks (employers, petty bourgeoisie, supervisors, expert managers, experts, skilled workers and workers), and for a permeability analysis (analysis of family ties, family composition and intergenerational class mobility) Wright reduced the scale to a 7 rank social class scale (employers, petty bourgeoisie, experts managers, managers/supervisors, professionals, skilled workers and workers). The scheme has been used extensively in epidemiological research in the in several countries including the US, Spain, and Israel, and in the UK where the classification of contradictory classes has been used to assess material wealth in health studies.

Another classification system based on Marx's theories is the Lombardi et al social class classification system that was developed in Brazil and includes several new contradictory categories that include persons who may be both exploiters and exploited (e.g. middle managers with supervisory control of junior staff) (Galobardes *et al.*, 2006b).

There exist a number of country specific occupation-based classification systems that are constructed with combinations of occupation, education, and often also income. Many of these systems have been developed by the governments and national statistics departments of these countries to aid census collection and policy making. The British Registrar General's social class classification system has frequently influenced these schemes as has Wright's social class classification system (Galobardes *et al.*, 2006b; Wright, 2015).

Scales for subjective assessment:

The advantages of subjective assessments of socio-economic position and social class over a purely objective assessment have been discussed in Section 3.4. The assessment of subjective social measures is generally undertaken through two main scales, one in which individuals are asked to categorise themselves according to social class categories such as *working class* and *upper class* such as undertaken in The Great British Class Survey, and the second that is popular

in the fields of health and social psychology of which the MacArthur Scale of Subjective Social Status is prime example.

The MacArthur Scale provides a 10 point ranking system or *social ladder* on which individuals rank their subjective socio-economic status based on their perceptions of their occupation, income, and educational prestige relative to their peers (i.e. their socio-economic position), and rank their subjective social status based on their perception of status in society or social class also referred to as the *community ladder* rankings. The dual ladder assessments have been proven to be beneficial in representing the complex construct of social class, and have led to the understanding of the relative importance of subjective assessment over objective measures in certain conditions (Adler and Stewart, 2007; Rubin *et al.*, 2014). Both of these subjective assessment scales have been found to be correlated when used in the same study (Adler and Stewart, 2007). Through these scales it has been shown that the relative importance given to status identifiers such as material wealth and education, varies with race and ethnicity. Similarly, within a social group, subjective scales have been found to be non-linear and temporal in nature. (Singh-Manoux, Adler and Marmot, 2003; Adler and Stewart, 2007; Rubin *et al.*, 2014).

The Great British Class Survey conducted in 2011 is a comprehensive survey and analysis of British class undertaken with over 160,000 respondents from across the UK. Through this, a model of contemporary British society was developed that focussed on assessing the cultural, social, and economic capital of the population groups. This model provided a breakdown of the British society into 7(seven) social classes, only two of which appeared to fall within the typical middle and working class distinctions determined by previous sociological models (39% of the population). The model also highlighted the existence of a discernible elite, and a sizeable (15%) of the population with no tangible capital (identified as the precariat). The Great British Class Survey also highlighted the lack of boundaries between the different social classes, and determined the inaccuracy of using occupation as the primary classification tool for social classes (Savage *et al.*, 2013).

3.5.1 Socio-economic measures in the developing world

The social and economic inequity between rural and urban populations in developing countries necessitates the use of either different classification systems for the two populations, the use of different identifiers to assess socio-economic position within the same classification system, or the selection of such indicators that can accommodate the inequity providing a realistic classification of socio-economic position.

An example of the latter is the assessment of socio-economic status in the data collected for national census in developing countries such as Pakistan and India. These census documents provide data on countrywide assets such as trade, transport, population, access to education, health facilities, and potable water, as well as on private assets including land, livestock, and levels of income, education and transport. This provides a region-wide socio-economic profile for each region, city and street, which is also known as area-level measures or indices of deprivation, (Government of Pakistan, 2002; Galobardes *et al.*, 2006b; B.O.S. Punjab, 2015). The ability of these development profile and census studies to assess varying socio-economic conditions across regions of stark inequity is due to the assessment of communal wealth on the basis of ownership of assets which accommodates a much larger group of profiles than an

assessment of fewer indices would allow. These documents therefore do not provide a socio-economic classification system that identifies the socio-economic position for individuals.

Comprehensive measuring schemes of socio-economic position have been developed by the advertising and market research agencies in both Pakistan and India, which have been referenced in local government policy and used by analytics companies such as Gallup International (Gallup-Pakistan, 2016; Sharma, 2017). These socio-economic classification systems developed recognised the difference in wealth and asset assessment between rural and urban populations and this was reflected in the choice of different indicators used for both. The urban populations have largely been assessed on the basis of the objective parameters of socio-economic position including education, occupation, and income to provide a scaled ranking system. In rural populations the parameters used in the assessment have often included assets as an indicator of wealth, as in the case of the Socio-economic Classification (SEC) developed by the Market Research Society of India (MRSI) the rural SEC is assessed on the basis of education of the head of the household (or chief wage earner) and type of house (permanent, semi-permanent, or shanty) or on the basis of the material used in construction. This provided a 4-scale ranking system of socio-economic class.

Kappuswamy's socio-economic scale initially proposed in 1976 for urban populations in India is another popular scale that has undergone several updates and revisions most recent of which was undertaken by Sharma (2017) and involved an online interactive scale that can be easily modified to incorporate for inflation etc. This scale incorporates measures of the three objective parameters of socio-economic position with scores allocated for the education level and occupation of the head of the family unit along with a scoring for the monthly family income (drawn from an online form). These scores are tallied and the socio-economic class determined by the total score (presented in Table 3.2) (Sharma, 2017)

<i>Education</i>	<i>Score</i>	<i>Occupation</i>	<i>Score</i>	<i>Family income per mo (in Rs)</i>	<i>Score</i>	<i>Socioeconomic class</i>	<i>Total Score</i>
Post-graduate or professional degree	7	Professional	10	Real-time updated income 1 to 12 categories using www.scaleupdate.weebly.com	12	Upper	26-29
Graduate degree	6	Semi-Professional	6			Upper Middle	16-25
Higher secondary certificate	5	Arithmetic skill jobs	5			Lower Middle	11-15
High school certificate	4	Skilled worker	4			Upper Lower	5-10
Middle school certificate	3	Semi-skilled worker	3			Lower	<5
Literate, less than Middle school certificate	2	Unskilled worker	2				
Illiterate	1	Unemployed	1				

Table 3.2 – Socio-economic status scale by Kuppuswamy, revised with real-time update (Sharma, 2017, p. 870).

The revised and updated Kuppuswamy Scale by Sharma (2017) also provides explanatory text as to the meaning and allocation of the education and occupation parameters. These are presented in Table 3.3.

The Socio-economic Classification developed by the Market Research Society of India (MRSI)(2011) caters to both rural and urban populations in one classification system. This was developed primarily as a measure of socio-economic class to help media researchers, and understand consumer choice and thus required a robust cross-socio-economic position ranking scheme. This has been done by using two variables, the education of the chief earner,

and the number of consumer durables (from a pre-determined list of 11) owned by the family, resulting in a 12 grade ranking system (as represented in Table 3.4). The selection of assets is based on the relevance of the indicators in consumption preferences and purchasing power of households, this SEC is primarily for use by the advertising industry and as such the primary concern of the quality of the assets signifying differences in socio-economic position is not of consequence. The income level is not included as this is difficult to ascertain particularly in agricultural economies where the income stream may be seasonal (MRSI, 2011). Due to the variability in user preference of durables including changes in their availability and affordability, classification systems that measure their ownership as an indicator of socio-economic position have to be revised regularly.

<i>Occupation category</i>	<i>Salient points</i>	<i>Examples</i>
Professional	Decision making, formulating policies and execution of policies. Jobs that need creative work. Jobs involving high organizational ability, and control of large number of humans. Or, jobs that involve dealing with large amounts of money. Most require very high general or professional education, but this is not compulsory.	Doctors, Advocates, Engineers, Architects, Directors, Managers, senior administrators, Readers and Professors, newspaper editors, college Principals, Architects, Bank managers.
Semi-Professional	Jobs requiring post-high school education. But routine nature of jobs.	High school teachers, College lecturers, junior administrators, junior medical practitioners.
Arithmetic skill jobs	Jobs that require some training in arithmetic and probably also reading, writing. But jobs that are basically repetitive in nature. 'Arithmetic skill' in context of higher arithmetic skills required for job.	Clerk, accountant, typist, elementary school teacher, farm owner, shopkeeper, salesman, insurance agent, news journalist.
Skilled worker	Long training in complicated work	Driver, telephone operator, mason, carpenter, mechanic
Semi-skilled worker	Jobs that require some training	Factory labourer, car cleaner, petty shopkeeper
Unskilled worker	No education or training required	Domestic servant, peon, watchman
Unemployed	Irrespective of education level	Self explanatory

<i>Education category</i>	<i>New name for the category</i>	<i>Salient point</i>	<i>Examples</i>
Profession or honors	Post-graduate or professional degree	Any Post graduation. Any high grade professional education (which may directly be after class XII)	M.A., M.Sc., Ph.D., M.Ed. M.B.B.S., B.E., B.Arch.
Graduate or post graduate	Graduate degree	Any graduation deegree (other than high grade professional education)	B.A., B.Sc., B.Ed.
Intermediate or post high school diploma	Higher secondary certificate	Class XII pass	Class XII pass, Class XII with vocational diploma
High school certificate	High school certificate	Class X pass	Class X pass, Class XI pass (didn't complete Class XII)
Middle school certificate	Middle school certificate	Class VIII pass	Class VIII pass, Class IX Pass
Primary school or literate	Literate, less than Middle school certificate	Literate would be as per the definition followed by Census of India. That is, person aged ≥ 7 years who can read and write with understanding in any language.	Any level of literacy below Class VIII (that is, did not get Class VIII pass certificate)
Illiterate	Illiterate	Person aged ≥ 7 years who cannot read and write with understanding in any language. Or, any person aged < 7 years	Person who can only read but not write with understanding in a language.

Table 3.3 – Explanation and examples of classification of Occupation and Education of Head of Family as per the revised Kappuswamy Scale (Sharma, 2017, pp. 868–869)

No. of Durables Owned	Education of CWE						
	Illiterate	Literate but no formal school/ School up to 4 yrs	School: 5 to 9 years	SSC/ HSC	Some College (incl Diploma) but not Grad	Grad/ PG: General	Grad/PG: Professional
	1	2	3	4	5	6	7
None	E3	E2	E2	E2	E2	E1	D2
1	E2	E1	E1	E1	D2	D2	D2
2	E1	E1	D2	D2	D1	D1	D1
3	D2	D2	D1	D1	C2	C2	C2
4	D1	C2	C2	C1	C1	B2	B2
5	C2	C1	C1	B2	B1	B1	B1
6	C1	B2	B2	B1	A3	A3	A3
7	C1	B1	B1	A3	A3	A2	A2
8	B1	A3	A3	A3	A2	A2	A2
9 +	B1	A3	A3	A2	A2	A1	A1

Table 3.4 – Classification grid for socio-economic position for rural and urban populations in India. Where, A= Upper Class and E= lower class (CWE = Chief Wage Earner) (MRSI, 2011; BARC, 2015)

A similar socio-economic classification was also developed in Pakistan, this was undertaken by independent research house and funded by the Pakistan Advertising Society (PAS), with similar intentions as the Indian SEC to assist media researchers understand consumer choice. The PAS-SEC grid (Table 3.5) was developed as a socio-economic position classification of the urban population of Pakistan. The grid classifies the relationship between the occupation type and education level of the chief earner (or head) of household. This results in a 5-scale ranking from A (upper class) to E (lower class) with the highest and lowest classes further divided into two for increased distinction. The PAS-SEC has been a successful classification system for conditions where income cannot be used as an indicator. Income percentiles are however available from census documents and the Household Integrated Economic Survey (B. O. S. Punjab, 2014) which have been used to augment the SEC grid by Gallup Pakistan to provide a robust socio-economic position classification system that uses occupation, education and income levels (Table 3.6) (Gallup-Pakistan, 2016). The income ranges within this classification do not appear to have been adjusted for inflation and are at present conservative estimates.

An updated asset-based SEC that will cater to urban and rural populations is under development by the PAS. The use of assets will utilise the indicator of wealth instead of income making for a rounded and stable classification system (P.A.S., 2015).

These socio-economic position classification schemes recognise that greater social and economic inequity exists within developing world countries that needs to be dealt with sensitively to ensure continuity in the ranking system of classes across varying socio-economic conditions. While the main differences in socio-economic position is expected between rural and urban areas, significant social and economic variation exists within each rural and urban region, which the current classification schemes do not cater to. The new asset-based SEC schemes aim to rank populations based on their socio-economic position on one scale, however the value, affordability, and relevance of different durables and assets varies between rural and urban environments and as such the accuracy of a single classification scheme would need to be rigorously checked.

OCCUPATION OF CHIEF EARNER	EDUCATION OF CHIEF EARNER						
	Illiterate	Less than Primary	School 5-9 years	Matric	Intermediate	Graduate	Post-graduate
Unskilled worker	E ₂	E ₂	E ₁	E ₁	D	D	C
Petty Trader	E ₂	E ₂	E ₁	E ₁	D	C	C
Skilled Worker	E ₂	E ₂	E ₁	D	D	C	C
Non-Executive Staff	E ₂	E ₂	D	D	D	C	C
Supervisory Level	D	D	C	C	B	B	B
Small Shopkeeper/Businessmen	D	D	C	C	B	B	A ₂
Lower/Middle: executive, officer	D	C	C	C	B	B	A ₂
Self-employed/Employed professional	B	B	A ₂	A ₂	A ₂	A ₁	A ₁
Medium Businessmen	B	A ₂	A ₂	A ₂	A ₂	A ₁	A ₁
Senior Executive/Officer	B	A ₂	A ₂	A ₂	A ₁	A ₁	A ₁
Large Businessmen/Factory owner	A ₂	A ₂	A ₂	A ₁	A ₁	A ₁	A ₁

Table 3.5 - Socioeconomic classification grid for urban populations of Pakistan (P.A.S., 1997)

A1	Upper Class	Upper Upper Class	2.8%	Rs. 50,000+
A2		Upper Middle Class	3.8%	Rs. 30,001 to Rs. 50,000
B	Middle Class	Middle	10%	Rs. 15,001 to Rs. 30,000
C		Middle	18.5%	Rs. 7,001 to Rs. 15,000
D	Lower Class	Lower Middle	21.6%	Rs. 3001 to Rs. 7,000
E1		Lower Class	19.4%	Less than Rs. 3000
E2	Very Lower	Lower Lower Class	23.9%	

Table 3.6 - Pakistan Advertisers Society (PAS) income classification with respect to perceived social class (Gallup-Pakistan, 2016)

The SEC schemes discussed in this section focus on the developing world scenario and appear to provide a rigid objective description of socio-economic position. While this may be adequate for the purposes of market research, the incorporation of a measure of social class through a self-assessment may be beneficial as discussed in Section 3.3 and Section 3.4.

3.6 Socio-economic position and architectural form

The socio-economic position of an individual or population is intrinsically linked to the urban spaces they occupy and the infrastructure that is available to them.

The socio-economic position is a complex construct with numerous interrelated and independent indices that relate to exposures, resources and susceptibilities of individuals and groups as discussed in detail in Section 3.2 and Sections 3.3. Amongst the parameters that effect the socio-economic position and social class of an individual or population group is the physical environment and allied infrastructure available to them. The links between spatial arrangements and social behaviour have been examined with empirical evidence supporting this influence (Lipman, 1969). The relationship between urban layout, land-use patterns, and economic activity have been shown to be linked with the socio-economic position of residents and users (Stead, 2001; Zertuche, 2015; Brelsford *et al.*, 2018), and as such, the physical environment and the allied infrastructure as objective parameters, both define the socio-economic position while simultaneously reinforcing it.

As indicators of socio-economic position, the urban spaces and the architectural form are particularly useful as they can be read as literal measures of social class and do not require much dissection beyond the objective. An example of this are existence of slum or squatter settlements that provide stark visual contrast with the residential areas of higher socio-economic populations as presented in the following images.



Figure 3-2

Images from the Unequal Scenes series by Johnny Miller (2019) presenting a visual reference of socio-economic position through the various urban forms of a city.

Clockwise from top left: Mumbai (India), Santa Fe (Mexico), Ballard in Seattle (USA), Durban (South Africa), Dar es Salaam (Tanzania), Mexico City (Mexico).

The lack of planning of space and infrastructure provision in low-income settlements that stands out from these images is similar to the differences in urban space and architectural form between other socio-economic groups within a socio-cultural population which is present even within planned regions as visible in Figure 3.3.

The primary visual difference between the urban spaces catering to different socio-economic populations is the allocation of space for both residential units and public spaces. This has considerable ramifications on the exposure and experiences of the residents and can therefore, in the academic context, be taken as the field within which the habitus of the various populations develops (leading on from the discussion in Section 3.3). Understanding that the architectural form of each socio-economic region is dictated by the space available or allocated, leads to the understanding that the particular lifestyle of the residents and their

interactions with each other, in short the culture that develops within a socio-economic region is largely dictated by the urban spaces and architectural form (Lipman, 1969; Navarro, 2006).



Figure 3-3

Different spatial quality to the urban fabric visible along socio-economic lines in formally planned estates in Lahore, Pakistan on left and Rutherglen, Scotland on right (Images from Google Maps 2019).

The architectural form, particularly of residential buildings, is connected to the disposable income of the residents and is therefore linked to their socio-economic position. This may also be more obvious from the condition of the residential units, the density of occupancy (persons/room), or the materials used in construction. These choices are largely dependent on the economic position of the residents, with empirical evidence indicating that changes in socio-economic position influence changes in architectural form (Etich, 1992).

The architectural form and its condition (state of repair) that an individual or family unit occupy can thus be indicative of their socio-economic position. And in the same way, the socio-economic position of a population can be gauged through the urban spaces and architecture they occupy or are restricted to.

3.7 Conclusion

The discussion presented in this chapter has provided an outline of the complex construct of social class, explaining the difference in meaning between social class and socio-economic status, and providing insight into the multiple variables that form and influence social status. Through this, the understanding of social class as a contextual entity that evolves through changes in situation and time is established. The implications of social class on the infrastructure and opportunities that are available to an individual, and that effect and influence a person throughout their life has also been explained. This has led to an understanding of this influence extending to the decisions and choices that are available to individuals of different social classes and socio-economic positions, with these experiences and opportunities together forming a person's habitus. The chapter also included an explanation of the various scales of measurement that have been popularly used to assess the social status of individuals within a population which is based on particular indicators of socio-economic and social status. Through this discussion, an understanding of how the socio-economic position of a population group manifests in the built environment and architectural form has also been established.

The primary aim of this thesis is to undertake an investigation in to the effect of socio-economic position on the perception of thermal comfort. Given the implications of social status and socio-economic position on the affordability and lifestyle choices of an individual, one can imagine the thermal comfort choices would *possibly* be influenced by the socio-economic background and indeed, it could be hypothesized, the preferences for thermal environments to which they are accustomed.

This chapter, through establishing an understanding of social class and presenting the scales by which the socio-economic position of an individual or family group can be determined, has provided the groundwork based on which an assessment in to the effect, if any, of the socio-economic position, on the thermal comfort perceptions of a population group can be conducted.

Chapter 4

Thermal Comfort & Socioeconomic Position – Interactions in literature.

4.1 Introduction

This chapter provides an overview of existing literature that addresses the interaction between the concepts of thermal comfort and socio-economic position.

The concept of thermal comfort and its perception and expectation has been discussed in detail in Chapter 2 (Thermal Comfort). Thermal comfort has been explained to be a primarily subjective entity that is contextual to the local climatic and cultural profile of each region and has been described to be a socio-cultural construct. Of the indicative factors of thermal comfort perception, the socio-economic profile of an individual or community group has been alluded to in a number of studies and review papers as a major influence in the subjective assessment of environmental parameters and comfort (Chappells and Shove, 2005; Nicol, Humphreys and Roaf, 2012; Taleghani *et al.*, 2013) however this has not been rigorously reviewed or tested.

Socio-economic background is traditionally assessed through a composite of the education, income, and occupation, which enables the person (or group) to be assigned a rank relative to the larger society (discussed in detail in Chapter 3). The social and economic parameters within which an individual (or community group) resides determines the extents of exposure to the various environments they experience during the course of their lifetime. This results in a familiarisation with certain physical and psychological environments that are considered to be of acceptable comfort. Socio-economic status is thus central to the evolution of thermal comfort perception, and it is through the study of the effect of socio-economic status on thermal comfort perceptions that informed decisions and policy changes can be undertaken that will improve health and well-being, sustainable housing, energy efficiency, controlling climate change, adaption, and increasing social equity.

At present studies in the field of thermal comfort that have addressed and acknowledged socio-economic influence have primarily focused on the building stock type and age, passive control techniques as a means of addressing cooling/heating costs, and income related to affording mechanical cooling (Santamouris, Kapsis, *et al.*, 2007; Yun and Steemers, 2011). The effect of socio-economic parameters on thermal comfort perception has therefore been discussed with anecdotal evidence and although not contested, few attempts to quantify the influence have been undertaken.

The proceeding sections of this chapter (4.2 and 4.3) contain a systematic summary of the relevant literature that discusses the subjective assessment of thermal comfort and the related concerns of energy efficiency, building envelope, and housing typologies, through socio-economic parameters and relevant social aspects that are implicit in them. An outline of the literature that references socio-economic status and thermal comfort explicitly is first provided. This is followed by a summary description of the studies that have looked at either thermal comfort or the associated fields of building energy use, energy efficient design etc. and have used within their investigation one or more parameters that are traditionally used to

describe socio-economic status. This discussion leads on to Section 4.4 where the links between thermal comfort, socio-economic status and architectural form is presented. Through this it is established that the achievement of thermal comfort is as dependent on the socio-economic position of the occupants of a space or building and as such should be as central to the concept of comfort perception and comfort practices as the study of objective parameters of environment and material.

4.2 Acknowledgment of interactions of thermal comfort and socio-economic position

The necessity for the study of socio-economic influence on thermal comfort perception discussed in the previous section (4.1) has been referenced in numerous thermal comfort studies that have acknowledged that ‘comfort is a part of a dynamic process exhibited partly through the interaction between people and buildings that is in turn dependent on economic and social condition as well as the thermal environment’ (Nicol, Humphreys and Roaf, 2012, p. 8).

Our current understanding of thermal comfort is largely due to the field study methodology which has in particular enabled thermal comfort studies to go beyond the mechanical dissection of the thermal environment, and helped recognise thermal comfort as a complex social construct that is developed through the interplay of the particular environmental, cultural and technological factors. These studies have established that ‘people of different cultures manage, value, and maintain very different indoor conditions and interpretations of comfort’ (Chappells and Shove, 2005, p. 34). The effect of exposure to different environments on thermal comfort perception has also been acknowledged with evidence cited showing the expectation of, and desire for, indoor thermal conditions differs significantly between people who are accustomed to naturally ventilated environments and those who are regularly exposed to air-conditioned environments and as such these cultural variations in thermal comfort perception and practice exist within similar climatic environments (Cândido *et al.*, 2010; Nicol, Humphreys and Roaf, 2012; Siddiq and Hanna, 2017). It was in fact, an observation based on field data of the variations in thermal comfort parameters of populations from different climatic zones and the possible links such variation may have with exposure that was reportedly one of the influencing factors prompting the development of the adaptive approach to thermal comfort in the 1960s (Humphreys, Nicol and Roaf, 2016, p. 357). The discussion of variations in exposure to thermal environments resulting in different expectations of thermal comfort is therefore not recent, and had been linked to social class as early as 1974 in Hanes as referenced in Hanna (1990, p. 120) ‘the expectancy about environmental conditions may affect comfort; low income people might not expect the same comfort quality as people with high incomes, although both sets of people might feel comfortable under the same conditions’.

Despite this (relatively) early awareness of the interplay of socio-economic status and thermal comfort perception few studies have involved empirical investigation that quantify the relationship. A possible explanation for this might be that the field of thermal comfort has predominantly been the forte of engineers with the air conditioning industries providing the funding for much of the early research which worked towards their agenda of normalising artificial conditioned environments (as discussed in Sections 2.5 and 2.7) (Chappells and

Shove, 2005; Nicol, Humphreys and Roaf, 2012; Shove, Walker and Brown, 2014). An exception to this is a conceptual formula for thermal comfort presented by Humphreys et al (2016, p. 89) that acknowledges the constraints within which thermal comfort is achieved. These constraints can be divided into four (4) main headings dependent on their root cause; climate, poverty, social custom, and task or occupation. This explanation supports the premise that thermal comfort is largely dependent upon the climatic condition, but could also be significantly affected by cultural, and socio-economic factors.

Of note also, is Shooshtarian's review into the socio-economic factors that influence the perception of outdoor thermal environments. This review paper included previously published examples that referenced either the social or economic factors in their assessments of thermal climate. Through this, the author attempted to develop a conceptual framework linking socio-economic factors and psychological adaption with the aim 'to facilitate the process of collecting information on socioeconomic factors as an input for the climate sensitive design process'. The framework lists **social factors** to include *culture* (social norms, religious background, environmental attitude), *lifestyle* (pattern of usage, companionship), *climate/geographical zone* and *education* (qualification, skill) while the **economic factors** include *economic background* (individual scale, society scale), *job status* (income, job satisfaction, job position, activity type), *level of technology* (heating and cooling systems, comfort-inducing facilities), *health status* (health care options, insurance coverage, individual's health status), and *place specifications* (design, access, management, facilities) (Shooshtarian, 2015, pp. 48–49).

The influence of socio-economic position was also a factor in an empirical assessment of the psychology of thermal comfort in the built environment in Lagos Nigeria (Sangowawa and Adebamowo, 2012). This study involved a participant group that was selected based on its affluence (wealth capital) and its access to air conditioned environments and was thus limited to a narrow range of socio-economic background. The questions focused on the adaptive practices and preferences for colours and lighting of the participants, and as such no significant addition to our current understanding of the link between socio-economic position and thermal comfort practices was made. Relevant to, and of interest to this thesis is the ranking of a number of socio-economic 'issues' that the participants were asked to do. The ranking was in order of importance to them in which the achievement of thermal comfort ranked after financial assets (ranked highest), the condition of infrastructure (2nd) and health (3rd), and followed by only indoor aesthetics and décor (5th). The authors interpreted this ranking to mean that 'most people are able to tolerate the least important issues without expressing a feeling of discomfort' (Sangowawa and Adebamowo, 2012, p. 8), however keeping in mind the narrow socio-economic range of the participant group the ranking cannot be taken to be applicable across different populations.

The 'effect of the socio-economic and cultural diversity on thermal comfort, behaviour and use of space' was the focus of a study that looked at the differences in thermal comfort perception in outdoor spaces within two (2) culturally different but climatically similar regions. These studies were undertaken in Marrakech in North Africa and Phoenix-Arizona in North America and while the reason cited for the choice of case study sites was 'to represent a variety of users in similar climatic contexts' this also meant that the differences in cultural use of space and lifestyle were ignored and would possibly act as confounding variables in the study (Aljawbrra and Nikolopoulou, 2009).

The data included both environmental and human behaviour monitoring. The data pertaining

to the socio-economic background of the participants was evaluated through their educational level, job type and economic capital (based on a self-evaluation). One of the lines of enquiry took the length of time spent in a space as an indicator of satisfaction with the thermal environment, however the correlation of low-income families spending greater times in outdoor spaces than high-income families seems to be related to the ability of the higher earners to afford access to different leisure activities rather than differences in thermal perception.

The cultural differences that pertain to space-use as well as thermal comfort perception were not addressed in this paper, and although the thermal comfort practices were assessed with respect to the socio-economic positions of the participants, the significant differences that exist between similarly classified individuals from developing and developed world regions (the locations of the case study sites) in terms of their socio-economic ranks, lowers the relevance of the findings.

4.3 Using socio-economic indicators to assess comfort et cetera

The indicators of socio-economic position have, on occasion, been used individually in research to provide an indication of the participants' social and/or economic position within society, and also occasionally as a means narrowing the focus of a study, or as a means of participant selection. The lines of enquiry within which partial socio-economic data was collected or analysed and that align with this investigation are varied and range from thermal comfort perception, thermal comfort practices, energy efficiency, to social and aesthetic factors of the environment. The main indicators that have been so referenced are as discussed in Chapter 3, are the social aspects or human factors, education, income, and occupation. And it is along these core terms that an exhaustive review of existing literature was undertaken of which the relevant are summarised in this section.

4.3.1 Social aspects and human factors

A number of studies have examined the concept of thermal comfort perception and the practices of populations through their interactions with the social and built environment. This section references studies that looked to understand thermal comfort through its interaction with the social and human factors.

One such example is a review of literature pertaining to an overlap of the fields of environmental psychology and thermal comfort undertaken by Heijs and Stringer (1988) which, although almost three decades old, provided evidence through literature of the influence of familiarity, acclimatisation, and lifestyle on thermal comfort perception. The term socio-economic is not used explicitly in the paper, however, the discussion includes reference to the influence of culture and experience on thermal comfort expectation which is directly related to socio-economic position. The effect of colour, furniture, spatial qualities of a space, and the knowledge of the prevalent temperature were also presented as influencing variables to thermal comfort perception.

More recently, an investigations taking a socio-technical approach to thermal comfort and heating behaviour in residences was presented by Ben and Sunnikka-Blank at CISBAT 2015 in which data was collected and analysed from 14 UK residences and their occupants. The socio-economic positions of the occupants surveyed for this study was not a primary factor,

however details including household types, sizes, and tenure types were collected which could be taken to provide an indication of social and economic position. The study looked at determining the aspects of the thermal and physical environment that occupants associated with comfort, finding that the definition of comfort was multi-variable and complex, being both time and situation dependent. The study showed that occupants framed thermal comfort through environmental parameters which included warmth, lighting, fresh air, lack of noise, odour, access to toilet/shower facilities etc. and also included descriptions of the physical, psychological and social aspects influencing thermal comfort such as 'sense of security, coziness and homeliness, feeling relaxed, life quality, fulfilment from work, physical activity, social life, wellbeing, feeling secure and at ease, intellectually stimulating environment, having a peace of mind and equanimity, and meaningful relationships with family and friends' (Ben and Sunnikka-Blank, 2015, p. 341).

Also pertinent to this thesis is the case-study undertaken by Andamon, Williamson, and Soebarto (2006) in which the socio-cultural aspect of thermal comfort is established through taking the city of Manila in the Philippines as case-study. This study reviewed the evolution of the thermal preferences of the residents of the city through a chronologically presented account that assessed interactions between people, technologies, and indoor environments including the effect of colonisation and the popularity of artificial air conditioning. The authors advocate for the assessment of thermal comfort through understanding the underlying behavioural patterns that form thermal comfort preference and practice which include both the societal norms and expectations and the adoption of technological means of thermal conditioning as the norm and expected. Although the influence of socio-economic positions on thermal comfort is not an explicit focus of this paper, the cost, expenditure and consumption of energy in adopting artificial air conditioning is discussed which provides a notion of the symbiotic relationship of thermal comfort perception and technological advancements.

A slightly less relevant, but interesting study looked at the *Human Factors in the Thermal Performance of Naturally Ventilated Buildings* (Gomez-Azpeitia *et al.*, 2005). This was undertaken through a measure of the level of (domestic) violence in comparison to the architectural space in Colima, Mexico. Alongside looking at the thermal performance of the buildings, and the relationship of violence with indoor temperature and comfort levels, this study looked at the social factors of density (number of people in the dwelling, number of people per bedroom), the need for personal space, the interconnection of the different spaces, and included aspects of the internal space such as colours, furniture, layout etc. The research thus provided an understanding of the interconnectivity of human factors, mood and behaviour, due to the physical environment as well as attempting to draw links between the mood and behaviour of occupants and thermal comfort perception, but the work did not include a measure of the effect of socio-economic background of the inhabitants on their thermal comfort perception.

4.3.2 Education

Education has been used as a sole indicator for socio-economic position in some studies as the data is easy to collect and rank, the limitations to the use of education have been discussed in Section 3.2.1. Two examples of the use of education in thermal comfort studies were highlighted in the literature search.

One such study undertaken in Thailand looked to develop comfort standards for air conditioned buildings with a reference to both the local climatic conditions, and the acclimatization of occupants to the air conditioned environment (Yamtraipat, Khedari and Hirunlabh, 2005). The study also attempted to determine the effect of education on the occupants thermal comfort perception. However the authors did not recognise education level as a socio-economic factor, expressing disappointment at higher educated users preferring lower indoor temperatures as ‘one might hope that educated people would prefer higher air temperature, since this could help reduce the use of energy cooling’ (Yamtraipat, Khedari and Hirunlabh, 2005, p. 513). The authors also failed to associate education level with the acclimatization due to air conditioning use which may have resulted in a more robust study. Nonetheless, the study provides valuable insight in to the link between acclimatization to mechanical cooling and its comparative significance in thermal comfort perception, laying the groundwork for further investigation.

The second study was undertaken in the Ibadan region of Nigeria by Adunola and Ajibola (2016), and looked to assess the factors significant to thermal comfort in residences as well as the preferences of (adult) resident’s use of space. The relevant part of the study was based on the assumption that ‘characteristics of building users that may actually take a role in the determination of their pattern of use of the room spaces’ (Adunola and Ajibola, 2016, p. 2) the ‘characteristics’ include the ‘socio-economic, educational level, enlightenment and intellectual exposure, cultural and traditional values, and background’. The data collected included the educational level (highest achieved) and type of tenancy (owned/rented) as proxy for the socio-economic status of the residents. And although the study did not directly link the socio-economic positions of the residents to the levels of indoor thermal comfort experienced, correlations were reported between thermal comfort and the spatial diversity of the buildings as well as the urban physical contextual diversity of the neighbourhoods in the study area, both of which are indicators of socio-economic position.

4.3.3 Income

Income is more difficult to ascertain than the other socio-economic parameters and is not always directly translated to wealth, quality of life, or buying power, and thus does not provide an accurate indication of socio-economic position when used alone. Nevertheless income has been used in thermal comfort studies particularly in studies that look at energy use within buildings, energy consumption, and affordability. Examples of such research is presented below along with studies in which income was indirectly referenced such as those looking at low-income or social housing. Research looking into the effect of high energy or fuel prices that has resulted in fuel poverty is also referenced.

Yun and Steemers (2011) looked at the significance of socio-economic, behavioural, and physical factors in domestic energy cooling demand and use. Analysis was undertaken on existing data from a 2001 survey of Residential Energy Consumption in the USA, however the focus was on understanding the factors that influence energy use and not into the effect of socio-economic factors on thermal comfort perception. The study is important as it highlighted the indirect influence of socio-economic factors that cannot be ignored. The primary socio-economic factors assessed were economic: household income, and demographic: size (number of occupants) and age of the head of the household. While the study determined the direct influence of these socio-economic factors on the energy

consumption was limited, the indirect influence was significant as the size of the residence, number of conditioned rooms, and number of air conditioning units are all determined by the income and showed significant influence on cooling energy demand.

A similar study undertaken in Athens, Greece looked to assess the relationship between energy and social characteristics of the residential sector through an assessment of social, financial, energy, and technical data from over 100 households. Thermal comfort was not a central parameter of this study however, with the (directly) related aspect of energy use being the focus. The incidence of fuel poverty, the condition of the building stock, particularly the age, use of insulation and double glazing in residences was compared with the occupants from different income groups, and significant correlations between the type of residence and the incidence of energy saving features (double glazing and insulation) was found to exist (Santamouris, Kapsis, *et al.*, 2007).

Of the studies that have examined social or low-income housing, the Patino et al (2018) study is relevant to this thesis as the focus was on 'Thermal comfort in multi-unit social housing buildings' and the authors recognised the occupants of social housing to have low incomes and the likelihood they were from a vulnerable population groups such as the elderly. However the relationship between the income-group of the residents and thermal comfort was not one of the factors assessed, the assumption was that all such residents would be from the same or similar income group. The focus of the study was on the thermal performance of the building envelope, thermal comfort and indoor environmental quality and its potential effects on the health of the occupants.

Fuel Poverty

Fuel poverty is intrinsically tied in to thermal comfort and socio-economic position as it refers to the inability to afford fuel due to low incomes, domestic energy inefficiency, and high energy prices. The phenomenon is understood to be multi-dimensional, dependent on the social position and geographic location as well as being subject to the distributive injustice of energy tariffs (Walker and Day, 2012; Robinson, Bouzarovski and Lindley, 2018).

The term fuel poverty was originally used in cold climatic conditions where the methods of achieving thermal comfort have been dependent on fuel based mechanical devices for heating. With the recent changes in technological advancements, lifestyle trends and consequent changes in comfort expectations, the reliance on fuel based conditioning devices for cooling has increased thus making the use of the term for hot climatic conditions equally relevant.

Fuel poor households are those that spend more than 10% of their income on fuel for heating 'up to a decent standard' (Department of Trade and Industry pg.108 cited in Chappells (2005)). A new system of measurement of fuel poverty known as the Low Income High Cost (LIHC) indicator has recently been developed and used in parts of the UK that is reflective of regional variations in income and energy costs (Robinson, Bouzarovski and Lindley, 2018).

The inability to afford fuel for heating has been a regular feature in recent thermal comfort studies and journalistic articles. These have often been linked with the urgency of tackling climate change with examples ranging from heat waves to extreme cold, and the vulnerability of the increasing geriatric population worldwide. (Carrington and Marsh, 2018; Crilly, 2018; Irfan, 2018).

In discussing the fuel poverty and incidences of vulnerability to heat events, both economic and social aspects have been cited for the elderly (over 65 years old) and very young (less than 4 years old). This vulnerability has been linked to people's socio-economic status with their ability to afford air conditioning units or make the necessary adaptations to housing and lifestyle. The location and condition of the physical environments that they live in, which is also dependent on their socio-economic position, has also been cited as a cause for increasing vulnerability to heat events, as persons' living in unsafe neighbourhoods have been found to be resistant to opening windows and improving indoor thermal conditions. (IOM, 2011; Rosenthal, Kinney and Metzger, 2014). Similar reports in extreme or prolonged cold climatic conditions have been reported where isolation and limited mobility also contribute to the vulnerability of the fuel poor (Healy and Clinch, 2002; Robinson, Bouzarovski and Lindley, 2018).

Much of the research into fuel poverty relates to its effect on the health and life quality of the vulnerable, and as such the focus of existing studies has been on the improvement of the building envelope, energy efficiency, and ensuring social justice, and not on the achievement of thermal comfort.

4.3.4 Occupation

The socio-economic indicator of Occupation has not been used as an independent indicator in thermal comfort studies or associated fields. The references to occupation have generally been deployed in order to provide demographic information of the sample set or participant group, and in some instances to ascertain behaviour patterns such the study undertaken by Gomez-Azpeitia et al (2005) who investigated the relationship between domestic violence and indoor temperature and comfort conditions.

In some instances the selection criteria for field studies was restricted to particular building types, and through that, the data is limited to occupants based on their occupation or type of work, for example, factory settings, bank, office environments etc. The general trend has been to refer to the occupants of a type of building as a singular population and as such variations in comfort perception between persons of different occupations have not been the focus of these investigations. An exception to this is the investigation into 'Occupant response to transitions across indoor thermal environments in two different workspaces' (Loomans *et al.*, 2018) which focuses on the thermal comfort perception of occupants of disparate work environments, hospitals and offices (taken from a single case study site). The participants were thus either nurses or office workers, and acknowledged to be two different populations with differences with respect to work environments and activity levels and were thus assessed independently of each other. The thermal perception of each occupation group was then compared. The occupation was thus explicitly used as an identifying factor in this study but not used a socio-economic identifier.

The recording of occupation status of participants in the thermal studies has been incidental rather than as part of a measure of socio-economic position.

4.4 Thermal comfort, socio-economic status and architectural form

The manifestation of socio-economic position of an individual, family group, or larger population in the urban and architectural form has been discussed in Section 3.6. This presents an understanding that the availability of space, the infrastructure available, the quality and form of the residential buildings, and the materials used in their construction, to be reflective of the socio-economic position of the inhabitants, thus showing that socio-economic position and architectural form are intrinsically tied.

Indoor thermal comfort perception is assessed and measured with respect to physical environmental parameters and the subjective responses they invoke in the occupants of these spaces. It is thus dependent on the urban spaces and architectural form occupied, which, in the case of residential buildings, is linked to the socio-economic position of the residents or occupants. From this logic we can see that a direct link between thermal comfort perception and socio-economic position exists particularly within the realm of the built environment. This concept has been referenced by researchers who acknowledge that wealth, lifestyle, the condition of housing, and the availability of artificial air conditioning devices, all potentially have an effect on thermal comfort perception (Cândido *et al.*, 2010; Nicol, Humphreys and Roaf, 2012). As well as being tacitly acknowledged through government-level policy such as the Energy Company Obligation (ECO) subsidy schemes run in the UK that incentivise the energy efficient practices including lowering of carbon emissions and tackling fuel poverty (OFGEM, 2019). These schemes are available to person's within a pre-set low income support bracket and include subsidies for wall and roof insulation, the replacement of old in-efficient boilers or glazing, as well as incentives such as feed-in-tariffs toward solar panel installation.

Such policy is based on the understanding that the achievement and maintenance of thermal comfort is reliant on the ability of the occupant to afford it; to afford the fuel as well as access to the built environment. Despite this, little academic scholarship linking socio-economic position and thermal comfort perception with respect to the architectural form currently exists.

Although a significant amount of work looking at the thermal and insulative properties of different building materials has been undertaken, much of the development in technology and new materials is industry-driven where the focus is largely on an improved building envelope that is more conducive to achieving and maintaining indoor thermal comfort, and an understanding of the human factors aspects including the costs and affordability of these new developments is largely absent. Studies into examining the thermal properties of older buildings and materials have ranged from investigating traditional materials such as adobe construction and its thermal properties (Srivastav and Jones, 2009; Abanto *et al.*, 2017), the changes in thermal behaviour of the building envelope through retrofitting of new materials (Evola *et al.*, 2017) and double glazing (Coillot, Mankibi and Cantin, 2017). However, there appears to be a lack in scholarship investigating the limitations of the socio-economic position on choice of both new and old materials.

This lack of attention toward the effect of socio-economic position on thermal environments within the built environment is also reflected in examinations of the architectural form. A substantial body of research looking at the architectural form and its environmental suitability

has been undertaken previously. This ranges from the traditional or vernacular form that developed within a particular climatic and social-cultural environment, to the more modern built form that does not appear to have socio-cultural influences and is a product of homogenization through globalization. These studies include a general measurement of thermal properties of the built form and have also led to an understanding of the thermal practices of the inhabitants as part of the socio-cultural formation of space. Comparisons of the indoor thermal environments in traditional buildings and modern builds have also been undertaken, these studies include Oktay (2002)'s investigation into traditional Cypriote houses, and Hanna (1990)'s investigation in to the effect of traditional courtyards on indoor thermal comfort. Further studies include investigations in to the historical changes in thermal properties of buildings such as was chronicled in Scotland during a period of 100 years (1915 to 2015) by Rezvani and Bribian (2018) and the effect of change in the spatial characteristics of a space on the thermal environment (Coskun *et al.*, 2017).

As such there are a number of studies establishing a direct link between the socio-economic status of the occupants of a building and the thermal properties of the building, however the general consensus within the research community has been that the thermal properties of the vernacular architectural form of a region are better suited to the climatic environment than modern architectural form. However modern lifestyles and the prohibitive cost of land particularly within urban areas do not make the re-adoption of or adaption to such architectural form a viable option for many. Similarly the ability to afford thermally efficient building materials or to retrofit an existing residence to improve the indoor thermal environment is also tied in to one's socio-economic position.

The discussion in this section makes apparent the existence of an associated, possibly symbiotic relationship between one's socio-economic status, the urban spaces, and architectural form that are accessed through that socio-economic position, and the thermal exposure and consequent thermal comfort perception within that built environment. This location of the socio-economic position as an influencing variable on thermal comfort perception through the architectural form takes the discussion beyond the *affording* of comfort, toward the development of habitus through the long-term exposure to a particular social and economic environment and its effect on the consequent expectation and perception of thermal environments.

4.5 Conclusion

This chapter has provided a comprehensive summary of existing research and journalistic literature in which thermal comfort has been referenced with social and economic parameters. The discussion has shown that the construct of thermal comfort is formed within *constraints* that include the social, cultural, and economic conditions of the individual or community group, and as such the study of thermal comfort perception cannot be complete without the inclusion of socio-economic parameters. Traditional thermal comfort studies have acknowledged the effect of socio-economic position on thermal comfort perception, but as the literature presented in this chapter has shown, the influence of these parameters has not been quantified, with few studies empirically measuring the socio-economic parameters.

The conversation around the manifestation of the socio-economic position of an individual or family group within the urban form and the particular architectural form: the building type, condition, and materials used has been presented. The influence of the architectural form and building envelope on the indoor thermal environment and consequently on thermal exposure and thermal comfort perception has also been clarified. This has led to the logical connection between the socio-economic position and thermal comfort experience, and formed an understanding that the influence of one's socio-economic position goes beyond the ability to afford comfort. With the long-term exposure of a set of socio-economic and cultural environments influencing the habitus of an individual and thus possibly also affecting their perceptions of their thermal environment.

The current practice within the field of thermal comfort studies has been to define the parameters of comfort at the climatic level which means that thermal comfort is typically taken to be a regional entity and the entire population of a climatic zone assumed to experience thermal comfort within the same environmental parameters. The variations in socio-economic position between individuals of a regionally specific population group may however translate into variations between their thermal comfort perceptions, which, if significant, could mean that the current practices of assessing comfort perception may be not be wholly accurate and may need to be revised.

The influence of socio-economic position on thermal comfort perception thus could have an implication on the study of thermal comfort as an investigation in to establishing the extent of this would determine how thermal comfort perception varies within a specific climatic and cultural population and through this the granularity of comfort perception and consequently the predictive equations can be determined.

Chapter 5

Research Design

This thesis presents an assessment of thermal comfort perception in the developing world, primarily in hot climatic conditions with a focus on establishing thermal comfort as a climatic and cultural entity.

To this end an exhaustive review of the literature detailing the fields of thermal comfort was presented in Chapter 2, and the socio-cultural and economic parameters that inform a person's perception of the physical environment has been presented in Chapter 3. While the studies that considered the interactions of thermal comfort and socio-economic position particularly within the built environment have been presented in Chapter 4. This literature highlighted a discrepancy in existing thermal comfort knowledge where the subjective influences on thermal comfort are acknowledged but not quantified and the thermal comfort for a population is taken to be a uniform entity without consideration for variations due to subjective choice (Section 4.5).

This chapter presents the research design and methodology through which the inquiry into addressing this gap in knowledge is undertaken.

5.1 Introduction

The concept of thermal comfort has been explained in detail in Chapter 2 where it is described as a social construct; an objective entity based on the physical environmental parameters and the body's automated physiological responses to them, but that is formed, as are all our expectations, within the social parameters of culture, society, and affluence (discussed in detail in Chapter 3). Thermal comfort is therefore understood to be a subjective entity that is unique to each person's lived exposures and experiences.

The Adaptive Theory of thermal comfort recognises that the occupants of a space modify or adapt themselves and their environment in order to achieve and maintain indoor thermal comfort. These adaptations vary between different climatic regions and within a particular climatic region due to seasonal variations in outdoor parameters. Thermal comfort perception is therefore regionally specific reflecting the climatic conditions as well as the local cultural practices of a population. Variations in thermal comfort perception have also been noted to exist in different indoor environments (within a particular climatic and cultural region), with occupants of air-conditioned spaces having different expectations of thermal comfort than occupants of unconditioned spaces. This understanding of exposure to an environment affecting the expectation and consequent perception leads to the logical conclusion that in regions where such conditioning of spaces is widespread, the thermal comfort preferences of the local population will vary according to their exposure to conditioned environments. Despite this acknowledgment of the influence of regional, cultural, and socio-economic positions of the local populations on their thermal comfort perception, the calculations of acceptable thermal comfort ranges, as provided in thermal comfort standards, are derived solely from the interactions and balance of environmental variables.

It is the aim of this thesis to address this discrepancy in knowledge regarding thermal comfort perception, with the intention to quantify the influence of the regional, cultural, and socio-economic positions of the populations on their thermal comfort perception. This chapter thus presents the methodological outlines of two separate analyses through which the assessment in to the variations in thermal comfort perception are undertaken:

- The first seeks to establish thermal comfort perception within the physical environmental parameters and ascertain the variation in thermal comfort perception between the various culturally diverse populations within a single climatic zone, thus establishing the regional specificity of thermal comfort perception.
- The second investigation, looks at establishing the presence of variations in thermal comfort perception amongst individuals or groups within a population that experience the same climate and hold the same cultural values.

The work presented in the proceeding sections of this chapter details out the hypotheses establishing the direction of enquiry and methodology through which data is collected and analysed for both investigations; along with the physical requirements of the investigations: the equipment and questionnaire. An indication of appropriate quantitative analysis, as well as anticipated results are also discussed.

5.2 Lines of Enquiry

Given the background discussed above, the thesis intends to establish the regional and cultural specificity of thermal comfort perception. The study is structured in two parts.

Part 1 – The regional specificity of thermal comfort perception.

Part 2 – The influence of socio-economic status on thermal comfort perception.

In order to conduct a robust enquiry, the following physical parameters were established and it is within these that the focal area and focal population of the investigation was determined: the focus of the study is on the hot-dry climatic conditions within a developing world region.

Conducting a rigorous investigation that is sensitive to real-life thermal experience of the population, necessitates the accurate measurement of their thermal environment and a systematic recording of their thermal comfort preferences. The approach most suited to this is the field study methodology (as outlined in Chapter 2 Section 2.6.2).

The reason for focusing on hot-dry climatic conditions is due to the differences in thermal comfort practices between hot and cold climatic conditions and the ease and accuracy with which they can be measured in the field. In the absence of centrally conditioned spaces, the adaptations undertaken to achieve thermal comfort in cold climatic conditions revolve primarily around modifying ones' self and immediate environment, and may involve spot or localised heating such as the wearing of insulating clothing and the use of a hot-water bottle or heating element. These modifications and adaptations are not as easy to measure or accurately quantify in the field setting environment. On the other hand, in warmer conditions, there is little variation in the insulative value of clothing between individuals, while thermally comfortable conditions are achieved through the adaption of the general indoor environment such as

through the recirculation of air, and cooling through mechanical cooling devices such as air conditioners and desert coolers. These practices are more common in developing world regions of the world where the use of central conditioning of spaces (hot and cold) is not widespread in residential buildings and is mostly limited to office and commercial spaces. The indoor environments in hot-dry climatic conditions within the developing world are thus the most suited for this investigation. This is further bolstered by the large socio-economic inequity in developing parts of the world that translates to varying access and exposure to conditioned environments because lifestyles, amenities, occupations and opportunities in the developing world is very closely linked to socio-economic position (discussed previously in Section 3.6 and 4.4). And as such, it would be safe to assume the exposure to mechanically conditioned environments in the developing world generally follows a person's socio-economic position within society.

The selection of the case study site within a hot-dry climatic zone and within a developing part of the world would therefore be most appropriate for the investigations in to the variations in thermal comfort perception in a population and to ascertain if socio-economic position has an influence on these perceptions.

5.3 Part 1

– Regional specificity of thermal comfort perception

The first part of the analyses presented in this thesis sets out to establish the regional specificity of thermal comfort perception, furthering the previously prescribed definitions of thermal comfort based on a climatic classification to include the possible variations in thermal comfort perception between different regions due to cultural norms and local adaptive practices.

5.3.1 Hypotheses

Target hypothesis: There will exist a difference in thermal comfort perception of populations resident in geographically (and hence culturally) different regions within the same climatic classification.

Null hypothesis: There will exist no difference in thermal comfort perceptions of the populations resident in geographically (and hence culturally) different regions within the same climatic classification.

In order to test the truth of these hypotheses the following variables are to be determined:

- i. The indoor climatic conditions within which the occupants reported thermal comfort sensation within all the geographically (and hence culturally) different regions within the climatic classification.
- ii. The indoor climatic conditions within which the occupants report thermal comfort sensation for each geographic (and hence culturally different) independent region within the climatic classification.

These variables will enable the development of relationships between the prevalent outdoor conditions and the indoor thermal comfort conditions. Two sets of such relationships will be established, one for the entire population within the climatic classification and the second for each geographically disparate, and hence culturally independent, field study site within the climatic classification. A cross comparison of these two sets of thermal comfort formulae will provide an assessment of the regional specificity of thermal comfort perception.

The investigation will also include a study of the various outdoor temperatures that are used as reference in the development of the predictive thermal comfort equations in order to establish which provides the most accurate predictive values of indoor thermal comfort. The outdoor reference temperature found to predict indoor thermal comfort most accurately will be used in the analysis.

The hypothesis is broken down into the following propositions which will be independently evaluated in order to gauge the truth of the target hypothesis.

- i. The thermal comfort formula (Y) developed from the an entire region that is of a single climatic classification (X) will provide accurate predictions for the populations of each culturally independent field study site within the same climatic classification ($X_1, X_2 \dots X_n$).

The current standards for thermal comfort perception aim to provide comfortable conditions for 80% of the resident population of a climatically classified region. If such a distinction along climatic lines is appropriate, one would expect that, as a minimum, the predictive formula provides thermal comfort conditions for 80% of the populations of each of the independent field study sites within the same climatic area. In other words, the predicted thermal comfort parameters should not be significantly different from those empirically measured in the different parts of the region.

- ii. The thermal comfort formula (Y_1) developed for a particular culturally independent field study (X_1) site should provide accurate predictions of thermal comfort for other culturally independent regions within the same climatic classification ($X_2, X_3 \dots X_n$).

If the thermal comfort perception is a climatically defined entity then the predictive formula developed for a particular region within a climatic classification should provide adequate prediction of thermal comfort conditions for other populations exposed to the same climate. In other words, the predictive formula developed from the empirical readings from one field study site should provide accurate predictions of the thermal comfort parameters for other sites within the same climatic classification and the predicted parameters should not be significantly different from the empirically measured for these sites.

It is anticipated that this investigation will lead to a better understanding of variations in thermal comfort perception within a climatic zone and establish if the accuracy of the predictive formulae is improved when they are developed within the climatic environment in which they are to be applied.

5.3.2 Methodology:

The investigation is undertaken through the analysis of a part of the field study data that underpins the adaptive theory: the ASHRAE RP-884. This large dataset comprises of data from thermal comfort field study sites that are climatically and culturally diverse (detailed in Section 2.6.2). The data has been reclassified climatically by Toe & Kubota (2013) and the data pertaining to hot-dry climatic regions is acquired for this study.

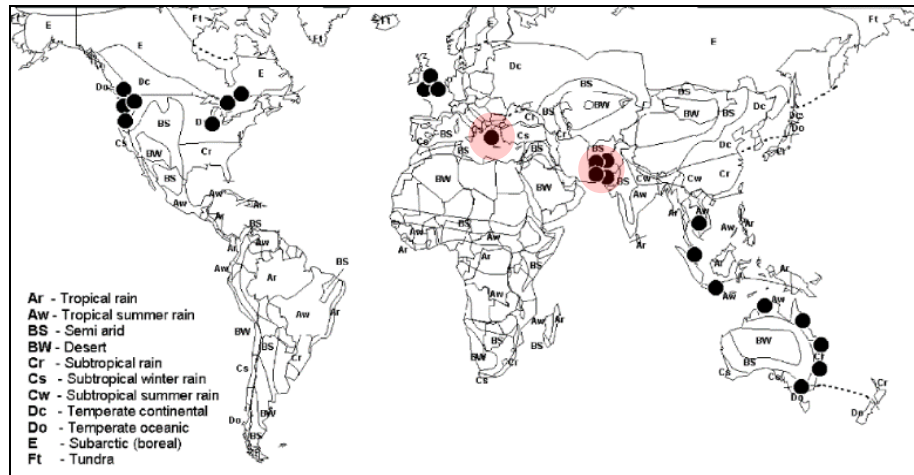


Figure 5-1

World map indicating extent of initial field study sites comprising RP-884 and indication of primary climatic classification of each region. (de Dear and Brager, 2002)

Site location = solid black circle

Sites within hot-dry climatic zone = orange circle

This data comprises of 6 geographically, and hence culturally disparate urban centres, thus fulfilling the requirement of case study qualities detailed in Section 5.2. This enables a statistical analysis of the thermal comfort equation (X) developed for the climatic region (Y) as well as of thermal comfort equations developed from the data specific to each individual case study region ($X_1, X_2 \dots X_n$).

The data and its suitability to the investigation is described in the proceeding section. The anticipated modes of analysis are also discussed.

5.3.2.1 The Data

A perusal of the six (6) hot-dry climatic field study sites of the RP-884 brings to light the inclusion of two coastal urban regions, Karachi and Athens. However as coastal climatic environments are defined by high levels of humidity and diurnal directional winds which are not exemplary of hot-dry climates, the dataset was pruned to exclude these coastal sites and the resulting dataset is taken to represent thermal comfort perception in hot-dry climates. This dataset comprises of four (4) culturally diverse yet climatically similar field study sites: Multan, Peshawar, Quetta and Saidu Sharif, which fall within the developing world region of Pakistan thus fulfilling the limiting factors for this study (outlined in Section 5.2 above).

The field study sites selected are part of the *Pakistan Project*, a thermal comfort field study undertaken in 1994-95 by Oxford Brookes University in order to lay the groundwork for establishing thermal comfort standards for the country. The Pakistan Project included the thermal comfort data of 4783 readings from a somewhat limited sample set of 36 individual

survey participants located in 5 different urban centres within the country. The small sample size of the project as well as the methodology of recruitment which involved social or business contacts raises concerns regarding the sample not being representative of the population of the region. The methodology of data collection for the Pakistan Project was different from previously conducted field studies as where such studies recorded the thermal conditions of a building or indoor space with simultaneous surveys logging the thermal comfort levels of the occupants, the Pakistan Project focused on recording the thermal comfort perception of the survey participants at different times of the day without prioritising the building typology or thermal conditions of the spaces they occupied. This method of data collection involved an increased level of participatory willingness and responsibility as the participants carried the equipment for recording the environmental conditions (enclosed within a custom-designed container) with them and record their own perception of the thermal environment at regular intervals.

The weaknesses within the field study methodology have been outlined in Chapter 2 (Section 2.6.3) where the decreased control over the thermal environment and a compromised accuracy in measuring metabolic activity may lead to data that is not as indicative of thermal environment induced physiological changes when compared to those achieved through steady state studies. However this is off-set by the advantage of collecting empirical data that is reflective of real-life where the participants are in familiar environments and continuing in their normal routines resulting in minimal distress. The field study methodology used in the Pakistan Project does not restrict data collection to particular times of the day nor to specific buildings and therefore provides a more wholesome indication, (through the realistic daily experience) of the thermal comfort profile of the residents of the region. This methodology does however rely on the involvement of the participants to carry the equipment and log their thermal comfort perceptions via the questionnaire which, it may be argued, could increase the margin of error. These concerns can be allayed by the use of automated data-loggers that minimise human error while providing accurate measurements of the environmental conditions. Another potential benefit of automated data-loggers is the agency afforded the participants in recording their own perceptions of thermal comfort will do away with any unintentional bias or influence the researcher may instil during the filling in of the questionnaire.

This methodology and consequently the data collected in the Pakistan Project is suited to the study as it focuses on the perception of the individual participants in different environmental conditions and is not limited to measurements within the same environment for all occupants of the space. This enables an understanding of the variations in perception that an individual can undergo at different times and within different environments and leading to further investigations in to the influence of regional differences including societal cultural and economic positions.

5.3.2.2 Modes of Analysis:

An assessment of this dataset developed for hot-dry climatic conditions is undertaken which will include a detailed statistical analysis of the data using the analytical software the 'Statistical Package for Social Sciences (SPSS).

5.4 Part 2 - Influence of socio-economic status on thermal comfort perception.

The second part of the study builds on the regional specificity of thermal comfort perception to explore the extent to which it is affected by the exposure to varying indoor environments within a particular climatic and cultural region. The variation in exposure is taken as measured through the socio-economic position of the individual.

The exposure to varying indoor environments particularly in developing world countries is largely dependent on the economic and social position of individuals which affords them access to conditioned environments within their residences and work environments. This means that people who are financially more comfortable will be exposed to a different thermal environment than the people who do not hail from the same socio-economic background thus resulting in a difference in expectation of thermal environments for members of the same regional population.

5.4.1 Hypotheses:

Target hypothesis: There will be a significant difference between the range of environmental parameters within which populations of low(er) socio-economic position perceive thermal comfort and the range of environmental parameters within which populations of high(er) socio-economic position perceive thermal comfort.

Null hypothesis: There will be no significant difference between the range of environmental parameters within which populations of low(er) socio-economic position perceive thermal comfort and the range of environmental parameters within which populations of high(er) socio-economic position perceive thermal comfort.

The variables to be ascertained in order to test the hypothesis are:

- i. The environmental climatic parameters that have the most influence on thermal comfort perception.
- ii. Socio-economic status of the participant members of the local population.
- iii. Thermal comfort range for the local population of low socio-economic status.
- iv. Thermal comfort range for the local population of high socio-economic status.

The queries raised by the target hypothesis can be further expanded in to the following independent lines of enquiry that focus on the particular relationships between the relative thermal comfort ranges of the various socio-economic population groups.

- i. The population of lower socio-economic status will report thermal comfort for a wider range of outdoor thermal conditions than the population belonging higher socio-economic status.
- ii. The populations with different socio-economic status will have a range of thermal comfort that is equal (or similar) in magnitude but the temperatures at which thermal comfort is reported will not be exactly the same. In hot climatic conditions this would

mean that the population of low socio-economic position would report thermal comfort at higher temperatures than the population of high socio-economic position.

- iii. The members of the population of low socio-economic position that are regularly exposed to artificially conditioned environments (such as work environment etc.) will be less comfortable in hot climatic conditions compared to the rest of the low socio-economic population.

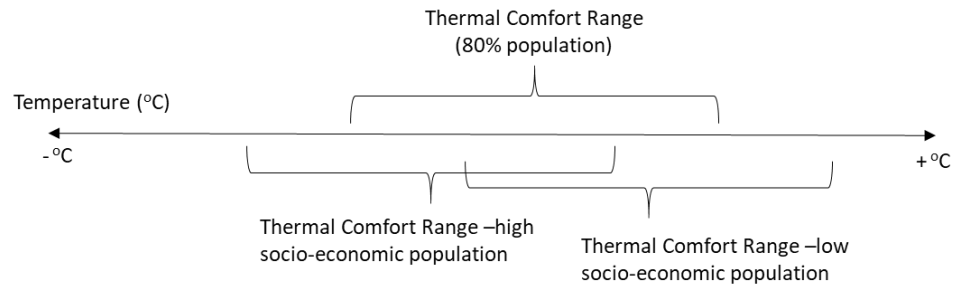


Figure 5-2

Diagrammatic representation of hypothesis: showing different extents of comfort temperature ranges between members of low socio-economic position and high socio-economic position.

It is expected that a relationship between thermal comfort and socio-economic status will be established during this investigation. During this process any anomalies that come to light, or possible relationships or associations between the different variables or their components will also be investigated with the intention of conducting a robust enquiry in to this relationship.

5.4.2 Methodology:

The methodology involves the collection of empirical measurements of the environmental variables of temperature, relative humidity, and wind speed, and a simultaneous recording of the participants' perceptions of comfort within those conditions. The data thus collected is to be statistically analysed using the IBM statistical program SPSS (Statistical Package for the Social Sciences) to determine the validity of the hypotheses.

The particular regional characteristics suitable for this study as outlined in Section 5.2 are restated for clarity purposes as a developing world region located in an area which is climatically classified as hot-dry:

The developing world urban settlement found most suited to this study was the city of Lahore in Pakistan. A precedent for field studies in thermal comfort exists within Pakistan with the Oxford Brookes led research in 1993-4, now part of RP-884 as the *Pakistan Project* having been undertaken in the country (Nicol *et al.*, 1999; ASHRAE, 2016). Lahore was not one of the urban regions surveyed as a case study site during the Pakistan Project, as the selection of the urban centres was largely dependent on convenience of social contacts (Nicol *et al.*, 1994). This makes Lahore an original case study which may add new insight to existing literature.

The Pakistan Project was led by the Oxford Brookes University who were engaged by the Energy Commission of Pakistan (ENERCON) with the aim to develop indoor thermal comfort parameters for the country. The study undertook surveys in 5 major cities which were classified as hot-dry however based on the updated Koppen-Geiger climatic classification by

Peel et al. (2007) are all located one in different primary climatic zones (see Figure 5.3 and Figure 5.4).

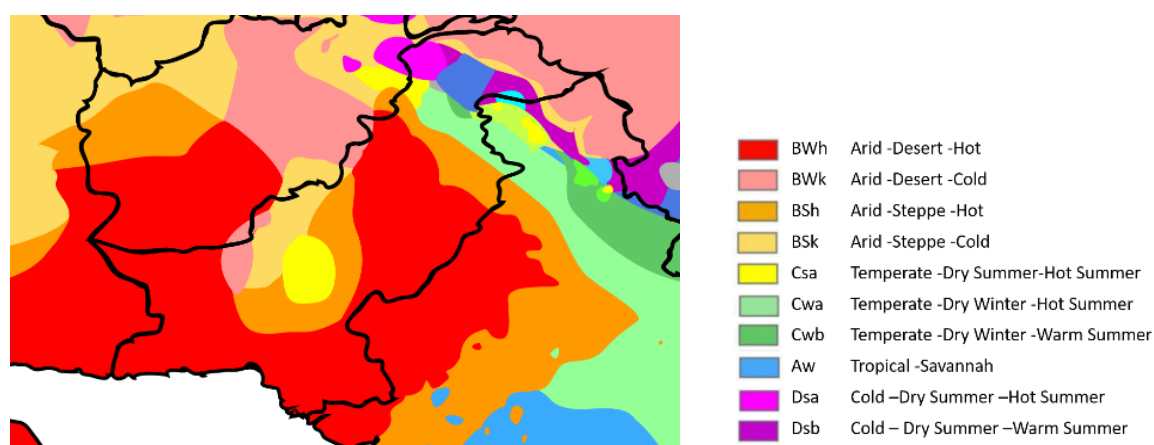


Figure 5-3

Koppen-Geiger climatic classification of Pakistan (Peel, Finlayson and McMahon, 2007).

The city of Lahore while within the same country as other field study sites of *The Pakistan Project*, is located in a climatic zone that differs from those previously surveyed. The broader cultural milieu of the regions' urban areas across Pakistan remain comparable and as such *The Pakistan Project* provides a contextual model for this research, providing insight to the social and cultural norms including preferred methods of thermal adaption.

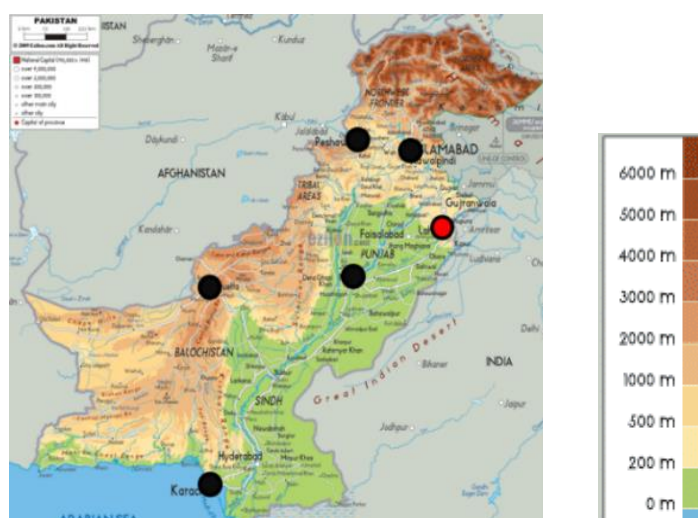


Figure 5-4

Relief map of Pakistan with indicators for RP-884 *The Pakistan Project* field study sites (black solid circle) and the city of Lahore (red solid circle).

Lahore is a pertinent choice for this research as the region experiences a significant seasonal climatic change with the median outdoor temperature in both summer and winter seasons necessitating adaption of indoor environments to ensure comfort. Furthermore, Lahore is a sprawling metropolis that has a high rate of urbanisation consequently the population is diverse in its social and economic position. Both these attributes of the city make for a robust study into the effect of socio-economic position on thermal comfort perception.

A descriptive analysis of the case study site is provided in the proceeding Chapter 6 where the precedence for the site, its suitability for the project as well as a profile of the resident population is detailed.

The study is undertaken through the field study methodology described in Chapter 6 and that has been the preferred method of onsite thermal comfort data collection for the Pakistan Project, however the concerns raised through previous criticisms of the study regarding the small sample size, the methodology of participant recruitment and the possibility of the experiences of the participants not being representative of the population are addressed in this study.

The study involved an extensive field survey over two summer seasons: from May to August in 2014 and 2015. A total of 269 individual participants from a diverse range of socio-economic backgrounds were recruited for the study. These participants were all adults between 16 to 78 years of age, and included both men and women so as to provide a good cross-sectional sample of the resident population. The participants to the study were required to carry a small container housing the equipment to measure and record the physical environmental parameters, henceforth known as ‘the box’, and complete, at one hourly intervals during their waking hours (as convenience allowed) a short questionnaire regarding their perceptions of thermal comfort. While participants in the Pakistan Project were required to carry their equipment for week-long periods, this duration of participant involvement was limited to 48 hours initially and further reduced to 24 hours as it was found that participants were stricter in the timing and regularity of their readings up to 24 hours beyond which they apparently lost interest. The participants who carried the box for approximately 24 hours recorded on average 14.68 readings each while the participants who had the box for longer recorded on average 16.63 readings each. The total number of readings thus recorded were 4155.

The contents of the box and the details of measurement and recording are in the proceeding Section 5.4.3. Images of the box and equipment are in Figure 5.5.

5.4.3 Equipment:

The variables of temperature and relative humidity were measured with the use of an automatic data logger that both records and stores the readings at a predetermined time interval which can be downloaded and accessed later. The wind speed was measured with an anemometer that had to be manually read and recorded. The details of the particular models of each used and their suitability to the study are discussed in the following paragraph. The equipment along with the other items required including the questionnaire, pen and small digital clock-face (synchronised with the datalogger) were housed in a plastic box also discussed in the proceeding section and in Figure 5.5. Due to financial constraints 12 sets of equipment were available for the study which limited the number of active participants to the study at any one time, and consequently was a limiting factor to the total number of participants and the size of the dataset.

Datalogger: The physical variables of temperature and relative humidity were measured and recorded with the automatic data logger, the *LogTag HAXO-8 Humidity and Temperature Data Logger*. This thermo-hygrometer is housed in a polycarbonate casing, it is approximately the size of a credit card with a profile of about 5mm and weighing only 35g. The device was thus suited to the study’s requirements of being robust enough that it could take the wear and tear

of being handled and transported by the various participants and endure all sorts of weather conditions as well as being unobtrusive.

The LogTag can measure and store temperature readings over a range of -40°C to $+85^{\circ}\text{C}$ (-40°F to $+185^{\circ}\text{F}$) and humidity over 0 to 100%RH, thus covering the range required for this study. Furthermore the device has a fine measurement resolution of 0.1°C and 0.1% relative humidity, and was standardised at a 2 point calibration of $-5/40^{\circ}\text{C}$ and 30/80% thus ensuring accurate readings between the different apparatus used. Further useful features of this particular model are its programmability where the time intervals between measurements, starting the logger at a preselected time, and of limiting the time the logger remained active can all be adjusted, and the ease with which data can be downloaded on to a computer in a file that provides descriptive statistical information and can also be exported to various file formats including excel thus minimising the chance of human error (LS Technology, 2015.)

A handheld thermo-hygrometer, the *ETI 6500*, was used to measure the temperature and relative humidity in those cases where persons of lower socio-economic status who were not literate enough to fill in the questionnaire were surveyed on-site by myself (the researcher) and the LogTags were all in use with other participants. The *ETI 6500* was well-suited to the study as it has a temperature range of -20°C to 70°C and is sensitive to the full humidity range from 0% to 100%. The resolution of the temperature readings was similar to the LogTag thermos-hygrometers at 0.1°C and 0.1% for relative humidity, with the same levels of accuracy as well. The equipment was standardised at the same two point calibration of $-5/40^{\circ}\text{C}$ and 30/80% as the LogTag, ensuring that all thermo-hygrometers used in the survey were accurate on the same scale.

The use of these thermo-hygrometers and the method of data collection had the advantage that the participants were not aware of the numerical value of the environmental readings and hence could not be influenced by them in any way.

Anemometer: The wind speed was measured with a handheld anemometer the *JDC Skymatch Eole* which is a robust device with a multi-directional impellers. The anemometer measures wind speeds in several formats and has a memory feature providing maximum and average wind speed. The unit measurement is to the 10^{th} , and the precision is of $\pm 3\%$ between the temperature range of -10°C to 50°C . The accurate measurement range is from 0.45m/s to 13.9m/s . Although not as sensitive at wind speeds lower than 0.45m/s , the *Skywatch Eole* is suitable for this study as it is anticipated that most unconditioned spaces will have higher wind speeds through fans. Furthermore as the impellers are multi-directional, the equipment is sensitive to air movement from any direction.

A data-logging anemometer that could automatically measure and record the wind speed would have been the instrument of choice doing away with possible human error and the possible Hawthorne Effect (due to which the participants' responses can be effected by the knowledge of the numeric value of the measurements). Unfortunately such instruments were too expensive to be acquired on a student budget, hence the *Skywatch Eole*, an anemometer that is hard wearing, waterproof, and very easy to use, read and re-set was chosen. A set of instructions was taped to the inside of the box (Figure 5.5) in order to minimise the errors and every participant was given the chance to 'play' with the anemometer to understand how it worked: how to start, reset and take readings. Additionally the anemometers were checked

prior to each distribution, the first reading taken under of the researcher's supervision and the final reading was tallied with the last recorded reading to weed out possible misreading or misrecording.

The box: The data logger was hung on the top of a plastic container with a lockable removable lid (typically used as plastic food storage container) with the means of a wire frame. This ensured that air could flow around the logger freely and that it was not in contact with any surface that could influence the readings. The frame provided a handle for the box for ease of carriage while another wire was looped around the logger so as to hold it steady. This wire loop could be slipped off the logger to enable the logger to be plugged into the dock to be programmed to record or download collected data. This meant the logger did not have to be removed from the frame and could not easily be tampered with.



Figure 5-5

'The box' with datalogger, anemometer, clock and pen. Of note are the instructions to use the anemometer pasted to bottom of box in easy to follow steps.

The box contained all the items necessary for the study: the anemometer, the questionnaire, a pen, and a digital watch-face. The box and anemometer were numbered with the last two digits of the serial number of the data logger. This ensured that the sets of equipment remained the same and any variations in results due to variations in the calibration or sensitivity could be highlighted during analysis. Furthermore, when data is downloaded it is automatically saved with the serial number of the logger which was an additional measure to ensure data was not lost or mislabelled. The watch was set to the same time as the data logger thus doing away with any discrepancies with the time differences between individual time-pieces. A step by step description of reading and resetting the anemometer was fixed to the inside base of the box in case participants needed a reference, and a visiting card with the researcher's contact details was fixed to the box in case the participants' had a query, and it was emphasized that they should not hesitate to contact if required.

Specific instructions were provided to the participants regarding the equipment; they were to keep it with them constantly and within the same space as far as was possible, with precise directions to ensure the box was exposed to the same environmental conditions as them by

not placing it under a desk, or directly in front of the vents of an air conditioner et cetera. Advice was given to not to cover the logger or place it in a bag for transportation, except in cases of severe monsoon rain or sandstorm. A question was incorporated in the questionnaire that dealt with such cases where the equipment had to be covered or was not with the participant for any length of time (so that the proceeding comfort readings could be managed during analysis). The participants were also told that where required, the wire handle could be bent to enable hanging from the handle of a motorcycle, or bicycle.

The first reading by each participant was taken in my presence so that if there was any confusion regarding the use of the equipment or any ambiguity regarding the questionnaire it could be clarified.

In order to ensure these instructions were followed, the follow-up questions included a discussion of the participant's anticipated routines as well as discussions of appropriate places to store the box. The importance of recording in the questionnaire if the participant had not been within the same environment as the box (if it had been covered or stored elsewhere) in the time leading up to the taking of readings was emphasised, and they were given assurances that there were no negative repercussions of this to the study so long as it was properly recorded. When debriefing the participants at the end of their participation very direct questions regarding the ease of usage and storage of the box were asked in order to ensure the accurate recording of activities and locations by the participants. On several occasions I was able to observe participants use the equipment and take readings (as when briefing new participants within the same environment) which provided an audit of the data collection and briefing procedures.

5.4.4 Questionnaire

The questionnaire through which all relevant information was collected was divided in two parts. Part 1 recorded the physiological, social, and economic information of each participant while Part 2 recorded their subjective thermal sensation.

5.4.4.1 Part 1 - The physiological, social, and economic information

The Questionnaire Part 1 (Appendix 5.3) was filled in (by myself) during the recruitment process. This questionnaire provided background information about the physical state of the participants, their age and gender, and through questions about lifestyle, enabled an estimate of metabolism. Information about their socio-economic status and the various climatic environments they are exposed to was also collected.

Traditionally methods of determining socio-economic status take indicators from occupation, income, and include ascertaining the buying power through ownership of household appliances, cars, washing machines, livestock etc. (Vyas and Kumaranayake, 2006). For the purpose of this study, the socio-economic status of the participants was gleaned from questions regarding the occupation, income (personal and household), type of household (personal/individual or joint-family system), and number of dependents, and their primary mode of transportation. Wherever possible the recording of information that could be regarded as personal by the participant or that may have resulted in social desirability bias where the answers are *padded or inflated* by the respondent to give the appearance of higher social and economic standing (Oppenheim, 2004), was undertaken in isolation and care was taken to phrase the various available options as equally weighted and of equal importance to the study thus reducing the chance of such bias in the responses. Participants were also asked

to self-assess their socio-economic positions as a means of determining subjective social status.

The questionnaire also included a section regarding the various climatic environments the participant experienced during the course of a standard day. These were broadly classified into the categories of work environment, home day environment, and home night environment and were to be used to assess if regular exposure to a particular environment would have a significant effect on expectations of the thermal environment and perception of thermal comfort, as well as provide an indication of socio-economic position (with use of artificial conditioning devices in their residences being an indicator of disposable wealth).

As a means of setting a base-line, the participants were also asked how they would classify the current seasonal temperature as either hot, moderate, or cold. This question was often met with amusement from the participants as the answer to the question was perceived as self-evident (the survey was undertaken in peak summer months). However, it provided interesting anecdotal insight in that people who spend the night sleeping in the open air, on roofs or in open courtyards, irrespective of whether this included the use of a fan, would describe the weather as moderate. This reinforced the foundation for enquiry into exposure being a significant factor in comfort perception.

5.4.4.2 Part 2 – The subjective thermal sensation

The subjective response to the physical parameters was collected through a questionnaire that was filled in by the participant. This questionnaire Part 2 (Appendix 5.2) comprised of a column of seven (7) themes that required simple tick-mark responses from the participant, and would take approximately a minute to complete. A single questionnaire page contained 16 such columns which amounted to approximately a day's worth of readings and subjective responses. A one hour interval was recommended between readings, but the frequency was at the participant's discretion and so extra questionnaire pages were provided with each box.

The questionnaire sheet was marked with the participant's identification number (id) and the project date label and the pages were numbered for day 1, 2 and 3 of the project to ensure they could be put in order in case the stapling was lost or if the pages were not dated.

The participants were asked to provide information about their clothing from a pre-specified list with additional space provided for any items not listed in order to highlight any influence of clothing insulation on their thermal comfort perception.

There is little variation in the type of clothing and their material normally worn in hot-dry climatic conditions such as the case study region as is discussed in detail in Section 5.2 and below. However the participants were also asked to note any change in clothing during the course of the day along with the time at which the change occurred in order to enable the assessment during analysis, of the effect of such a change on thermal comfort perceptions. Particular emphasis was placed on the importance of information on shoe type (closed or open/sandal), head cover (hat or scarf), and abaya (a loose cloak worn by some women over their normal clothing) as it was anticipated that these items could have measurable influence on thermal comfort perception.

A dedicated space on each column was provided for the participants were to record the anemometer readings with a note of the time the readings were taken.

A section of the questionnaire was assigned to note the location and activity of the participant in the 15 minutes prior to the recording, as this provided a baseline for previous environmental conditions the participant was experiencing and their metabolic rate based on their activity level against which their current thermal perception could be gauged. Two questions regarding skin wettedness were included, one addressing skin wettedness through means such as bathing and swimming, and the second regarding the current sweat situation of the participant. This is because skin wettedness can have a significant impact on the perception of climate in hot dry climatic conditions, however the cooling effect of both types of skin wettedness on thermal comfort perception were expected to be different.

Another series of questions related to the current environment of the participant with regard to the method of mechanical conditioning within it, the options provided included the use of air conditioning, fans, desert coolers, and whether any windows were open or not.

Two questions related to the perceptions of thermal comfort of the participants. The first dealt with their perception of the current thermal environment and the second related to the changes to the thermal environment they desire in order to achieve optimum thermal comfort. These questions were laid out on a Likert scale where the response could range from an extreme (very cold) to neutral (comfort) to the opposite extreme (very hot). The first of these is based on the traditional 7-point Bedford Scale (Nicol, Humphreys and Roaf, 2012) while the second question pertaining to the desired comfort levels is based on a similar but simplified Bedford Scale with 5-points. It is worth noting that these two questions regarding the comfort levels of the participants were not specific to any environmental parameter, and was taken to encompass the combined exposure to temperature, relative humidity, and the effect of air movement.

The final section asks two questions about wind speed and its perception. The participants were required to rank the wind speed with regard to the disruptive nature of the wind rather than its cooling or comfort effect, and to specify their satisfaction with the speed, if they desired change, and whether that change should be an increase or decrease in speed.

5.4.5 Lahore profile and the methodology for recruitment:

The basis for undertaking thermal comfort research within the city of Lahore in Pakistan has been described in 5.3.2 and 5.4.2. A detailed description of the city of Lahore that includes an impression of the social character of the region, the demographic, and socio-economic qualities of the resident population, the urban character and construction techniques and also the climatic environment as well as thermal comfort practices, is provided in Chapter 6 (Thermal comfort practice in Lahore).

The following section describes the sample set of participants: their occupations, socio-economic backgrounds and demographic indicators. The section also provides an indication of the geographic extent of the survey.

5.4.6 The sample set:

The study endeavoured to recruit participants for the field study in a manner that the sample was representative of the resident population of Lahore. Several organizations including banks, factories, shops and offices, as well as private individuals from across the city were approached for access, the geographic extent of which is shown in Figure 5.6. The employees of these organizations were briefed on the aims of the project and the method of data collection through an oral presentation and printed information sheet, along with a demonstration of the equipment, and on the basis of this some volunteered to participate in the study. A total of 269 participants were thus recruited, of these, 62.6% were male, and 37.4% female, and ranging in ages from 16years to 78years with a median age of 29years. The data thus collected was (from a geographic point) spread over the entire city extents as is indicated through a mapping of the residential addresses of the participants in Figure 5.7.



Figure 5-6

Plans of Lahore showing primary routes (red) travelled and primary sites of access to participants (black dot).

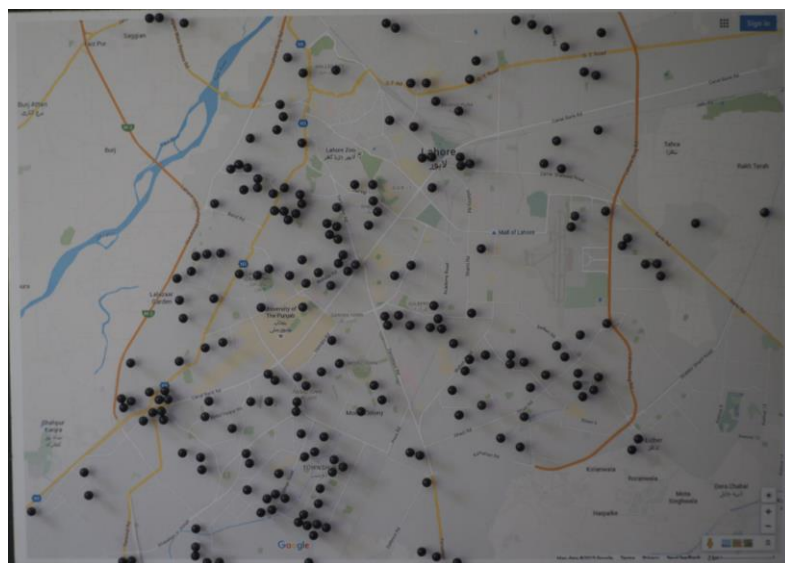


Figure 5-7

Plans of Lahore showing extent of data collection through residential addresses of participants (black dot)

The participants were of diverse occupational backgrounds ranging from housewives, house-help (cooks and maids), retired persons, managerial staff, customer service providers, private and public servants, drivers and manual factory workers. This provided a sample group of varied socio-economic backgrounds and occupations that ensured that the participants were exposed to varied environmental conditions during their daily routines, and which would therefore provide sound data for analysis regarding their thermal comfort experiences and preferences. It was not possible to recruit persons from the lowest socio-economic tier as such persons often reside in slum settlements, have no permanent or traceable address, are often also illiterate and would not have been able to participate in the same manner as others. It was also advised that including persons of such economic hardship could result in the loss of the survey equipment. However a number of the participants of lower socio-economic status were who were surveyed were illiterate though of a known traceable address and working in unskilled employment as factory shop-floor workers and domestic help which provided an indication of the thermal comfort experiences of the lower socio-economic population.

5.4.7 Mode of analysis:

The data analysis is undertaken through the statistical software SPSS (Statistical Package for Social Sciences). The data collected through the dataloggers is downloaded as excel (*.csv and *.xls) files then pruned to maintain only relevant readings, these were collated with the questionnaire replies and readings which have been manually coded.

5.5 Anticipated results & Conclusions:

The study undertaken along the research design methodology outlined in this chapter intends to provide an improved understanding of thermal comfort perception in the developing world primarily in hot climatic conditions.

The study described divides the investigation in to two parts, the first focussing on the objective parameters of thermal comfort perception, and the second on the subjective parameters. The section dealing with objective parameters will determine which environmental parameters are most correlated with thermal comfort perception thus determining which are most appropriate for use in formulating predictive thermal equations. The investigation will also look in to determining the regional specificity of thermal comfort through comparing the thermal comfort equations of geographically different but climatically similar urban regions. It is anticipated that the analysis of this will help to establish to what extent thermal comfort should be defined within a particular regional (cultural and climatic) context. This will determine the accuracy of existing predictive thermal comfort equations and lay the groundwork for the development of thermal comfort recommendations and building guidelines for future reference.

The subjective aspect of thermal comfort perception is the focus of the study in the second part of the investigation. This is primarily undertaken by the analysis of the empirical data collected in the case study site and it is anticipated that this will, in the first instance, provide a predictive thermal equation for the population of the case study site of Lahore. Further analysis on the various populations within the sample will focus on their socio-economic status and determine if there is a significant difference in the thermal comfort perception of

these population groups along the lines of their socio-economic position. It is anticipated that these analyses will provide an understanding of whether, in developing world regions of high social and economic inequity, the provision of a single predictive thermal equation is adequately representative of the resident populations.

A summary diagram of the research methodology is provided in Figure 5.8.

In order to fully understand the context of current thermal comfort practice within the chosen case study site, the proceeding chapter (Chapter 6; Thermal comfort practice in Lahore) provides a detailed description of the urban geometry, construction techniques and local climatic conditions that can influence thermal comfort practices of the region. An overview of the lifestyle and clothing practices of the local population and a comprehensive socio-economic profile of the resident population is also provided.

This Research Methodology chapter thus provides the hypotheses that this study is seeking to theorise, and maps the outline through which this is undertaken.

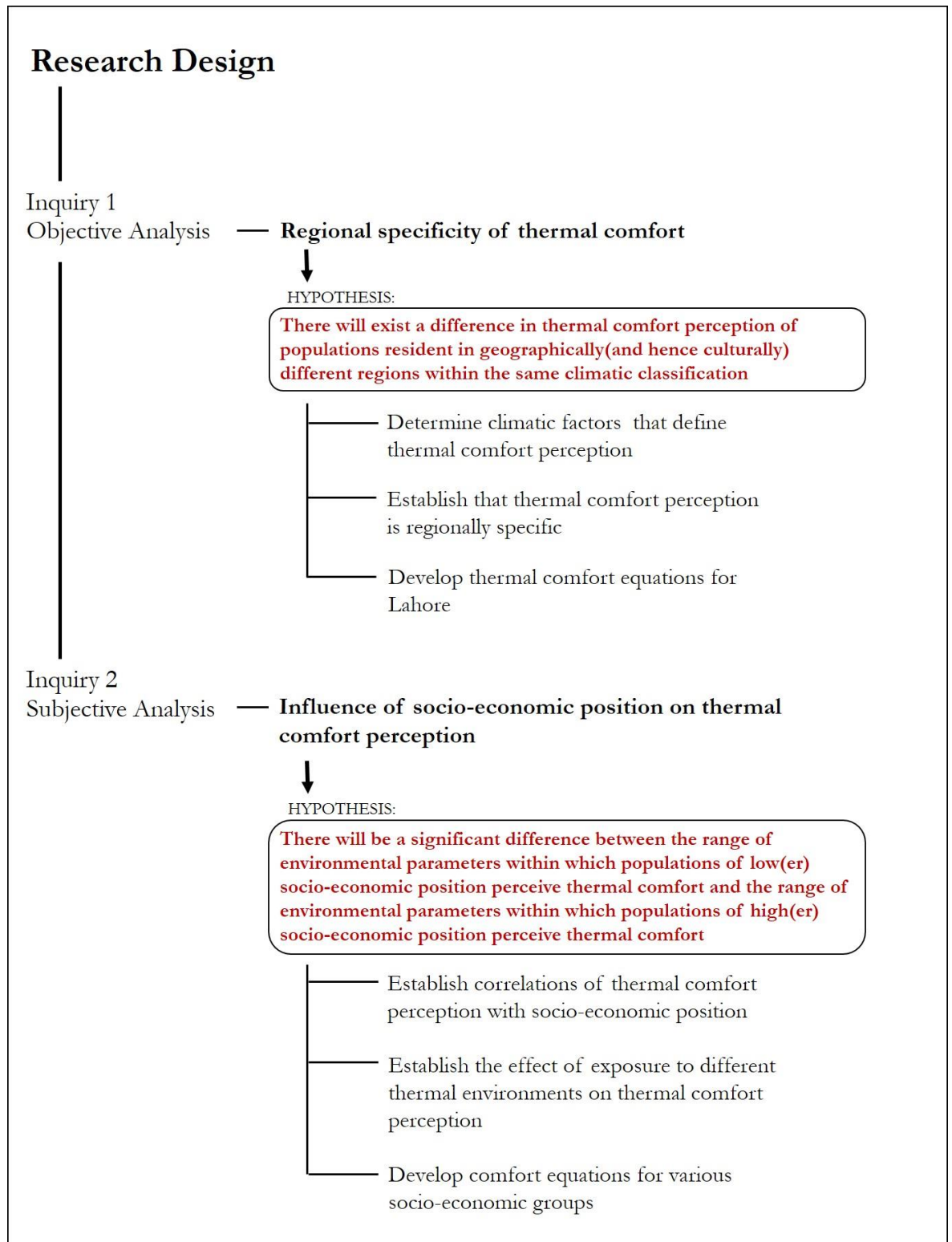


Figure 5-8
Summary diagram of research methodology.

Chapter 6

Thermal comfort practice in Lahore

6.1 Introduction

The primary focus of this thesis is to investigate the influence of the subjective parameters on thermal comfort perception. This is undertaken by means of assessing if variations in thermal comfort perception of a population group is influenced by socio-economic position of the population. This is based on the understanding of the particular influence one's socio-economic position has on lifestyle, exposure to different environments, and consequently, on their expectation and perception of the physical environment as discussed in Chapter 2 and Chapter 3. The case study selected for this investigation is the city of Lahore in Pakistan which as a hot-dry climatically classified region within the developing world has been identified as suited for the investigation based on the discussion presented in Chapter 5.

This chapter describes the city of Lahore in order to provide a rounded impression of the social character of the region, the resident population from which the sample set was drawn, along with a thorough understanding of the variations in thermal comfort practice of the local population. The discussion presented will clearly show the position of Lahore as a typical developing world city and consequently its suitability as case study.

This chapter also includes a brief overview of Pakistan in order to provide an understanding of the particular geo-political forces within which Lahore has developed. This is followed by a description of the geographic location of the city and an explanation of its choice as the case study with reference to established precedents of field studies. A further section details out the urban character of the city with an explanation of traditional and modern urban form and construction trends and their implications on thermal comfort provision. Finally the population demographics of the region and an explanation of the socio-economic ranking or class system is provided along with a description of how representative the participant sample is of the population.

6.2 Understanding Lahore

This section provides an overview of the particular geographic and climatic character of the country of Pakistan in general and of the city of Lahore as the main focus.

Lahore is a prototypical developing world city that has had a very central position within the geopolitical landscape of Asia; the city can be traced back to medieval times with early recordings of the city as far back as circa 1000AD. The current city has a complex urban fabric, each region reflecting the stylistic, cultural values, and socio-economic characteristics of when and for whom it was built.

6.2.1 A summary of Pakistan

Pakistan is located in the Northern Hemisphere in South Asia (Figure 5.1). It is geographically diverse country with a topography that ranges from the highest mountain range in the world to low lying coastline of 650 miles, and includes heavily forested areas, desert, and tundra as presented in Figure 5.4. The consequent climatic zones are wide-ranging from temperate to tropical. Much of the country experiences four (4) distinct seasons with some regions experiencing an additional monsoon season (Figure 5.3).

Pakistan has a population of over 189 million, which equates to a density of 245 persons/km² (B.O.S. Punjab, 2015). Over half (104 million) are under the age of 30 years and around 35% are under 15 years of age. The most populous of the 4 provinces that make up Pakistan is the Punjab constituting 55.6% of the population of the country of which 32% reside in urban settlements. The divide between the country's urban and rural population with respect to income, education and social mobility is glaring and has been exacerbated by political support and infrastructure development focussing on existing urban settlements. The consequent rate of urbanization at 2.81% is considerably higher than the world average of 2.05%. Pakistan has the most urban population in South Asia with 38% of the population living in cities, and over 50% of the population living in towns of 5000 people or more (Central Intelligence Agency, 2016).

The large urban settlements of the country are primarily organic in growth, having a historic presence, with newer settlements developing near or around intercity motorways and junctions. Urban development in large cities was initially undertaken as the laying out of satellite towns at a distance from the historic centre of the city, but is now largely at the behest of privately owned commercial companies, and only loosely constrained by building codes. The resulting urban form predominant in Pakistan is that of a sprawling expansive city which has encroached upon and in many instances overtaken the agricultural hinterland.

The country is considered a developing world economy of which 58.8% of the GDP comprises of the Services sector (Education, Medical, Banking, etc.), 20.9% is Agriculture, and 20.3% is from the Industry sector. Pakistan has the 67th largest export economy of the world and is currently South Asia's second largest economy making up 15% of the regional GDP however 21.04% of the population are reported to live below the poverty line of US\$1.25/day.

6.2.2 Lahore – geographic location

Lahore is the second largest city in Pakistan and is the capital of the Punjab province. The city is located at 31.34°N and 74.22°E, at an altitude of 217m. The land is generally flat with an average gradient of 1:3000 down towards the south and south-west. Lahore was bounded on the North and North-West by the River Ravi with the original city walls bordered by the river, however the path of the Ravi has moved further west-ward and the river has dried up significantly due to damming and diversions upstream. The city lies on the alluvial plain called Bari Doab (doab being the land between two rivers), with the area of current urban Lahore being under cultivation.

The city is spread over an area of 156 sq. miles, and is located at a distance of 15 miles from the international border with India.

6.2.3 Lahore - climate

The city of Lahore experiences five (5) distinct seasons predominant of which are a dry winter, hot-dry summer and a hot and humid monsoon season during the months of July and August with a mean of 183mm rainfall. The temperature ranges from a mean minimum of 5.9°C to mean maximum 40.4°C, with a summertime diurnal range of 12.4 °C (May to July). There is no prevalent wind direction and the area is not prone to high wind speeds with an average maximum of 6m/s (Weatherspark, 2016).

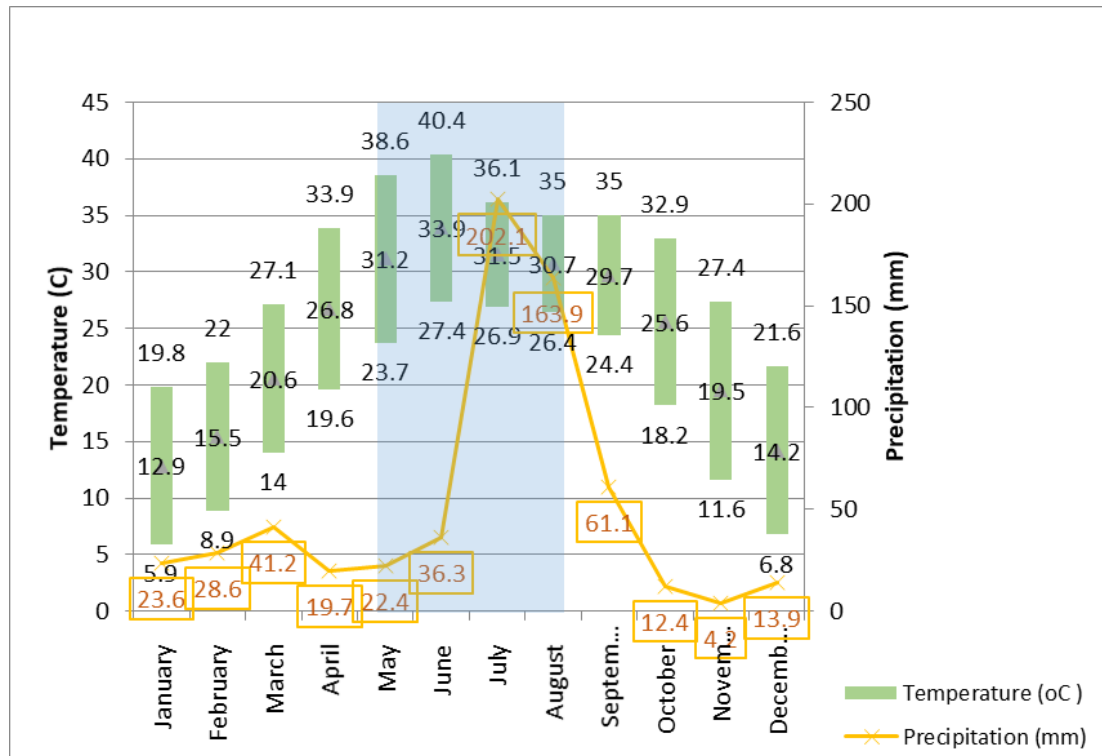


Figure 6-1

Climatic data for Lahore -Tempertaure (historical maximum, minimum and mean) and Percipitation (average) (HKO, 2003; PMD, 2017)
 Blue highlight indicates months of survey.

During the months of April to June, the effect of high afternoon temperatures are increased through a hot dry westerly wind from the desert regions of South Asia, known as *lu*. With temperature of between 45°C to 50°C, prolonged exposure to the *lu* could cause heat stroke (Rana, 2007) which may be why afternoon hours were traditionally spent indoors or in shade. The summer also brought with it frequent dust storms known as *aandhi* or *kaali aandhi* (kaali = black) because of the reduced visibility caused by large amounts of suspended dust. Lahore experiences *aandhi* of *light* and *moderate* classification which range from 4-8 on the Beaufort scale (wind speeds of between 38-75km/h) and with visibility restricted to between 1000-500m (light) and between 500-200m (moderate) (Joseph, Raipal and Deka, 1980). Anecdotal evidence of locals referring to *aandhis* by colours other than black (kaali *aandhi*) of which red (laal *aandhi*) is most common is based on the colour of the dust which was closely linked to the direction of the wind.

The prevalence of the *lu* and *aandhi* is now not as common nor as predictable within urban Lahore. One could assume this may be due to a change in the microclimate resulting from the sprawl of the city or with the built-up area providing resistance to the wind, and also because

of large tracts of previously uncultivated land on the outskirts of the city brought under crop reducing the amount of moveable dust.

The Monsoon season is characterised by high levels of rainfall (due to a change in atmospheric pressure and consequent change in wind direction). Lahore receives the tail end of the Indian Monsoon, (also known as the Southwest Monsoon), which usually lasts from July to September, and as such marks the end of the hot-dry summer season. The rains are heavy and abrupt, and make up on average 68% of the annual rainfall in the city (PMD, 2017). The climate during the early Monsoons (July-August) is hot-humid with relative humidity measuring at 100%.

The study:

The field survey was undertaken in the summer months from mid- May to mid-August, across the years of 2014 and 2015 and as such the field work took approximately 6 months. The months surveyed are historically the hottest times of the year, and include the beginning of the monsoon season. This detailed description of the climatic environment of Lahore provides the background for understanding the particular thermal comfort practices that have developed within the larger socio-cultural environment of the region and also the reasons for these customs and practices.

6.2.4 Urban character of the city: expansion, infrastructure, population

This section describes the urban character of the city of Lahore through a chronological discussion of its formation or urban space and simultaneous development of its cultural identity. The purpose of this is to build an image of the city and the people in order to provide the background understanding of the particular physical and socio-cultural parameters within which their habitus developed and the lens through which they perceive their physical environment.

The historic city of Lahore was a fortified settlement along the banks of one of the main rivers of the Indus River Basin, the River Ravi, and included within it on the highest point of the local topography the Royal Palace (visible in North-West corner of relief map in Figure 6.2). The wall surrounding the city was 13metres high with a total of 13 gates and enclosed an area of 2.6km². The interior of the city comprised of several localities of various density and housing type, and included numerous religious buildings catering to different faiths, and a public baths. The city and the surrounding area also included planned gardens which incorporated the use of courtyards, covered pavilions, and fountains and streams used as cooling devices, which were designed for recreational use by nobles and of which sections were open to public, some of these still exist and several are UNESCO World Heritage sites. Originally the town comprised of several localities with different urban characters and densities, and included large courtyard houses traditional to the plains of Punjab known as *haveli*, however the recent (mid-18thc and post-partition of the Indian Sub-continent in 1947) unchecked construction and encroachment of open areas as well as within the existing buildings has resulted in an urban form that is dense and compact. The area now referred to as *androon shehar* which translates to 'inner city' and has a population of over 200,000 which equates to approximately 77,000persons/km². The urban form of the town is low-rise, with most buildings not more than 4-5 stories above ground, with the buildings being a mix of residential and commercial use. The Walled City area contains numerous specialist wholesale

markets that cater to the larger district to the extent that most localities are now recognised by, and named for, the specialist goods that are available there.



Figure 6-2
Image of relief map of Walled City of Lahore, circa 1800s. (Original in British Museum archives).

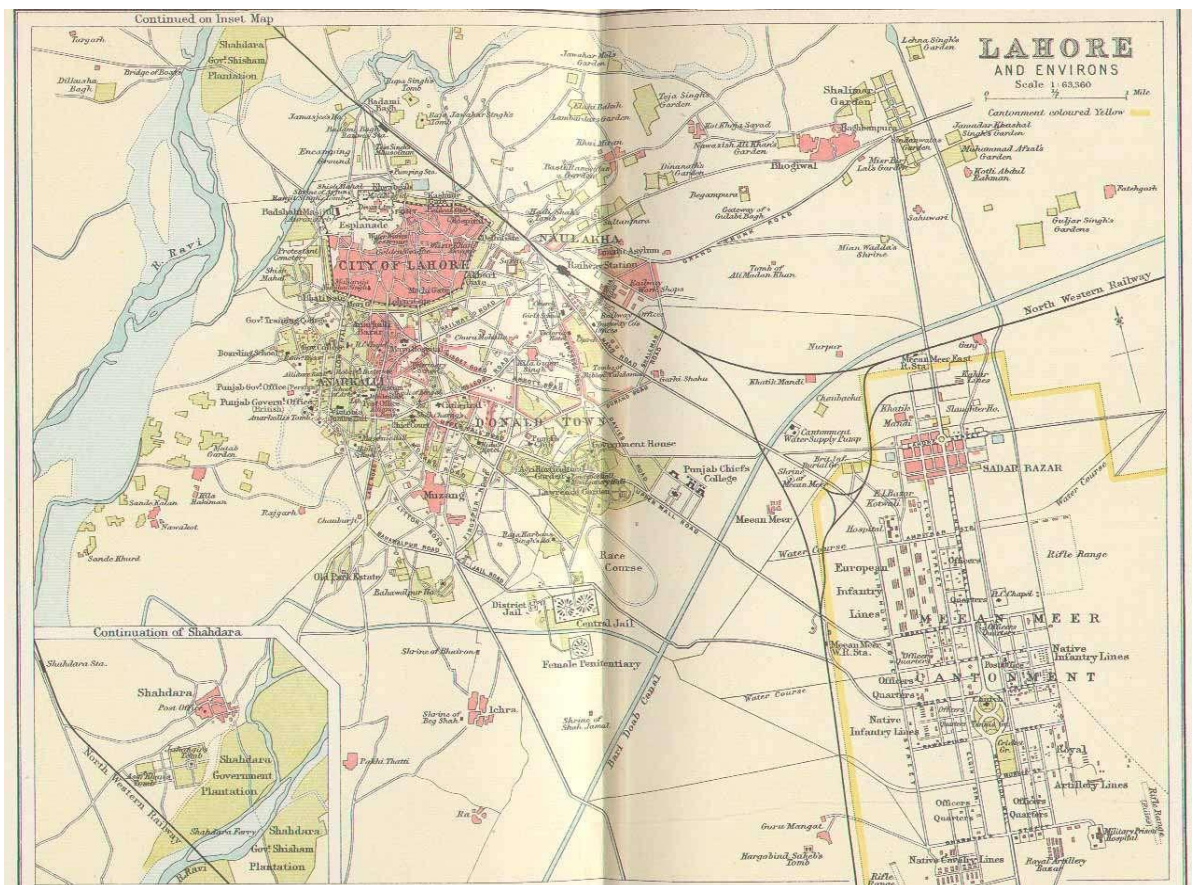


Figure 6-3
Map of Lahore circa 1893 –showing the Walled City and pre-colonial areas within Lahore as well as the British era expansion and infrastructure including roads, secretariat and courthouse, canal systems, railways and cantonment areas. (New World Encyclopedia, 2009)

- pre-British era built-up area
- planned/formal gardens – pre-British era
- boundary of cantonment areas

By the mid 20th century, Lahore had seen significant expansion beyond the original walled city as is represented Figure 6.3. The British contribution to the urban fabric of Lahore saw an expansion of the city towards the South and South-East. This included the Railway systems, the Secretariat buildings, Transport infrastructure, Cantonment areas and Civil Lines as well as the Canal systems. This era saw the development of a water pumping station within the Walled City as well as the laying of a sewerage system. Residential buildings constructed during this era were either close quartered reflecting the *traditional* form of the walled city residences (e.g. Gawal Mandi and Anarkali regions), large courtyard *haveli* type houses (e.g. Garhi Shahu and Baghbanpura localities), and those built in the style of the quintessential British Bungalow (e.g. Mayo Gardens and Model Town).

The post-independence period from 1947 onwards has seen an exponential increase in the extents and population of Lahore. At present, Lahore is the second largest city of Pakistan with a population of over 11.13million and a population density of 3566persons/km² (B.O.S. Punjab, 2015; P.B.S., 2018). The rate of urbanisation of the city has been staggering especially within the past 4 decades where the infill of open areas within the city extents and the subdividing of larger plots, have resulted in an unprecedented increase in urban area of over 68% since 1972 (Riaz, 2013) as represented in Figure 6.4. Much of this expansion is in the form of planned residential colonies, however a large number of previously outlying villages have been absorbed into the city, and currently 17.8% of the urban population is estimated to be living in slums (B.O.S. Punjab, 2015).

This rapid horizontal expansion has resulted in the absorption of previously cultivated land into the city extents which are represented in Figure 6.5. this has resulted in an increase in the cost of farmed goods, more pressure on the already underdeveloped infrastructure and has also resulted in an increased urban heat island effect.

Private vehicle use is high with over 4million registered vehicles in Lahore (B.O.S. Punjab, 2015), which amounts to approximately a vehicle per household and does not account for the vehicles registered in other cities that are driven within Lahore. Such high traffic volumes are a cause of much congestion and pollution. The public transport infrastructure has been insufficiently developed to meet requirements of the local population, this is primarily formed of a network of privately run buses and vans (12 seater) servicing routes between main nodes, along with private hire taxis including uber and other ride-share companies, and motor rickshaws however recent development has included government regulated fares, an elevated bus route, and initial work on an intra-city above-ground train line. The use of domesticated service animals within the urban space is not as common as it once was. Mule and donkey drawn carts are used as a mobile shopfront by fruit and vegetable sellers and as a means of transport of goods in some localities. Horse drawn carriages (*tonga*) have been largely replaced by motorised vehicles, though some remain in use in the older parts of the city. Lahore is an international travel hub served by a single commercial airport.

The education system in Pakistan is based primarily on the British system, with students undertaking exams at 16 and 18 years of age and either moving on to professional degrees based on a merit system or moving into apprenticeship systems which are often more informal. The primary and secondary education is provided by a mixture of both public and private schools, with only lower socio-economic group sending their children to public schools. The majority of reputable higher education institutes in the city are public, and both

public and private universities have a significant number of their graduates going on to further education and specialization in Western countries. There is consequently a considerable ‘brain drain’ with an estimated 2.7million Pakistanis emigrating between 2008-2013. The substantial loss of human capital has had an effect on the economy of the country (Ahmed, 2018).

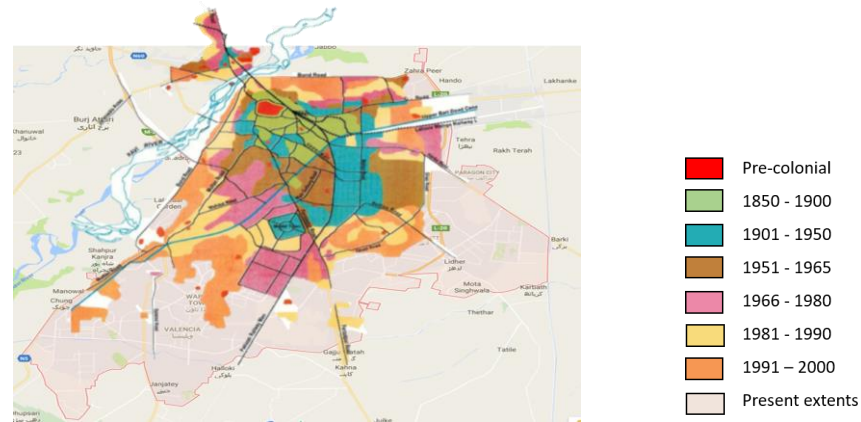


Figure 6-4
Chronological expansion of urban Lahore extents circa 1850 to present day. (Shirazi and Kazmi, 2014; Google, 2017).

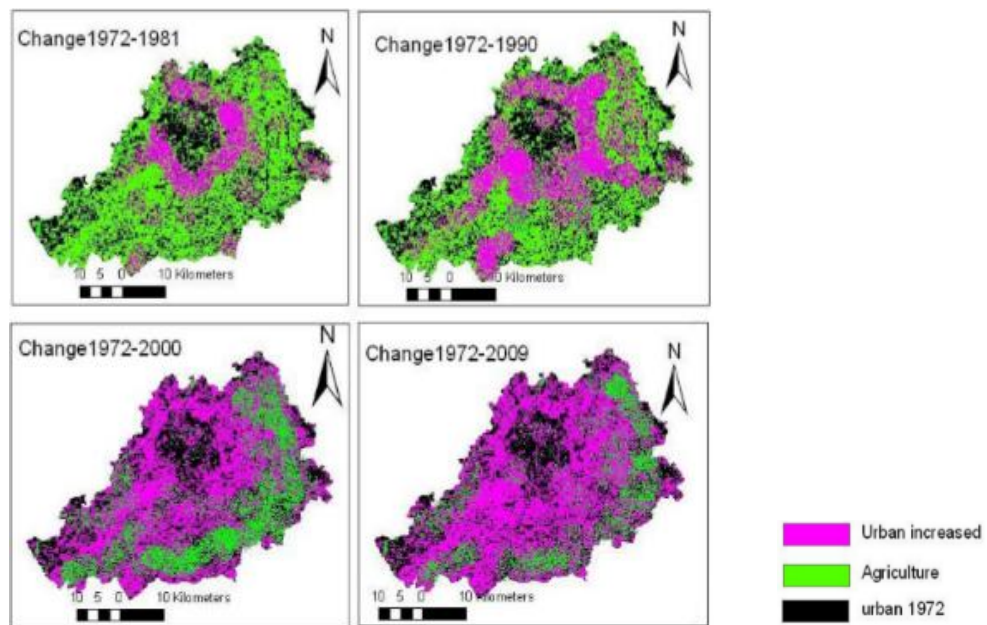


Figure 6-5
Urban land use change of Lahore district 1972 – 2009 (Riaz, 2013).

Health services available in Pakistan are not free except for the poorest who qualify for limited support of medicines. In Lahore, there exist 17 government (public) hospitals and tertiary support clinics, and numerous private and specialist hospitals. Most people who have the means prefer to be seen at private hospitals and clinics. The government sponsored social services within the country are undeveloped, and this remains the initiative of private enterprises, NGOs and private individuals. The social support character of Pakistan and particularly within Lahore is noteworthy as the Edhi Foundation which runs the world’s largest ambulance service is in Pakistan and is run entirely on donations, similarly the Shaukat

due to façade design and material to similar building-types in the developed world (Figure 6.7), however most are less than 100metres in height. Most of the 1950s-1970s residential Lahore which comprised of large British Bungalow inspired colonial and art deco houses have now been replaced by expanses of such commercial buildings with the additional repercussion of nodes of traffic congestion around those regions.



Figure 6-7

Examples of high-rise buildings in Lahore. From left to right: Siddiq Trade Centre, PIA Building, Eden Centre.

Over the past 3 decades the development of residential infrastructure in Lahore has been at the behest of private developers who buy up large swathes of land (both brown and green field sites), demarcate plots, and develop the basic infrastructure (roads, waterworks, gas supply etc.) and sell off individual plots of land to potential homeowners who then have their individual custom-designed houses constructed independently. More recently, real estate developers have also started offering fully developed housing schemes where constructed houses are sold at a considerable mark-up. Shared ownership such as in apartment buildings is not popular, and the few such buildings that exist are largely for government sector employees of the lower grades. The majority of such residences are limited in height being at most 4-storey walk-ups.



Figure 6-8

Google image of part of Defence Housing Scheme (DHA) Lahore under which 70% of modern Lahore has been developed. The standard plot size and trend of constructing on maximum allowed area as well as the green medians and verges are clearly visible. (Google Maps, 2019).

The marketing and pricing strategies of the real-estate developers are based on government taxation slabs and historical land units which has resulted in four de-facto standard sizes of

residential plots: 125 sq.yd (104.6m²), 250sq.yd (211.3m²), 500sq.yd (418.3m²) and 1000sq.yd (836m²) (LDA, 2019). Most plots are rectangular in plan with approximately 80% of them conforming to industry standard dimensions in formal government approved housing developments. There is evidence to suggest these standards have been followed less rigidly in the housing schemes that do not have government approval. The majority of the building control agencies in the city assign similar bye-laws to the building of single-use residential structures that determine the allowable covered area as a percentage of the plot, specify minimum mandatory clear areas (typically 1.7m from boundary wall) and provide a limit to the height of the building at 8m. The bye-laws further limit the form as only two floors above ground (additionally a basement in some localities) is permitted, and the upper floor is restricted to 75% of ground floor area. The cultural trend, supported by high land prices, has been for houses to cover the entire permitted area of the plot. All houses have boundary walls which are allowed to a height of 2.13metres and most residences have utilised the full height thereby blocking all view from the inside out and vice versa, this is primarily for security but may also be influenced by the historic cultural desire to maintain privacy. All houses are also gated for security purposes. The gates of most houses particularly in affluent neighbourhoods are always closed and locked which is a more recent trend as approximately two decades ago most people would only lock gates at night time. In less formally planned parts of the city which are more congested, fewer residences are gated, this may be due to space constraints and possibly also linked to affluence as anecdotally, car ownership appears to be correlated with gated residences; one could assume that both car ownership and a residence with garage or parking space indicate relative wealth (Siddiq, 2013) .

The standard road widths within housing schemes range from 40m and 33.4m (main dual carriageway), to 18.3-12.2m. All dual carriageways have wide medians that are usually planted with trees and shrubbery, and wide borders are built in to the bye-laws to give a green verge alongside the road before the boundary of the residences is built.

The road widths, provisions of green belts, public parks, community centres and mosques as well as designated areas for commercial development are within the remit of the real estate developers, hence one can assume that their cost is incorporated into the land prices of individual residential plots and therefore the more upmarket housing schemes provide better social and public spaces for their residents.

6.3.1 Environmental sensitivity in the urban form

The urban buildings in Lahore as described in the previous section can be broadly divided in to three eras each with its own particular building form and construction materials and methods. Earlier buildings and urban form developed through an evolutionary process influenced by both need and desire and was constrained by the spaces, technology and materials available. The resultant urban buildings and the lifestyles of the residents were reflective of and sensitive to the climate, and incorporated within them the methods of achieving and maintaining thermal comfort.

The urban form of most of Lahore is dense and low-rise. With adjacent buildings being so close as to cast shadows on each other which can have an effect on the internal thermal environment of the building. This proximity also has an effect on the privacy of residents as gardens and open spaces can be overlooked and as buildings are designed in isolation, the

possibility for views into adjacent properties through windows is a concern for residents. The focus of both the private housing associations and the government owned development authorities is on profit and as such the master planning of new localities has been undertaken in way so as to maximise the marketable area, and as the land acquired for these developments is rarely regular in shape, the plots are not laid out in a rigid pattern. There is therefore no predominant orientation of the buildings, and consequently the internal layout of the buildings is not sensitive to the sun's path.

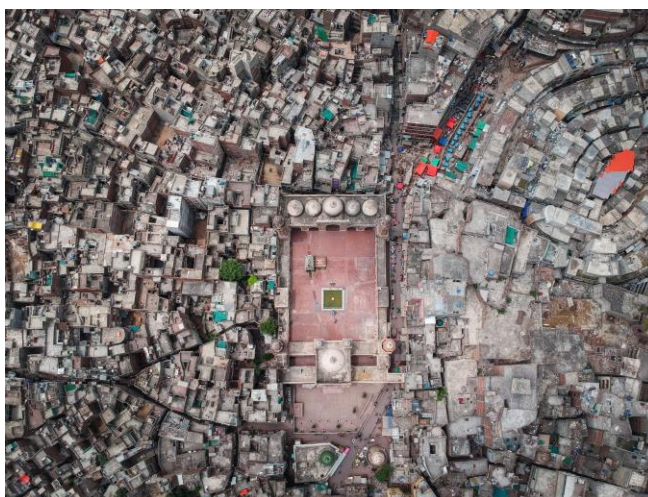


Figure 6-9

Aerial view of part of Walled City. Wazir Khan Mosque (pink courtyard) visible in centre of image. The dense urban form is clearly visible (AKDN, 2014).



Figure 6-10

Images of two housing schemes in Lahore: Army Officers housing Scheme and Askari Housing Estate. The close proximity of residences is visible. (Terraco, 2019).

The urban heat island effect is pronounced within the city; the increase in the built up area has resulted in an increase in the minimum summer temperatures, while a reduction in the diurnal variation in temperature in the city has also been recorded over the past 40 years (Sajjad *et al.*, 2015). This change in temperature has had an effect on the thermal comfort practices of residents as discussed in Section 6.5, along with an increased dependence on artificial air conditioning which also increases the outdoor temperature. Another effect of this extensive urban sprawl has been the loss of ground water both with respect to the massive pressure on the reserves by the large population and the loss of unconstructed land such as parks and fields etc. where rainwater can be reabsorbed to refill the existing aquifers.

The significant sprawl of the city has also resulted in an increased reliance on automobiles for all commuter needs. The lack of adequate public transport infrastructure means that the

number of privately owned vehicles is very high and is the cause of increased congestion on the roads. In order to ease this, most main thoroughways have been widened to include the previously green verges.

The air quality of Lahore has been consistently recorded at unhealthy levels with recent winter measurements of the Air Quality Index (AQI_{2.5}) at 'hazardous'. The air quality is adversely effected by the heavy traffic load and the emissions of the numerous factories that are located in the outskirts of the city. Of these, the brick kilns have been identified as a major contributor as the majority have incomplete combustion of fuel resulting in greater release of harmful particles. It has also been reported that sub-standard fuel that includes industrial waste such as plastic, tyres and general rubbish are used (Adnan, 2018). There is a marked seasonal fluctuation in the AQI with winter measurements being significantly higher, this is due to the cultural method of clearing of fields after the harvest by burning the stubble that is practiced in the months from August –to–November in Northern Punjab in both India and Pakistan. The dense smog caused by this is harmful to residents and has effected the use of outdoor spaces in the winter, and has also resulted in residents preferring to keep windows and doors closed thus reducing the use of passive cooling through natural ventilation.

6.3.2 The urban building

The urban buildings of Lahore are described in this section with a focus on the construction materials and the form of the plan with respect to the thermal performance of the building and the thermal comfort practices of the residents.

As described in the previous sections, the urban form of Lahore is predominantly low-rise with neighbouring buildings in close proximity to each other. The main climatic constraint of the design of the urban form in hot climates is traditionally the sun path, however in urban Lahore, there is no predominant orientation based on either the sun path nor wind direction. The summer heat in Lahore can be intense particularly at mid-day when traditionally locals would take a siesta, shutters would be drawn to close out the heat, and businesses would close for a few hours. Although modern lifestyles and technology include many more active conditioning methods, there is little difference in the environmental parameters within which these modern buildings have been designed and are used.

The current building stock in Lahore can be broadly characterised by their form and construction materials which varied chronologically giving us 3 main typologies of building styles: the traditional Walled City stock, the buildings that were built (or influenced) by the British, the mid-19th to mid-20th century buildings, and the modern building.

Traditional form and construction

The traditional form as found in the Walled City were characterised by their large thermal mass, small apertures, and the use of shading through jaalis and verandas. These buildings, particularly the residences are remnants of a time when strict demarcations between public and private life were translated in to the urban form, with the buildings facing inwards towards central courtyards. Most buildings in this part of the town share walls, and there is little or no set-back of the front from the road, the trend for a front garden does not exist and so front doors of buildings open directly on to the road. Examples of such buildings (plans, sections, images) are in Figure 6.11 and Figure 6.13.

There are typically two types of traditionally designed buildings within the Walled City at present, the large courtyard style also known as the Haveli and the smaller 3/4-storey walk-ups.

The Haveli was a popular form of building in South Asia and particularly in North Punjab (where Lahore is located). The building form typically consisted of a central courtyard off which all of the rooms opened. The courtyard served as the main social space of the building. In more affluent residences there were often two courtyards, one for the more public activities that may include entertaining guests and another (often smaller) that was considered more private and was for family use only (occasionally considered the women's courtyard). A room off the main entrance known as the *baitbak* traditionally served as the drawing room for male guests, and in smaller single-courtyard houses was the hearth beyond which non-family men were not allowed. The courtyard is usually surrounded by a covered colonnade or veranda. The roofs of the buildings were flat and completely accessible through staircases.

The construction of this era is brick masonry with timber beams and columns. Older buildings often had walls of rammed earth around which narrow *Lakbori* bricks were built up with lime mortar. The walls are thick, measuring upwards of 40cm, and plastered with lime mortar on both the interior and exterior of the buildings. These buildings thus had a large thermal mass that resulted in a slow transfer of outdoor temperatures to the interior, which meant that the indoor environment remained relatively cool during the intense summer heat and retained the indoor heat for longer during the winter. To add to the environmental sensitivity of the form, the windows were generally small and covered externally with openable wooden shutters often with intricately carved designs, these allow adequate daylight to enter while limiting solar gains. The windows were originally not glazed which also reduced the heat gain of the interior. Each room also had high level windows or ventilators that were for the purpose of maintaining air circulation as hot air was forced out of the interior as cooler air entered from lower level apertures (hot air rises). The wooden shutters on upper floors were often built into a balcony form known as a *jharoka* which provided the entry of cool air into the building while also adding aesthetic value to the façade. The roof and terrace areas of residences in this style often have high walls that are either perforated or have *jaali* screens in them, this provided a useable space for the family to sleep at night, taking advantage of cool night time air while also maintaining their privacy. Many buildings of this era had an enclosed room on the roof for the storage of beds and mattresses, known as the *barsati*.

The courtyards are often in the shadow of the walls of the building and as such provide a comfortable shaded environment which often includes a garden area, water feature and/or a well. Traditionally the floors of this area are of beaten earth which remains cool even in the intense summer heat (Srivastav and Jones, 2009; Qureshi, 2015), the floors were often also sprinkled with water (once or twice daily) to dampen the earth and reduce the amount of loose earth but also had the advantage of cooling the air (the temperature of hot-dry air over cold damp earth results in lowering of air temperature).

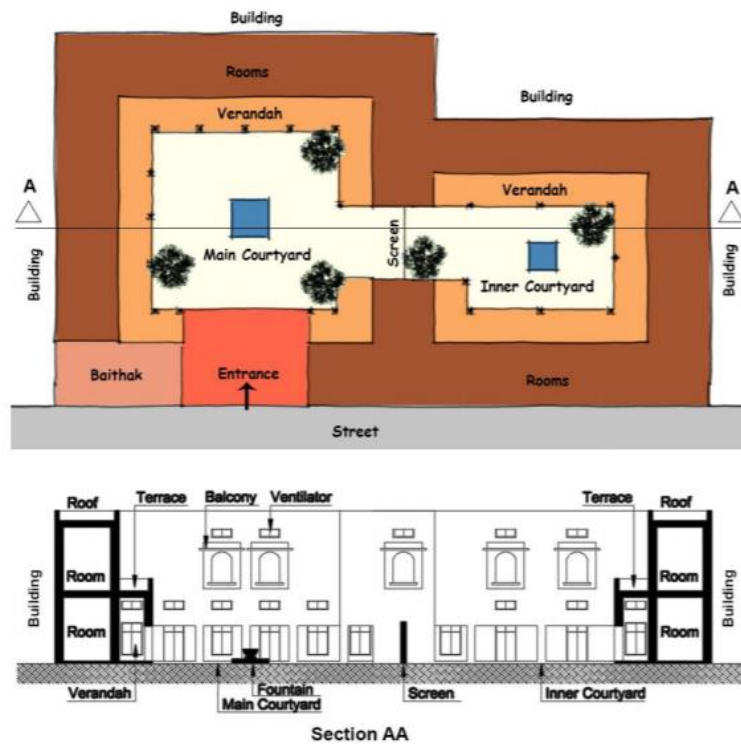


Figure 6-11

Plan and Section of a Typical Haveli in the Walled City (Qureshi, 2015, p. 45).



Figure 6-12

Images of the Walled City:

On left: West Façade of Naunehal Haveli. Of note are the wooden jharokas (window balcony jaali), and the jaali screens on the upper terrace and roof (Jodidio, 2016, p. 151);

On right: Birds eye view of Walled City. Dense and organic built form of the locality as well as the jaali screens of the roof top terraces on most buildings is visible (V&A, 1900).



Figure 4.3 Ground Floor Layout Plan



Figure 4.4 First Floor Layout Plan

Figure 6-13

Ground and 1st floor plans of Barood Khan Haveli in Walled City Lahore (Qureshi, 2015, pp. 56–57)



Figure 6-14

Exterior façade of Barood Khan Haveli main entrance (left image); Main courtyard (centre image); Inner courtyard (right image). (Qureshi, 2015, p. 59)

The non-courtyard buildings of this era are similar in their thermal mass and use similar design properties for passive control of the thermal environment such as thick walls (of up to 40cm thick), small shuttered windows, and high ceilings with high-level ventilators. Generally, the lack of a central courtyard translates to the building's roof spaces used more regularly (see Figure 6.12, image on right).

Mid-19th –to-mid 20th Century buildings:

The mid-19th to mid-20th century buildings in Lahore were primarily of brick masonry construction with wooden beams and column structures. The thermal mass of the buildings was not much different from the earlier buildings such as found within the Walled City, however the form of the buildings was significantly different.

The British popularised the use of a larger clay brick which resulted in the use of less mortar and more uniform walls, often having exposed brick work as external finish. These buildings were more outward looking with larger windows and often set back from the road with a front facing landscaped garden area. The official, government buildings were built with either the Greco-Roman style or reflected, at least in design of the exterior front facing façade, the local aesthetic with arched windows, domed pavilions and external covered verandahs right around

the building. In this way the traditional methods of passive thermal control of the indoor environment with protection from direct sunlight, high ceiling heights, and the use of high-level ventilators maintained the indoor thermal environment.

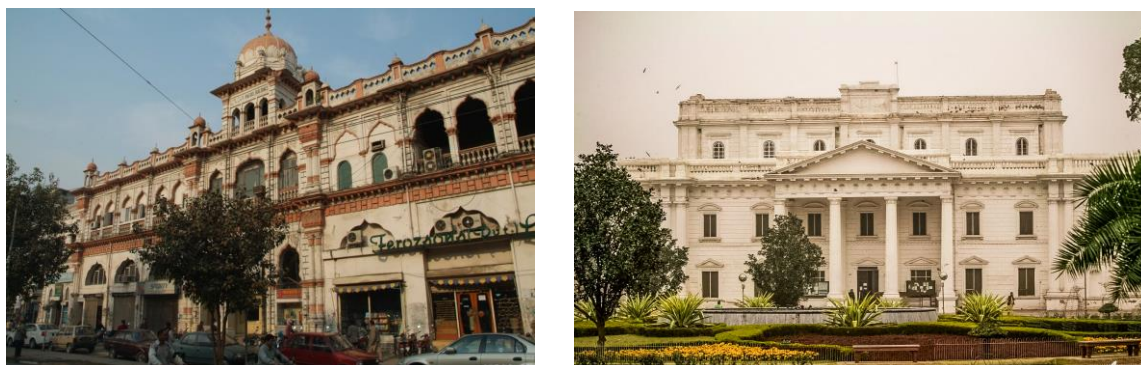


Figure 6-15

British era buildings;

On left: Ghulam Rasool Building on Mall Road. Built circa 1920. A commercial building

On right: Quaid-e-Azam Library on Mall Road, built 1866. Previously Lawrence and Montgomery Halls: a social club and dance halls.

The residential buildings of this era were typically bungalow in style, often with a covered veranda shielding the windows from the sun's glare. The building characteristics of private residential buildings were similar to government sanctioned ones with thick walls and high ceilings, which is indicative of similar passive means of indoor environment control. The roofs of most of the British era bungalows in Lahore are flat with easy access to the roofs. It can be assumed that the roof was used at night to take advantage of lower night-time temperatures.

Although new building forms and construction materials and techniques were introduced in this era, the thermal behaviour of these remained similar with respect to their thermal mass to earlier traditional built form. Also, due to the passive techniques including the use of shuttered windows, deep corridors and verandahs, it appears that the indoor climatic conditions did not vary significantly and remained within a range that was appropriate for achieving thermal comfort, and as such the lifestyle and thermal practices of the resident population did not change significantly due to these changes in urban form.

The Modern Building:

The modern urban form in Lahore has conformed to the influences of form, material, and technologies of the developed world and has a significantly lower thermal mass than the earlier (indigenous) urban buildings that developed within the specific climatic environment of Lahore. The built form therefore provides little respite from the outdoor environment which has resulted in an increased dependence on the use of artificial conditioning of indoor environments to provide comfortable conditions.

The typical modern residential building form and the market and social trends that dictate it have been discussed in the previous section (6.3.1). In general the trend is for the constructed area of the building to be the maximum allowed for each plot which results in a low-rise (generally 2-storey) dense urban form. The buildings follow on from the British era residences in that they are outward facing with few having interior courtyards; privacy is maintained through high boundary walls. The trend is for large windows which are glazed and although

newer builds have double glazed units, these have little effect on controlling solar gains through direct sunlight. Very few residences have the external marble and wooden jaali screens that were traditionally used to block out the sun, and the shading that does exist is largely for aesthetic purposes and does not contribute to the control of the indoor environment. Ceiling heights in new builds are low (compared to earlier buildings) being on average at 3metres, which may be due to the bye-laws limiting the maximum height of the building. High level ventilators are no longer used. Given the close proximity of neighbouring buildings and the effect of the urban heat island, residents of modern buildings rarely use roof spaces and hence although access to roof spaces is usually provided (this is where the overhead water storage tank is located), the high jaali screened parapets are no longer popular.

In residential buildings, brick masonry continues to be the predominant building material with typical external walls at 23cm thick, and with steel reinforced concrete (RCC) used for the building frame (columns and roof/floor slab), these surfaces are usually either plastered or left exposed internally (dependent on socio-economic status of the owners). There is no trend of insulating walls or using a double-wall for insulative purposes. These thinner walls have very little thermal mass with a thermal time lag (time taken for outdoor conditions to influence indoor environment) of 6-to-6.5 hours (Vijayalakshmi, Natarajan and Shanmugasundaram, 2006). External finishes vary greatly according to the preference of the owner ranging from exposed brick to sprayed cement, the choice is rarely based on the thermal value. The roofs of the majority of buildings are flat with a cladding of 3.8cm clay tiles, and an insulation layer of 7.6cm mud plaster over a 15cm RCC slab. Increasingly the use of foam insulation in roof cavities is being promoted however its use has not yet become widespread.

RCC is also the primary building material in multi-storey buildings. The use of concrete has encouraged a reduction in wall thickness to the minimum required for structural stability and this has compromised the insulative value of the building mass as well as reducing the air permeability of the structure which has negative effects on thermal comfort. The trend for a *modern* look through the use of large glazed surfaces in both commercial and residential buildings has also increased the solar gains and negatively impacted the environmental sensitivity of the built form. Additionally the trend of the commercialization of the urban environment through private real estate developers and property owners to maximise the built area of the plot has greatly enhanced the urban heat island effect raising the temperature of the city by several degrees in peak summer.

Currently the *Building Energy Code of Pakistan* (2013) that provides recommendations and lays down the allowable extents for environmentally sensitive design has a section dedicated to the thermal sensitivity of the building envelope. The focus of this is limited to commercial buildings that are air-conditioned and have an area of over 900m² or are non-conditioned with an area of over 1200m², while residential buildings are largely ignored. The building code does not address the provision of insulation in walls, and includes minimal direction toward recommended roof insulation. There is also very little guidance regarding glazed surface area with u-values recommended based on the percentage window area to total façade area while there is no recommendation to the allowable glazed area of a façade.

The Modern Building of Lahore is thus quite far removed in its thermal mass and thermal behaviour from the earlier built form of Lahore with a drastic change occurring in the construction methods, materials, and form of the building(s) in the past 5 decades. This has

necessitated a change in the lifestyle and thermal comfort practices of the residents which has seen an increased reliance on the artificial conditioning of indoor spaces.

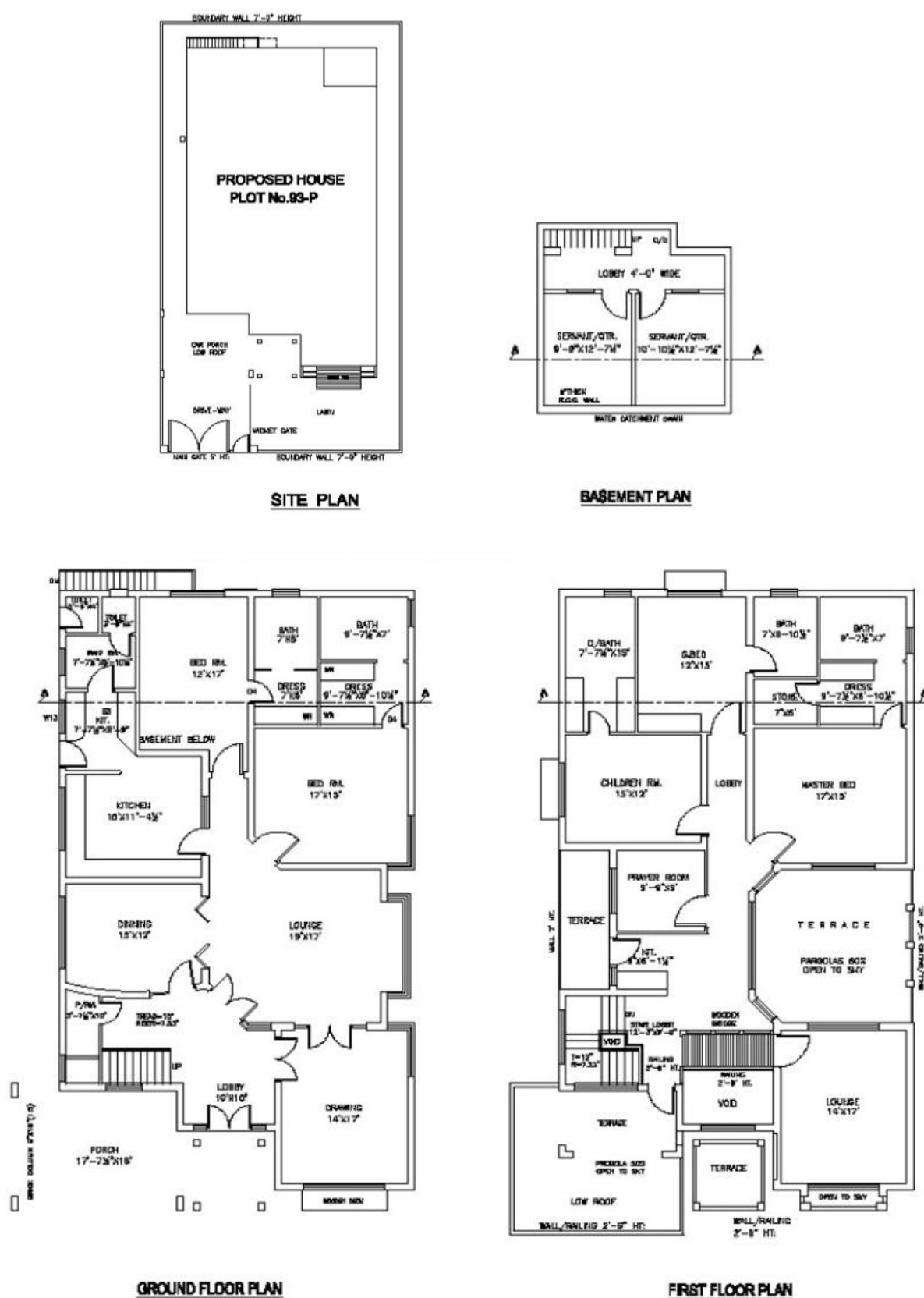


Figure 6-16

Site plans and plans of a representative example new 'modern' residential building in Lahore. – Barrister Umer Riaz's residence in DHA Phase VIII.

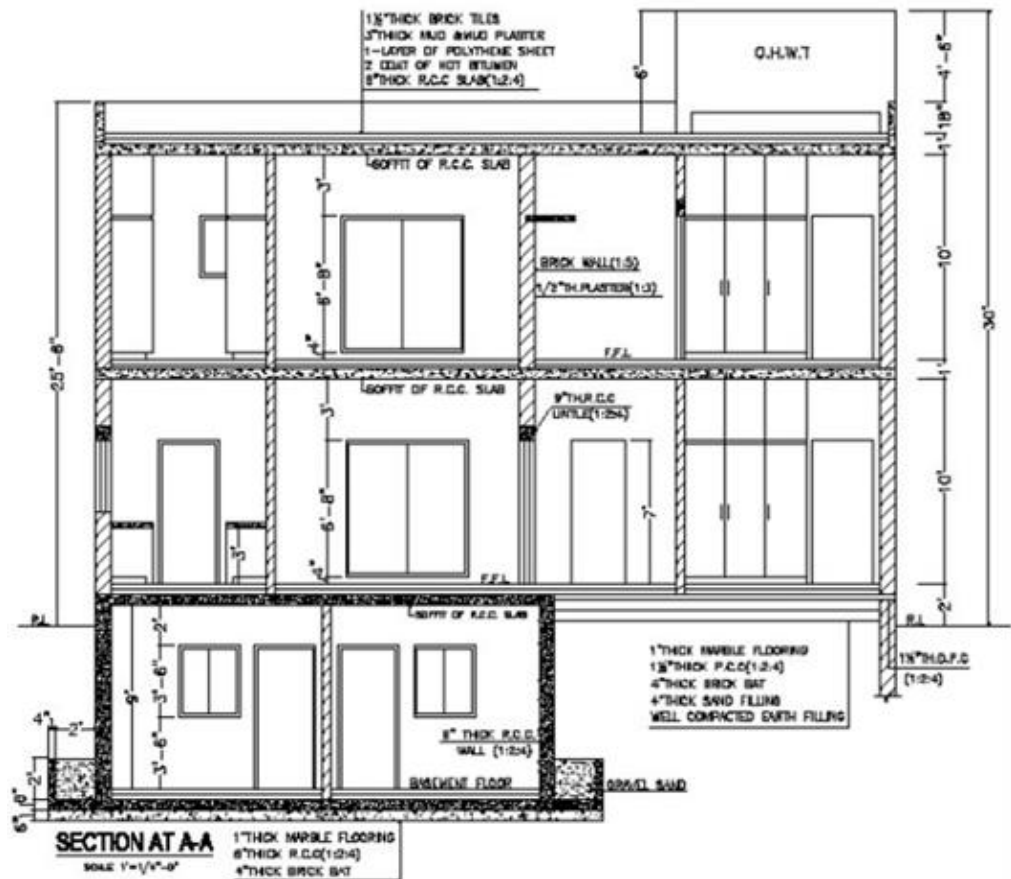


Figure 6-17
Section detail of a representative example new ‘modern’ residential building in Lahore. – Barrister Umer Riaz’s residence in DHA Phase VIII.



Figure 6-18
Computer generated 3D images of a representative example new ‘modern’ residential building in Lahore. –Barrister Umer Riaz’s residence in DHA Phase VIII.

6.4 The residents of Lahore: a socio-economic portrait

The population of Pakistan is relatively young with over 50% being under the age of 25years and less than 5% being older than 65years. The demographics of Lahore are similar to the national average, though as an urban centre with access to better education and health care

facilities the life expectancy of residents is higher than the national 67.7years (Central Intelligence Agency, 2016). The literacy rate of Lahore is higher than the Punjab urban literacy rate of 75.3% where male population is at 80% and female at 70.5% (B. O. S. Punjab, 2014).

Although Pakistan is recognised as a traditionally patriarchal society the significant influence of women to the society can be attested to by their contribution to the economy through participation in all manner of the workforce including policy development and implementation, the judiciary, policing and education. The presence of women in white and pink collar occupations is documented however a large part of the workforce undertakes blue collar jobs that are short-term contracts and based on hourly wages and that are not formally documented. The presence of females in this workforce is higher than in blue collar occupations (Government of Pakistan, 2002), as in the absence of a mandatory minimum wage, lower socio-economic households require more than one income to survive. The social structure of urban Pakistan includes a reliance of middle and higher income households on hired help for household chores. These positions are predominantly filled by women who live in unplanned colonies and slum settlements within the city, while the men often vie for daily labourer positions. Many larger urban residents incorporate an annexe within the grounds, or lacking that a dedicated bedroom and bathroom with independent entrance that is either rented to their help or provided in lieu of work.

Social mobility is high and on the rise in urban Pakistan (Ghani, 2011). One of the driving reasons is a merit-based system for college and university admissions, and for many government posts including bureaucratic positions. Education is the key driver of social mobility as the system involves a numeric rank based on test scores (which though doesn't overcome all aspects of bribery and nepotism that are rife in the developing world), it enables the economic status of families to be improved upon within a generation.

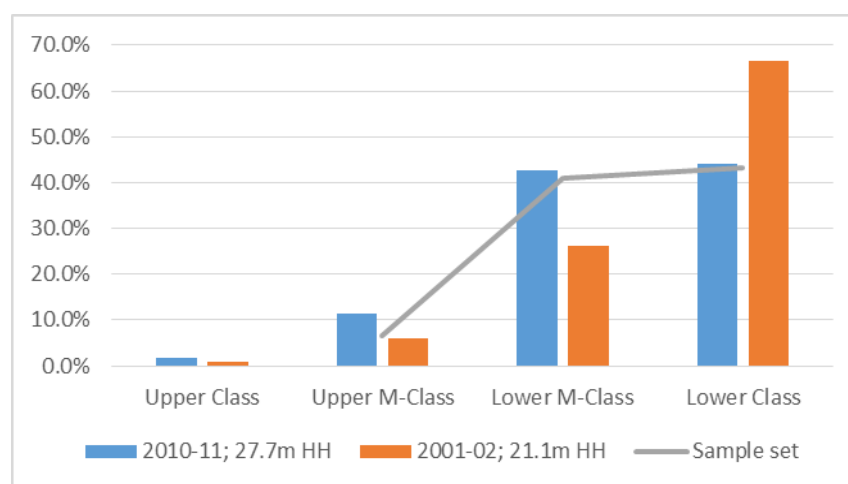


Figure 6-19

Percentage of households (HH) by socioeconomic class in urban Pakistan showing the upward trend of social mobility during the previous two decades (Ghani, 2011, p. 6). Percentage of various socio-economic classes from the sample population participant in the study is also indicated as similar to current population
M-Class = Middle class
m HH = million households

The socio-economic status of the participants of the study is largely representative of the breakdown of the socio-economic classes in Lahore with 43.3% and 41.1% of the participants

belonging to the lower and lower-middle socio-economic status, and 6.6% from the upper and upper-middle socio-economic background as can be seen from the graph in Figure 6.19.

6.4.1 Clothing

The regional traditional dress is the *shalwar qameez* which is tunic like shirt (qameez) worn with loose fitting trousers (shalwar). People of both genders wear shalwar qameez, though there are differences in style and material with men's outfits generally being less colourful and embellished. The type of material provides different levels of insulation with lightweight cotton and breathable materials preferred during hotter conditions.

Men usually wear a cotton vest underneath the qameez especially in the hotter months providing a measure of modest cover through the lightweight material, and also to absorb sweat. In colder conditions, the shalwar qameez is made of thick weave or wool blend materials with sweaters, waistcoats and coats worn as outerwear, and may be supplemented with an inner thermal layer as well. The shalwar qameez is also often worn with blazers and sports jackets in semi-formal situations. Occasionally men will use a large sheet-like scarf of a heavyweight material around their shoulders to shield from the cold known as *chaddar*, this is a common practice in rural and northern Pakistan, and is practiced in casual settings amongst the urban population. The majority of young and working age men will however be found wearing *western clothing*: trousers or jeans with either a shirt or t-shirt etc. modified as required through outerwear to the weather. Formal events and office wear for upper managerial level staff are western style suits irrespective of weather conditions or season.

Women predominantly wear shalwar qameez of different styles throughout the year, in both formal and casual situations. There is a greater variety of materials of different insulative value available. Traditionally the shalwar qameez is paired with a scarf known as a *dupatta* if it is lightweight or *chaadar* if of heavyweight material. The way the scarf is used has a significant effect on the warmth it provides as it can be used as an accessory or as an additional layer of clothing. The qameez may have any length of sleeve and women (especially the younger generation) may substitute the shalwar with tighter fitting leggings or jeans. Not all women use the dupatta, while some may use it cover their heads either as a sign of religious devotion, as a cultural practice, or as a shield from the sun. The more religious may wear additional clothing such as a folded and pinned scarf that wraps around their head and neck, leaving the face uncovered known as the *hijab*. This may extend over the upper torso depending on the style. The hijab is sometimes worn with a floor length cloak that provides an additional layer of clothing known as an *abaya*. This is only worn in public places. A small percentage of women additionally cover their faces with a veil, a *niqab*, and an even smaller number wear a *burqa*, which is similar to an abaya, hijab and niqab combined.

Footwear preferred by women during most of the year are open sandals, and it is only during the winter season (or exercise) that closed shoes are worn. Men wear mostly closed shoes in both formal and semi-formal situations, with open sandals only worn as casual wear during the summer. A traditional men's sandal the Peshawari Chapal which is slightly open from the toe and the heel is often worn with semi-formal dress with both the shalwar qameez and western wear in all seasons.

The material of the standard shalwar qameez worn by both men and women varies little during the hot season (when the field study was undertaken) being mainly light cotton. The

insulative value of the shalwar qameez is reported to be between 0.64clo to 0.92clo in the ASHRAE Transaction (Havenith *et al.*, 2015), but no mention of the material with which the clothes were manufactured is made. Anecdotal evidence suggests that the primary difference between shalwar qameez that are used in different seasons in Pakistan is the material from which it is manufactured. It could be assumed that the clo-value of a shalwar qameez ensemble worn in the summer season in Lahore Pakistan would be closer to the 0.64clo value, but this value can only be used as an approximate guide towards understanding the contribution of clothing towards thermal comfort. Office wear for men and women is often more formal with additional clothing (trousers, hijab etc.) are also worn.

A calculation of the exact clo of the clothing was not possible during the course of this study as this would have been an intrusion in to the daily lives of the participants and may have influenced their comfort responses through an awareness of its insulative value (the Hawthorne effect). There is however little variation in the insulative properties of various clothing types that are popular in the summer season, we can therefore assume similar clothing types to be of similar insulative value. Participants were asked to note their clothing type and its material as well as describe their footwear in a dedicated column on the questionnaire, this meant that in the case of any anomalies in the analysis it would be possible to refer back to the clothing type worn.

6.5 Thermal comfort practices in Lahore

The lifestyle and consequent culture of the city's residents' is affected by the prevalent climatic conditions. Schools and other academic institutions start earlier in the day than in the west, with school hours generally running from 7am to noon or thereabouts, thus reducing exposure to the afternoon heat. Most offices maintain international working hours from 9am to 5pm, while shops and markets are busiest in the early morning and late evening. Pakistan has not adopted the daylight savings time (except for a failed attempt in 2002 that was widely unpopular and only partially adopted) and so schools and government offices have different timings for summers and winters. Several annual exhibitions and festivals are held in Lahore, and are traditionally timed for the spring and winter seasons as are most weddings.

Except for large multi-storey commercial buildings, indoor environments of most buildings are not centrally conditioned. Indoor comfortable conditions are therefore maintained through the active management of the space by the occupants.

During the hot summer season windows are kept closed against the heat of the day with curtains or blinds keeping out the sun, and are opened to introduce cooler night time air. Indoor air is recirculated through the use of ceiling and pedestal fans. During the hot-dry summer months before the monsoons season, desert coolers that are evaporative cooling machines, are popularly used to improve indoor environments. These are highly successful in improving indoor comfort as the combined effect of the reduced temperature along with the increased water content of the air provide considerable relief. Air conditioning units that serve individual rooms (window and split units) are utilised in many offices and can also be found in select rooms of residents of middle and high socio-economic standing. The use of air conditioning units in such households is usually only for occupied rooms during the hottest parts of the day and during the night.

It was common practice a few decades ago for entire families to sleep outdoors either in the courtyard of the compound or more frequently on the roof. Some families particularly of the lower socio-economic backgrounds still do this, and often also make use of pedestal fans to increase comfort. The desirability of such sleeping arrangements has been overshadowed by the increase in urban crime, the densification of residential areas not affording privacy to sleeping families, and an unfortunate rise in night time temperature due to the urban heat island.

In the winter season (which is not within the remit of this investigation), the primary mode of adaption to the changing climate is through the modification of clothing hence the winter season in Lahore sees residents wear multiple layers. Indoor comfort is maintained through the use of gas heaters to provide spot heating where required. Rooms are not heated at night due to the gas supply being unreliable and the potential consequences of an unscheduled cut-off being fatal; duvets and quilts are therefore of high tog value (high insulation value). Outdoor spaces during festivals and weddings were traditionally heated with coal fire-pits, standalone gas heaters are now frequently used. Electric heaters are also in use but limited due to the expense of electricity. However in outdoor spaces where spot heating is required and in parts of the city where mains gas supply is not available, electric heaters are common.

6.6 Conclusions

This chapter has provided an overview of the city of Lahore in Pakistan focusing on both the urban and social character of the city. An attempt has been made to provide an understanding of the different factors that influenced the development of the city including the urban spaces, urban built form, and the behavioural choices, and practices of its resident population. The discussion has included an understanding of the resultant changes in the indoor thermal environments and the adaptations and modifications in thermal comfort practices of the residents that have developed as a result of these changes to the urban form and character to the city.

Lahore is described as a typical example of a developing world city that is facing the complex challenges of a rapidly growing population, inadequate infrastructure development, and socio-economic inequity. The urban form of the city has morphed under these pressures from one that was sensitive to the climatic and cultural character of the city, in to an extensive sprawl of brick and concrete where neither individual buildings nor the engendered lifestyle is respective of the climatic environment. Although older parts of the city retain some of the original climatically sensitive buildings, the newer parts of the city are largely populated by a modern, climatically insensitive urban form where those who are able to, rely on artificial conditioning of the interiors to maintain comfort. In many instances, either due to climate change, the urban heat island effect, the lifestyle change, and possibly also due to changing perceptions of what constitutes thermal comfort, many residents of the older more climatically sensitive buildings also rely on artificial conditioning of their indoor environments. Simultaneously, there are large swathes of the resident population of Lahore who cannot afford the artificial conditioning of their indoor spaces and rely on traditional methods.

The central premise of this thesis is that the thermal comfort perception of a population is a subjective choice that varies based on their exposure to different thermal environments. The

economic disparity between the different socio-economic classes that exist in Lahore manifests itself in to an unequal exposure to various indoor environments of the individuals. This makes Lahore an appropriate case study site where the thermal comfort perceptions of a representative sample group can be assessed against their socio-economic positions, thus making it possible to gauge the extent the exposure to different thermal environments influences the perception of thermal comfort.

Chapter 7

Physical variables in thermal comfort perception: the objective aspect of thermal comfort perception

7.1 Introduction

The central hypothesis of this thesis is that there will be variations in the thermal comfort perception of the members of a regional population based on their previous exposure to different thermal environments. The discussion presented in Chapter 6 (Thermal comfort practice in Lahore) has shown that in the developing world regions with large socio-economic inequity in the local population, the exposure to different thermal environments is predicated on the affordability and access to those environments. As such it can be posited that the variations in thermal comfort perception in a population will occur due to the variations in socio-economic position.

The trend laid out by previous thermal comfort studies has been to develop linear equations that predict thermal comfort where it is defined through a relationship between outdoor temperature and indoor comfort (Humphreys, 1975; Nicol and Humphreys, 2002; Toe and Kubota, 2013). These equations have been developed through many years of field and laboratory studies as detailed in Chapter 2 (Section 2.6.2) that have examined the effect of variations to the physical environmental conditions on the physiological responses of the occupants. The influence of these climatic variations on the psychological responses of the occupants has not however been examined in detail. It is therefore the intention of this research to address this gap in scholarship through an in-depth study based on empirical data that will re-assess the physical parameters that define thermal comfort, and the most accurate representation of this data in equation form. This investigation will thus establish the most appropriate measure of translating environmental parameters to thermal comfort perception.

The target lines of investigation as laid out in Chapter 5 (Research Design) are to investigate the regional differences in thermal comfort perception within a single climatic zone, and to establish if variations within the thermal comfort perception of a population from a mono-climatic and mono-cultural region exist due to their subjective psychological responses to their environment. The data used for these assessments was empirically collected by myself and has been described in Section 5.4.2. The first of these investigations is presented in this chapter, while the second investigation is presented in Chapter 8 (Subjective aspect of thermal comfort perception). In order to do this, it is essential to first provide a solid foundation to this study through defining the physical variables that influence the thermal environment and their comparative contribution to thermal comfort perception.

The analysis in this chapter therefore focuses on the physical environmental variables and includes outdoor prevalent temperature, outdoor relative humidity, indoor temperature, indoor relative humidity and indoor wind speed. Through a series of statistical tests the validity of the use of outdoor temperature as the primary predictor to indoor thermal comfort conditions as used in previous thermal comfort studies is also confirmed. The analyses

conducted will also investigate the difference between thermal comfort perception in both **conditioned spaces** where the indoor environment is maintained through the use of artificial conditioning devices including air conditioners and desert coolers, and **unconditioned spaces**, where the indoor environment is managed through actively opening and closing of apertures, and aided with the use of air movement through fan use. The analysis will examine differences between the perceptions of discomfort specifically querying the practice of equating **hot discomfort** (as reported by persons experiencing hot environmental conditions or reporting the thermal environment as being *too hot*) with **cold discomfort** (as reported by persons experiencing cold environmental conditions or reporting the thermal environment as being *too cold*). To this end the influence of the various physical variables (listed above) on both cold discomfort and hot discomfort is also measured and analysed. The data is assessed through both parametric and non-parametric statistical tests with the intention of being able to assess the results in tandem.

The chapter also includes a thorough examination of the various outdoor reference temperatures used in a thermal equations in order to determine which provide the most accurate representation of indoor thermal comfort temperature. This establishes the temporal and regional granularity of outdoor temperature that is most appropriate for use in predictive thermal equations. This investigation is then extended in to establishing the extents to which thermal equations developed for a particular climatic and cultural specification can be used with confidence in other regions.

Finally, this thesis develops a thermal comfort equation for the city of Lahore in Pakistan through an iterative process whereby the best fit equations for the thermal data are assessed in terms of their predictive power and accuracy.

7.1.1 Limitations to the dataset

The work presented in this chapter will be an analysis of the empirical dataset collected during the summer of 2014 and 2015 (outlined in proceeding section, and detailed in Chapter 5). The analysis undertaken in this chapter primarily looks at investigating the effects and influences of physical variables that comprise of, and influence, thermal comfort perception.

The dataset collected through the field study as described in Section 5.4.2 is comprised of data collected from a total of 269 participants with a total of 4155 readings and an initial number of 44 variables of which 5 are physical environmental variables. The dataset is strategically limited so as to control for conflating variables within the analysis. The dataset is analysed as a whole, as well as with cases restricted to either indoor unconditioned (free-running spaces with ceiling fans and/or wall-mounted or floor standing fans) and indoor conditioned (with air conditioner and/or desert cooler use).

The investigation in this section is limited to indoor thermal comfort perception where the occupants are indoors and partaking in at most sedentary activities (sitting, standing) so as to preclude the effect of a higher metabolic rate due to activity. Those instances where the occupant has recently moved from a different location are also excluded from the analysis to reduce the residual effect of change in thermal environment on their perception of thermal comfort.

7.2 Non-parametric tests:

In this section, the dataset is assessed through non-parametric statistical tests in order to determine the extent to which the physical environmental variables that are traditionally used to define thermal comfort influence thermal comfort perception.

Non-parametric tests are also known as distribution-free tests as they are the statistical procedures that are not dependent on a specific shape of the distribution of data (as required by parametric tests), in particular they do not assume that sampling distribution is normally distributed (Field, 2014). The tests undertaken look to investigate the correlation of each physical environmental variable with the indoor comfort and discomfort (both hot and cold discomfort as one entity), indoor comfort and hot discomfort (due to hot conditions), and, indoor comfort and cold discomfort (due to cold conditions).

The main test used in this analysis is the Point Biserial Correlation (as one of the variables is continuous (temperature, relative humidity and wind speed), and the other is dichotomous (comfort or discomfort)).

The results of the analysis are interpreted keeping in mind that large datasets increase the likelihood of small correlations shown to be significant, however large datasets also provide more accurate correlation coefficients (Hole, 2015). Furthermore, the point biserial correlation tests for linear correlation between the variables, however the behaviour of the physical environmental variables and comfort perception have not been confirmed to be linear, and with the likelihood of a monotonic or curvilinear relationship, the strength of the correlation (r) may be underestimated in the results.

The tables listing the results of these tests are in Appendix 7.5, Appendix 7.6, and Appendix 7.7. The interpretation of the effect of each physical variable on thermal comfort perception is presented in the proceeding sections.

7.2.1 Outdoor temperature and thermal comfort

The perception of indoor thermal comfort was found to be negatively correlated with the outdoor drybulb temperature [$r = -.081$ $p = .000$ $N = 2707$]. On limiting the dataset to unconditioned environments indoor thermal comfort was found to be more highly correlated with outdoor temperature [$r = -.127$ $p = .000$ $N = 1340$] while the correlation between thermal comfort and outdoor temperature in conditioned environments was not significant. This indicates that in buildings that are free-running, indoor thermal comfort is effected by outdoor temperature as occupants are exposed to changes and variations in the outdoor environment through open windows and active management of the indoor environment by the occupants. This is not however conclusive evidence to support the claim that the adaptive control exercised by occupants in free-running buildings has an effect on their perception of the thermal environment.

In conditioned spaces the indoor environmental conditions are maintained through the use of mechanical methods with minimal direct interaction with the outdoor environment (windows are kept closed etc.). This minimises the effect of sudden changes in outdoor conditions, as well as the time-lagged heat gain due to thermal mass of the building, and conduction through the windows, on the indoor thermal environment. This is reflected in the results of the

analysis that show that in such conditioned environments the indoor comfort perceptions of the occupants of the space were unaffected by variations in outdoor conditions.

The results of the point biserial correlation in unconditioned environments show that there is a difference between the occupants' perception of discomfort due to the heat and discomfort due to the cold. This was confirmed by the significant correlation of comfort and hot discomfort with outdoor temperature $r = -.135$ $p = .000$ $N = 1323$ while the same test when looking at comfort and cold discomfort did not show a significant correlation. The non-significant result for discomfort due to the cold can however be disregarded as the likelihood of a *too cool* environment existing in unconditioned indoor environments in the summer (hot-dry climate zone) of Lahore is very low.

7.2.2 Outdoor relative humidity and thermal comfort

An examination of the results of the point biserial analysis between outdoor relative humidity and indoor thermal comfort perception shows that in unconditioned environments there exists a positive correlation between the two variables. The strength of this is investigated through looking at comfort/hot discomfort and comfort/cold discomfort separately, where it is found that there exists a significant positive correlation, [$r = .059$ $p = .031$ $N = 1323$] between discomfort due to hot/warm conditions and the outdoor relative humidity. This means that in free-running unconditioned spaces an increase in outdoor humidity level increases the perception of hot discomfort indoors. The significance of this correlation may have been influenced by the large sample size, however due to indoor environments in unconditioned buildings being influenced by outdoor variations in climate, and the potential of air humidity in both aiding and hindering body heat regulation through sweat evaporation, the result should not be disregarded.

On the other hand, the analysis provides a non-significant correlation for the influence of outdoor relative humidity levels on the perception of discomfort due to a cool or cold environment. This does not mean that outdoor relative humidity does not have an effect on increasing cold discomfort, but that in the particular instance of this study in the hot climate months, there may not have been an adequate number of participants reporting a *too cool/cold* environment for the test to have any real value.

In conditioned spaces the correlations between outdoor humidity and both hot discomfort and cold discomfort are not significant, which means that outdoor humidity levels have no bearing on the thermal comfort perception in conditioned environments.

7.2.3 Indoor temperature and thermal comfort

Indoor temperature showed a significant correlation with indoor thermal comfort perception. In unconditioned environments, the correlation is found to be highly significant at the $p = .000$ level for comfort and hot discomfort and at $p = .006$ for comfort/cold discomfort, however the direction of the correlation is different for both. In hot conditions, where occupants would report either comfort or discomfort due to the heat, the results of the Pearson's product moment show a negative correlation which could mean an increase in indoor temperature results in an increase in discomfort [$r = -.140$ $p = .000$ $N = 1323$]. On the other hand, while looking at the colder conditions in which occupants would report either comfort

or discomfort due to the cold, the results show that an increase in indoor temperature will result in an increase in comfort [$r=.080$ $p=.006$ $N=1207$].

In conditioned environments, the correlation between indoor thermal comfort and indoor temperature is significant [$r=.116$ $p=.000$ $N=1201$], with occupants of such spaces reporting that an increase in temperature results in an increase in comfort, or in other words, cold discomfort can be alleviated through an increase in temperature [$r=.124$ $p=.000$ $N=1191$]. The test reports no correlation between indoor temperature and indoor thermal comfort in conditioned spaces where occupants would experience either comfort or discomfort due to the heat, probably because the likelihood of a *too warm* environment existing in a conditioned space is very low.

It can be inferred from these analyses that in cold environments, occupants report that an increase in indoor temperature results in greater satisfaction with the thermal environment while in hot environmental conditions, an increase in indoor temperature results in a decrease in comfort.

The ranges of temperature at which comfort is reported are described and assessed in Section 7.7.

7.2.4 Indoor relative humidity and indoor thermal comfort

The effect of indoor relative humidity on indoor comfort temperature in conditioned environments was found to be non-significant for both comfort/hot discomfort and comfort/cold discomfort conditions. In unconditioned spaces, Pearson's product moment showed a positive correlation in environments in which either comfort or discomfort due to the cold can be felt [$r=.063$ $p=.030$ $N=1207$]. This means that in free running spaces where discomfort may be reported due to the environment being *too cool*, an increase in relative humidity may result in an increase in comfort.

An explanation of the increase in comfort could be due to a reduction in the body's ability to lose heat through sweat production due to the high levels of relative humidity.

7.2.5 Wind speed and indoor thermal comfort

The Pearson's Product moment undertaken to establish the effect of wind speed on thermal comfort perception shows that there is no significant correlation between the two variables in unconditioned environments. However in conditioned spaces, the study found a significant correlation where an increase in wind speed resulted in an increase in discomfort in conditions where either comfort or discomfort due to the cold is experienced [$r=-.103$ $p=.000$ $N=1189$].

It can be inferred that the increased wind speed in conditioned environments results in an increased rate of heat loss through sweat evaporation which in already cool environments results in discomfort due to the cold.

7.2.6 Comparing cold discomfort and hot discomfort

Thermal comfort studies have typically focused on recording comfort while discomfort is assumed to be the absence of comfort, and a single linear scale is used to describe the relationship between the physical environmental parameters and thermal comfort (as

described in Section 7.1). The results discussed in the preceding sections suggest however that while comfort may be within a similar range of environmental parameters in both hot and cold environments, the environmental parameters that define discomfort in cold conditions and in hot conditions are not similar. We can therefore assume that discomfort from hot conditions and discomfort from cold conditions are two separate entities.

This statement is further bolstered by the situations where the polarity of correlation is reversed in a particular relationship, for example, as in the analysis above, it was found that indoor temperature in unconditioned environments was negatively correlated with comfort [$r=-.113$ $p=.000$ $N=1340$] however an examination of the variable and its correlation separately for hot discomfort and cold discomfort show starkly different results with a significant negative correlation reported for hot discomfort [$r=-.140$ $p=.000$ $N=1323$] and a significant positive correlation with cold discomfort [$r=-.80$ $p=.006$ $N=1207$].

This discussion has shown that a binary view of thermal comfort perception does not adequately reflect the influence of environmental parameters, and that discomfort due to the cold and discomfort due to the heat are diagrammatically opposite, and are based on different (combinations of) environmental parameters. This lends credence to the statement that discomfort due to cold and discomfort due to heat should be considered to be separate entities.

7.2.7 Inferences from analysis

The analysis in this section (7.2) clearly shows that the variables effecting indoor thermal comfort are different in conditioned and unconditioned environments, thus supporting the notion of dealing with thermal comfort in different environments independently of each other. The physical environmental variables that have a significant effect on thermal comfort perception in unconditioned environments are outdoor drybulb temperature (comfortable/hot conditions), outdoor relative humidity (comfortable/hot conditions), indoor temperature (comfortable/hot conditions/cold conditions) and indoor relative humidity (comfortable/cold conditions). The conditioned spaces are, as expected, less influenced by the effects of the outdoor environmental conditions with only indoor temperature (in comfortable/cold conditions) and wind speed (comfortable/cold conditions) having a significant effect indoor thermal comfort perception.

The results have established the need to assess cold discomfort (discomfort due to cold conditions) and hot discomfort (discomfort due to hot conditions) as two separate entities, as it is found that the physical environmental parameters that define comfort in both scenarios are different. When treated along the same scale, the directions of these correlations are often diagrammatically and mathematically opposite to each other, and so an assessment of the influence of a variable on comfort (in both hot and cold environmental conditions collectively) will often result in inaccurate information about the direction and strength of the influence of the variable.

Therefore, a linear interpretation of a binary model of comfort-discomfort might provide inaccurate results with potential consequences that include unsustainable and inefficient building designs and policy.

7.3 Parametric Tests

Parametric Tests are statistical procedures that require the data to follow a particular shape of distribution of which the most common type is the normal distribution. The tests also require homogeneity of variance, interval or ratio data (or a continuous scale), and independence. The Central Limit Theorem however allows for parametric tests to report accurately for large datasets that are non-normally distributed (Field, 2014).

An analysis of the data was undertaken to assess the extent to which physical environmental variables have influenced thermal comfort perception through parametric tests. Each variable was correlated with the indoor comfort and discomfort (both hot and cold as one entity) and hot discomfort (discomfort due to hot conditions) and cold discomfort (discomfort due to cold conditions) independently. The scale of thermal comfort perception used in these proceeding tests is binary, where the absence of comfort results in discomfort.

The results of the analyses are listed in Appendix 7.8-to-Appendix 7.13. The interpretation of the effect of each variable on thermal comfort perception are presented in the proceeding sections.

7.3.1 Outdoor temperature and indoor thermal comfort

An independent samples t-test conducted to investigate the correlation of outdoor drybulb temperature and indoor thermal comfort perception in unconditioned environments shows that there exists a significant difference between the means of the outdoor temperature at which people reported indoor comfort [$M=30.35$, $SD=4.12$] and at which people reported discomfort [$M=32.03$, $SD=3.86$] where $t(1338)=-4.688$, $p=.0001$, two tailed (mean difference= -1.68 , 95% CI: -2.38 to $-.98$) with a Cohen's d value of 0.42 which indicates a medium effect. This means that there is a mid-sized variance between outdoor temperature and indoor comfort.

Further examination of the influence of outdoor temperature on comfort perception in unconditioned environments showed that there was a significant difference between the means of comfort temperatures [$M=30.35$, $SD=4.12$] and discomfort temperatures due to the environment being *too hot* [$M=32.23$, $SD=3.51$], a significant difference was found where $t(1321)=-4.94$, $p=.0001$ (two tailed) (mean difference= -1.85 , 95% CI: -2.59 to -1.11). The Cohen's d value was 0.48 which indicates a medium effect which is higher than that when looking at the general discomfort (in both hot and cold conditions) thus indicating that the variance between outdoor temperature and indoor comfort perception in unconditioned environments is stronger in instances when discomfort due to hot conditions is experienced.

The study found that there was no significant difference in the means of the outdoor temperature when indoor comfort [$M=30.35$, $SD=4.12$] and indoor discomfort due to the experience of cold [$M=29.57$, $SD=5.86$] was reported. The mean difference of the two populations is $.778$ reported at 95% CI: -1.41 to 2.96 . This result indicates that in unconditioned environments the thermal discomfort reported due to cold is not influenced by outdoor temperatures. A better understanding of this result is achieved by looking at it in the climatic context of the case study (Lahore, Pakistan in hot-climatic conditions) where in

unconditioned spaces the chances of environmental conditions being *too cool* or *too cold* for comfort are low.

In conditioned spaces the indoor environmental conditions are maintained through the use of mechanical methods and by keeping windows and doors closed as far as is possible, there is therefore little variation in indoor conditions due to sudden changes in outdoor conditions. This was reflected in the results of the analysis where independent sample t-tests conducted to investigate the mean difference between outdoor drybulb temperature and indoor thermal comfort perception within conditioned environments show no significant difference in the means of the populations reporting comfort, discomfort due to hot conditions, or discomfort due to cold. It is thus shown that in such conditioned environments, indoor comfort perceptions of the occupants of the space are unaffected by variations in outdoor conditions.

7.3.2 Outdoor relative humidity and indoor thermal comfort

In the assessment of the effect of outdoor relative humidity on indoor thermal comfort perception, a series of independent t-tests were conducted to compare the means of the outdoor relative humidity levels for the populations reporting indoor comfort and indoor discomfort (due to either hot or cold conditions). These results indicated that in unconditioned indoor environments, a significant difference at $p=.031$ (two tailed) where $t(1338)=2.164$ was found between the means of the outdoor relative humidity recorded for those occupants reporting comfort [$M=64.78$, $SD=18.36$] and those who report discomfort (both cold and hot) [$M=61.33$, $SD=17.26$], the mean difference measured is 3.45 with 95% CI at .323 to 6.58 however the effect size as measured from Cohen's d is .019 which is very small indicating that the significance of the difference may be low.

However in the case of hot discomfort [$M=61.15$, $SD=16.41$] the mean difference and consequent effect size was larger [$MD=3.63$, 95%CI:.330 to 6.92 and Cohen's $d=0.26$], while in the case of cold discomfort and within conditioned environments no significant difference was found in the means of the outdoor relative humidity in conditions of comfort and discomfort due to cold. This can be explained by the location and climatic context of the study as in Lahore in the hot-dry climatic conditions, the chances of *too cool* environmental conditions in unconditioned spaces is slim.

The results from this sample indicate that in unconditioned environments, outdoor relative humidity is an important factor in the perception of indoor thermal comfort to a statistically significant ($p=.03$) but very limited degree particularly in conditions of hot discomfort. It is possibly due to the confounding effect of a different environmental variable that outdoor humidity does not have a very strong influence on indoor thermal comfort perception.

In colder environmental conditions (such as where cold discomfort is reported) and within conditioned environments where indoor conditions are not influenced by the outdoor environment (due to closed windows and doors and being a mechanically controlled environment), outdoor relative humidity levels are not found to be influencing factors on the perception of indoor thermal comfort and discomfort.

7.3.3 Indoor temperature and indoor thermal comfort

In order to assess the effect of indoor comfort temperatures on indoor thermal comfort perception, three independent t-tests were conducted with temperatures at which comfort and general discomfort, comfort and hot discomfort, and comfort and cold discomfort, were compared.

These tests confirmed that within unconditioned environments a significant difference exists between the means of indoor temperatures at which thermal comfort is reported for all three sets of the limiting variables. The mean difference in temperature for comfort [$M=31.77$, $SD=2.24$] and general discomfort [$M=32.6$, $SD=2.64$] is $-.832$ where $p=.0001$ (two tailed) 95%CI: -1.224 to $-.440$ however the effect size as calculated with Cohen's d was small at 0.3 . In comparison, the mean difference between comfort and hot discomfort [$M=32.85$, $SD=2.47$] was -1.077 where $p=.0001$ (two tailed) and 95%CI: -1.487 to $-.667$ and the Cohen's d effect size was at $.46$ which is a mid-strength effect. Similarly, when looking at comfort and cold discomfort [$M=30.09$, $SD=3.139$], the mean difference between indoor temperatures was significant [$MD=1.678$, $p=.006$ (two tailed) 95%CI: $.491$ to 2.865] the effect size as measured through Cohen's d was 0.62 which is medium strength.

These results illustrate that there is a significant difference between the temperatures at which comfort is reported and discomfort is perceived in both hot and cold conditions. These differences are however in opposite directions with comfort temperatures in hot conditions being lower and being higher in colder environments. The analysis leads to the inference that in unconditioned indoor environments thermal comfort may be largely dependent on indoor temperatures with the reported differences in the means and their effect size indicating that difference is both significant and purposeful, i.e., not accidental.

In conditioned environments the t-tests undertaken show that a significant difference between the means of indoor temperature existed where occupants have reported thermal comfort [$M=28.44$ $SD=3.009$] and thermal discomfort [$M=27.29$ $SD=4.037$] with $MD=1.146$ $p=.001$ (two tailed) 95%CI: $.445$ to 1.846 and a Cohen's d effect size of $.32$. When the grouping variable are comfort and hot discomfort, no significant difference was reported in the mean temperatures of the two conditions, however when conditions of comfort and cold discomfort were examined, a significant difference in the mean temperatures recorded comfort [$M=28.44$ $SD=3.009$] and at which discomfort [$M=27.17$ $SD=3.981$] was found with $p=.001$ (two tailed) [$MD=1.27$ 95%CI: $.549$ to 1.982]. The effect size was Cohen's $d=.36$ which was greater than when looking at general thermal discomfort.

The results of this analysis also demonstrate that in conditioned environments the indoor temperatures at which discomfort is perceived were similar for both general (hot and cold conditions) and for discomfort due to cold conditions (that is, it is perceived as *too cold*). This could possibly be due to the length of time the respondents had been within the conditioned environment prior to recording their comfort response, alternatively, an element of control of the environmental conditions, or lack of control, may have been a cause for the discontent of the respondents with the thermal environment.

The results also show that the instances of hot discomfort (discomfort due to its being *too hot*) were not affected by indoor temperatures, it is more probable however, that the dataset provided limited instances where hot discomfort was reported within conditioned

environments. We cannot therefore definitively say that indoor temperature does not influence discomfort due to heat in conditioned environments.

7.3.4 Indoor relative humidity and indoor thermal comfort

There is evidence in existing literature that suggests that a change in relative humidity does have an influence on thermal comfort perception, (described in Section 2.5). This is reported to be conversely linked to the temperature in hot climatic conditions with a rise in temperature necessitating a decrease in relative humidity to maintain comfort (Givoni, 1992).

The analysis of the dataset obtained for this study shows that the effect of indoor relative humidity on indoor thermal comfort is not found to be significant: A series of independent sample t-tests were conducted assessing the difference in the means of recorded indoor relative humidity levels for the reported thermal comfort, general thermal discomfort, and thermal comfort due to hot (hot discomfort) as well as thermal comfort due to the cold (cold discomfort). The results of all tests show insignificant p values thus indicating that indoor relative humidity has negligible influence on indoor thermal comfort perception.

The analysis undertaken (thus far) has dealt with indoor temperature and indoor relative humidity independently and their interaction has not been accounted for, and this may be an explanatory factor in the non-significant result. As it is possible that relative humidity does have an effect thermal comfort perception (as reported in existing literature) but not in isolation.

7.3.5 Indoor Wind speed and indoor thermal comfort

The influence of indoor wind speed on indoor thermal comfort perception was assessed through a series of t-tests comparing the means of ranges of indoor wind speed at which either comfort, general thermal discomfort, hot discomfort, and cold discomfort have been reported.

In unconditioned environments no significant difference was found in the means of the recorded wind speeds for any of the thermal comfort and discomfort groups. It can be inferred from these results that the incidence of thermal comfort is not dependent on the speed of air movement, and that comfort and discomfort (general, hot, and cold) are all perceived at similar mean wind speeds. The mean wind speed at which comfort is reported is recorded to be 1.23m/s which is within the range of air speed estimated to reduce effective temperature 0.5m/s-to-3m/s (Fountain and Arens, 1993; Baker and Steemers, 2000), the determining factor in the perception of discomfort within the thermal environment is therefore not wind speed.

In conditioned environments the difference between the mean wind speeds recorded for conditions of comfort [$M=.922$, $SD=1.378$] and cold discomfort [$M=1.417$, $SD=2.195$] was found to be significant at $t(140.53)=-2.503$, $p=.013$ (two tailed). The magnitude of the mean differences at $-.495$, 95%CI: -8.863 to $-.104$ with a Cohen's $d= 0.27$ which indicates that though the difference in means was significant, it was quite small in its effect. The results show that within cold conditioned environments an increase in wind speed causes the perception of cold discomfort to increase. This may be explained by the effect of air movement resulting in body heat loss through conduction, that in warm or hot environments

provide a beneficial cooling effect, however in cold (conditioned environments) result in increased discomfort due to cold.

The inference drawn from this analysis is that within colder environments where occupants experience either comfort or discomfort due to cold, the wind speed has a small but significant effect on their comfort level. In warmer conditions such as those experienced in unconditioned environments, the wind speed does not have an effect on the thermal comfort or discomfort perceived by the occupants. Interestingly, this is also the case for instances where hot discomfort is reported in conditioned environments (i.e. wind speed has no significant effect in the perception of thermal comfort). This implies that wind speed is not an influencing factor in the comfort perception in hot conditions however cold discomfort can be alleviated by a reduction in wind speed.

7.3.6 Comparing cold discomfort and hot discomfort

The detailed analysis of the environmental parameters that effect indoor environmental conditions as presented in the preceding sections (7.3.1-to-7.3.5) show that the influence of each variable on discomfort varies between hot and cold environments. From this analysis we can infer that comfort which is the absence of both discomfort due to the heat and discomfort due to the cold, can be defined by precise ranges of environmental parameters. On the other hand, the absence of comfort is defined by varying degrees of different environmental parameters depending on whether the environment causes cold discomfort (discomfort due to it being perceived as *too cold*) or hot discomfort (thermal discomfort due it being perceived as being *too hot*).

Therefore the comfort scale cannot be considered linear, and discomfort cannot be deemed a single entity as by disregarding the distinction between hot discomfort and cold discomfort can lead to inaccurate and misleading results about the respective influence of each environmental parameter on thermal comfort perception.

7.3.7 Inferences from analysis

The parametric analysis applied on the physical variables that define thermal comfort perception as described in this section (7.3) has provided two contexts: the first of unconditioned environments where the indoor environments are not mechanically controlled, and where the management of comfort involves the opening and closing of apertures and the use of air movement (aided by fan use), and secondly, that of conditioned environments, where the indoor environments are kept to within rigid limits, the apertures are generally maintained closed, and there is little interaction of the indoor and outdoor environmental conditions.

The analysis has shown that in an unconditioned environment the indoor thermal comfort perception is influenced by the outdoor temperature and outdoor relative humidity for the conditions within which comfort and discomfort due to the heat are reported. No other physical environmental variables are shown to have an influence on indoor thermal comfort perception (general as well as hot discomfort and cold discomfort) in both unconditioned and conditioned environments.

The results imply that the influence of outdoor variables on indoor comfort in hot conditions is due to unconditioned environments having greater interaction between the indoor and outdoor environment as the common thermal comfort practices of the region includes the opening and closing of windows and doors to take advantage of diurnal changes in temperature. This addition of the outdoor environmental variables to the indoor environment can therefore have a direct and often immediate effect on the indoor comfort perceptions. Following this logic, one could assume that the same outdoor environmental parameters would influence indoor thermal comfort perception in cold environments (where comfort or discomfort due to the cold are perceived), however the results of the analysis did not support this. This could either mean that the nature of discomfort due to cold is not effected by variations in outdoor environmental parameters of temperature and relative humidity, but a more likely possibility is that in the hot climatic conditions within which the study was conducted there were too few instances of discomfort due to the cold reported for there to be a recorded effect.

The construction materials and the prototypical form of the urban building in Lahore as described in Section 6.3, describe the building envelope as providing a substantial delay to the influence of outdoor temperatures into the indoor environment. If apertures are maintained closed (as is common practice in conditioned environments) the chance of this influence further decreases and also reduces the influence of outdoor relative humidity levels. This may be a possible reason for the analysis showing outdoor environmental parameters having a negligible effect on indoor thermal comfort perception in conditioned environments. Although there is undoubtedly an effect of outdoor temperature on the indoor environment, the thermal time lag did not allow for its influence on thermal comfort perception to be measured, and it was thus beyond the scope of this current study.

The only environmental variable that was reported to have an influence on indoor comfort perception in conditioned environments was wind speed in cold environments (where comfort/cold discomfort was recorded). This analysis implied that an increase in the wind speed (through the use of mechanical devices) in cold environments results in increased discomfort.

The use of air movement (produced through ceiling and wall mounted fans which are common thermal comfort practice in Lahore) results in aiding heat loss from the body through evaporation, increase in convection, and at very low temperatures, radiation, which in an already cool environment may result in the perception of *too cold* thermal conditions.

7.4 Note on statistical tests used – comparing parametric and non-parametric results

In the preceding sections (7.2 and 7.3) the physical environmental parameters that potentially influence the perception of indoor thermal comfort were assessed through a series of non-parametric and parametric tests.

The primary reasons for using both statistical procedures to assess the relationships between the same variables was to obtain a comparison of the influence of the variables using group mean values (parametric tests) and group median values (non-parametric tests). In normally distributed samples there is little difference between the mean and median values, however for

the purposes of filtering out particular conditions, not dissimilar to those in this study (including limiting the dataset to conditioned or unconditioned environments, and filtering out responses where participants had recently changed location, and also, when limiting the dataset to very specific responses such as cold discomfort in unconditioned environments), there was an increased chance that the distribution of the remaining sampling may be non-normal. Conducting both types of tests in this manner can evaluate the respective differences between the two procedural methods and provide a background so that a decision could be made regarding the statistical procedures that will be used further in this study.

The results of both statistical techniques were very similar indicating the same environmental parameters of outdoor temperature and outdoor relative humidity having a positive influence on indoor thermal comfort perception in unconditioned environments, and indoor wind speed influencing perception of comfort in conditioned environments where cold discomfort is reported (Table 7.1). Therefore, we can assume that the restrictions and limitations put on the dataset did not compromise on the robustness of either statistical procedure.

As noted in Section 7.2 some of the results in the non-parametric tests implied the strengths of the interaction between the environmental parameters was quite small, this was explained as an underestimation of the actual strength (as can happen when the relationship is non-linear). The associated parametric tests however provided more definite results, and it is because of this that despite there being no significant difference in the results of the two types of tests, all following analyses undertaken on this dataset is through parametric statistical techniques.

		Unconditioned Environments		Conditioned Environments	
		Parametric Test	Non-Parametric Test	Parametric Test	Non-Parametric Test
Outdoor Temperature	Comfort/hot discomfort	✓	✓	-	-
	Comfort/cold discomfort	-	-	-	-
Outdoor Relative Humidity	Comfort/hot discomfort	✓	✓	-	-
	Comfort/cold discomfort	-	-	-	-
Indoor Temperature	Comfort/hot discomfort	✓	✓	-	-
	Comfort/cold discomfort	✓	✓	✓	✓
Indoor Relative Humidity	Comfort/hot discomfort	-	-	-	-
	Comfort/cold discomfort	-	-	-	-
Indoor Wind Speed	Comfort/hot discomfort	-	-	-	-
	Comfort/cold discomfort	✓	✓	✓	✓

Table 7.1 - Comparison of results of parametric and non-parametric tests undertaken

7.5 Influence of the physical environmental variables on thermal comfort perception in unconditioned environments.

Many definitions of thermal comfort perception equate indoor thermal comfort with indoor temperature as a function of outdoor prevalent temperature, which is taken to be accurately predictable within a particular predefined humidity range (discussed in detail in Section 2.6.2). The statistical tests conducted in the previous sections (7.2 and 7.3) have shown that in unconditioned indoor environments the physical environmental parameters that influence thermal comfort perception are indeed outdoor temperature and outdoor relative humidity while indoor temperature has a correlation with thermal comfort perception. These tests also showed hot discomfort (discomfort due to hot environments) and cold discomfort

(discomfort due to cold environments) to be two distinct entities with the physical environmental parameters defining each varying in proportion.

In order to determine the relative influence of the outdoor environmental parameters on indoor thermal comfort in unconditioned environments, and to establish the strength of the influence of indoor temperature on thermal comfort perception, two tests were conducted and are reported below. Hierarchical logistic regression analysis tests were undertaken, where the dependent variable was comfort/hot discomfort and where the dependent variable was comfort/cold discomfort. The influence of indoor temperature was also quantified through binary logistic regression test for both scenarios of hot and cold discomfort.

Explaining statistical tests used:

The following summary of the statistical tests used in the proceeding section is provided in order to clarify the interpretation of the particular measures and their values. The statistical texts referred to for this data include The SPSS Survival Manual (Pallant, 2013) and Discovering Statistics Using IBM SPSS Statistics (Field, 2014).

The logistic regression analysis is a parametric statistical test that provides an indication of the respective influence of the independent variables in the model that together make up the dependent variable. This is undertaken as stepwise increments (blocks) where additional independent variables are included in the model at each stage to assess how they interact to produce the dependent variable, and through this, the 'goodness of fit' of the model is assessed. The hierarchical logistic regression involves the building of successive linear regression models wherein separate but related models are compared for fit at each step. The measures of assessing the goodness of fit are as follows:

- Hosmer and Lemeshow test – which is required to record a high significance value where $p > .05$ in order for the model to be considered a good fit.
- Pseudo R square values such as the Cox and Snell R Square and the Nagelkerke R square are indicators of the variation in the model that can be explained by the model. The value ranges from 0 to 1 (with 1 indicating the best possible fit).
- The odds ratio ($\text{Exp}(B)$) value for each variable indicates the change in odds of one of the outcomes occurring due to a unit change in a predictor. The odds ratio is interpreted in terms of change in odds where, if the value is greater than 1, an increase in the predictor results in the odds of the outcome occurring increase, while a value below 1 means an increase in predictor will result in the odds of outcome occurring decreasing.

7.5.1 Physical environmental parameters effecting the perception of hot discomfort

7.5.1.1 Outdoor variables: Temperature & Relative Humidity

Looking at unconditioned environments and determining the relative influence of the physical environmental parameters of outdoor drybulb temperature and relative humidity on the dependent variable of comfort ($N=1193$) and hot discomfort (discomfort from heat)($N=130$),

a hierarchical logistic regression analysis is undertaken of which the results are listed in Appendix 7.14

The Block 1 Model that includes the influence of outdoor drybulb temperature shows a highly significant chi square at 23.096 ($p < .001$) which indicates the inclusion of the outdoor drybulb temperature is a predictive parameter to thermal comfort perception resulting in a higher predictive power of the equation. The Hosmer and Lemeshow test of goodness of fit shows the model to be valid ($p = .21$) and the pseudo- R^2 (Nagelkerke) shows that 3.7% of the variability in the model is due to outdoor temperature. The odds ratio of .9 indicates a unit rise in outdoor temperature would result in a decrease in comfort.

The inclusion of outdoor relative humidity to the model has yielded a significant increase in chi square value of 30.37 ($p = .000$), and the Nagelkerke pseudo- R^2 showing an accuracy of the equation with the combined effect of outdoor relative humidity and outdoor drybulb temperature improved by 4.8% from when only the outdoor drybulb temperature was included. The Hosmer and Lemeshow goodness of fit test does not present the test as a good fit of the data recording low significance ($p = .005$).

When looking at the interaction of the variables of outdoor drybulb temperature and outdoor relative humidity, the chi square value has increased by 10.86 up to 41.23 ($p = .000$), with the Nagelkerke R^2 showing the model to improve the fit by 6.5%, . The Hosmer and Lemeshow Test being non-significant with $p = .78$ showing the Model with the two parameters and their interaction to be a good predictor of comfort. This means that the interaction of the environmental parameters of outdoor drybulb temperature and outdoor relative humidity has a significant effect on the perception of comfort and hot discomfort accounting for 6.5% of difference from the previous condition where the effects of outdoor drybulb temperature and outdoor relative humidity are considered separately.

Overall the predictive power of the Blocks does not improve beyond 90.2% correct possibly due to the logistic regression estimating by default in favour of the dependant variable that occurs more frequently in the dataset which in this case is the presence of comfort (SPSS is a 2-D matrix). As comfort is reported in the majority of the cases in the dataset, the initial predicted estimate results in all of the comfort cases being correctly predicted and the discomfort cases being incorrectly predicted.

As a means of understanding the improved predictive power of the model due to the inclusion of the interaction between outdoor temperature and outdoor relative humidity, the relationship between the two independent parameters in situations where thermal comfort is reported is assessed through a Pearson's correlation (Appendix 7.15). This shows that the two parameters are highly correlated [$r = -.75$, $N = 1193$, $p < .000$] with an increase in temperature seemingly necessitating a decrease in humidity levels in order to maintain comfort. This result falls in line with our understanding of the body's ability to lose heat at high temperatures through sweat evaporation which is not possible at high humidity levels.

The hierarchical logistic regression of the physical variables of outdoor temperature and outdoor relative humidity in determining comfort and hot discomfort shows that the largest effect on indoor comfort perception is due to outdoor temperature. The added effect of outdoor relative humidity also effects indoor comfort perception but not by as significant an amount, having less than one third of the effect (chi-square of outdoor temperature = 23.1;

chi-square of outdoor relative humidity = 7.27; chi-square of interaction between outdoor temperature and relative humidity = 10.86). With the inclusion of the interaction of the two outdoor environmental parameters, there is a greater effect on indoor thermal perception which is slightly more than that of relative humidity in isolation. The Pearson's product moment test clarified this by showing that the outdoor environmental parameters are highly correlated in conditions where thermal comfort is reported (possible reasons for this are outlined in the previous paragraph). Thus in order to build a statistical model that predicts thermal comfort parameters the inclusion of outdoor relative humidity is not as beneficial to the model as the inclusion of the interaction between the two parameters, and within this, outdoor temperature has the most influence and therefore can, to an extent, be used to provide an accurate indication of thermal comfort perception within the hot unconditioned indoor environment.

In such hot climatic conditions in the developing world scenario within which this data was collected, the indoor climate in unconditioned spaces is managed through passive means such as the opening and closing of windows and increasing air speed through fans. As such the management of the indoor environment is largely a management of the effect of the outdoor environmental parameters of temperature and relative humidity. The results of the statistical analysis, described above, is reflective of the considerable influence of outdoor environmental parameters, particularly the temperature on the indoor comfort conditions. It appears that the influence of outdoor relative humidity levels is not as strong as that of outdoor temperature, however the results are indicative of the combined effect of the two parameters on thermal comfort perception being additive to discomfort such that in order to maintain comfort at high humidity levels, a decrease in temperature was required. This may be due to the ability of the human body to regulate body temperature through sweat and evaporation in high temperatures, which becomes compromised at high humidity levels, and therefore in such conditions where humidity levels are higher, the temperature would have to be lower in order for comfort to be achieved.

The dataset shows that the range of outdoor relative humidity at which indoor comfort was reported was between 8%-100%, with 80% of the readings (as is typically used in thermal comfort studies) between 37%-88%.

7.5.1.2 Indoor variables: Temperature

In order to determine the accuracy of using indoor temperature to represent thermal comfort (as a scale), a binary logistic regression of the data was conducted taking hot discomfort as dependent variable. This provided an indication of the strength of the correlation between indoor temperature and indoor thermal comfort.

The results of the test confirmed the correlation of the indoor temperature with the perception of comfort and hot discomfort. The model showed a highly significant chi-square = 25.65 ($p < .000$, $N = 1340$) and accounted for an approximate change of over 4% (Nagelkerke R^2) in the perception due to change in temperature. This model was considered a good fit with a highly non-significant Hosmer and Lemeshow Test, and the odds ratio indicating a unit ($^{\circ}\text{C}$) increase in temperature results in an increase in hot discomfort by a ratio of .8.

7.5.2 Physical environmental parameters effecting the perception of cold discomfort

7.5.2.1 Outdoor variables: Temperature & Relative Humidity.

In order to determine the influence of outdoor drybulb temperature and relative humidity on the perception of comfort in cold conditions (in unconditioned environments), a hierarchical logistic regression analysis was undertaken. This was conducted with the dependent variable taken to be comfort and cold discomfort (discomfort due to cold). The results are listed in Appendix 7.17.

The Block 1 of the logistic regression model showed the influence of outdoor drybulb temperature to be non-significant, while the model was of good fit with Hosmer and Lemeshow being non-significant at $p=.16$. The inclusion of outdoor relative humidity in the model (along with outdoor temperature) in Block 2 was similarly non-significant. However the effect of the interaction between the independent parameters in Block 3 showed a significant improvement in the predictive power of the model with the Block ($\chi^2=7$, $p=.008$). This amounted to an approximate improvement of 5.7% in the Model (Nagelkerke R^2), however the Model can be considered a good fit having a Hosmer and Lemeshow test ($\chi^2=14.46$ $p=.07$).

This test showed that in unconditioned indoor environments in which the occupant report either comfort or discomfort due to the cold, the primary factor in the perception of comfort is the combined interactive effect of outdoor temperature and outdoor relative humidity.

The percentage of correctly predicted observations of comfort is very high at 98.8% for all blocks within the Model. The inclusion of the variables of outdoor temperature and outdoor relative humidity does not result in a change in this prediction. The reason for this value is likely the default setting of the logistic regression test being to predict the more commonly occurring outcome of the dataset. In this particular example, the perception of comfort was reported more often than cold discomfort and was therefore predicted.

7.5.2.2 Indoor variables: Temperature

A binary logistic regression was conducted to assess the strength of the relationship between indoor temperature and the perception of thermal discomfort due to the cold, in unconditioned environments. The results of this are in Appendix 7.18.

The test showed that there is a significant relationship between the two parameters ($\chi^2=7.21$, $p=.007$, $N=1207$) with an approximate effect size of up to 5% of the variation in thermal comfort perception due to the influence of indoor temperature (Nagelkerke R^2). The model was a good fit (Hosmer & Lemeshow $p=.428$) and the odds ratio reported an increase in comfort by over 1.3 times due to a unit increase in unit temperature.

This means that in unconditioned environments occupants who perceive discomfort due to it being too cold (will) report their comfort improving as it becomes warmer.

7.5.3 Differences in influencing parameters for comfort/hot discomfort and comfort/cold discomfort in unconditioned indoor environments. /OR/ Conclusion

In the previous section (7.3) it was shown that the outdoor physical environmental parameters that have the most influence on the perception of thermal comfort in unconditioned indoor spaces are outdoor drybulb temperature and outdoor relative humidity. While of the indoor parameters, indoor temperature is the only influencing variable. These tests also determined that thermal discomfort is not a singular entity and should be defined with respect to the thermal environment as either hot discomfort caused by the exposure to hot environmental conditions or as cold discomfort that is caused by the exposure to cold conditions.

Based on these findings, hierarchical logistic regression tests were undertaken on the data collected from unconditioned environments to ascertain the proportionate influence of the two primary outdoor environmental parameters. The results of these tests show that the perception of indoor thermal comfort is most influenced by outdoor drybulb temperature, and to a lesser extent, by the influence of outdoor relative humidity levels. In hot conditions, within which one would experience either comfort or hot discomfort, the outdoor temperature was found to have the most influence on the indoor thermal comfort perception while outdoor relative humidity has, in comparison, a statistically significant but practically negligible influence. However the combined effect of the two parameters has a significant influence on the perception of comfort with over 10% of the variations in perception being attributed to this interactive effect. The physiological reasons for this effect have been discussed in Section 7.5.2.1. This effect is small in comparison to the effect of outdoor drybulb temperature which is more than two times higher at 23%. It therefore, seems reasonable to assume that of the outdoor environmental parameters the only required indicator for indoor thermal comfort perception in unconditioned environments is outdoor temperature.

Indoor Temperature is the only indoor environmental parameter that was shown to influence thermal comfort in unconditioned environments. In order to establish the strength of the influence, binary logistic regressions were undertaken with dependent variables of comfort/hot discomfort and comfort/cold discomfort. These tests have shown that there the influence of indoor temperature on thermal comfort perception is between 4% (hot discomfort) to 5% (cold discomfort), and that this is opposite in direction with an increase in unit temperature resulting in a decrease in comfort in hot environments and an increase in comfort in cold environments.

Interestingly, the effect on thermal comfort perception due to the increase in temperature is more pronounced in cold environments than hot environments by 1.7 times. This may be because when an individual feels discomfort due to the heat, an increase in temperature increases their discomfort as their ability to regulate their core temperature becomes more difficult. Similarly, in cold conditions a person experiencing discomfort due to it being too cold would find an increase in environmental temperature to be more comfortable as their core temperature becomes easier to regulate.

The results of these tests have reinforced the idea of comfort being a non-linear entity with discomfort experienced in hot environments being different from the discomfort experienced

in cold environments. Furthermore, while this investigation has established the respective influence of different environmental parameters on indoor thermal comfort perception, it has also brought to light the lack of our current understanding of the parameters that inform the subjective perceptions of thermal comfort as explanations of the analysis results are reliant on anecdotal evidence of thermal practices and preferences.

7.6 Influence of the physical environmental variables on indoor thermal comfort perception in conditioned environments.

The influence of physical environmental parameters on the perception of indoor comfort within conditioned environments has traditionally been evaluated the same way as for unconditioned environments: with the values of outdoor environmental parameters used to predict acceptable indoor comfort ranges (Busch, 1992; Taleghani *et al.*, 2013; Toe and Kubota, 2013). This method does not take in to account that by their very definition, conditioned environments require the separation of the indoor environment from the outdoor climate, and as such any effect of the exposure to the outdoor climate on thermal comfort perception is residual and possibly rapidly overtaken by the expectation of the conditioned climate.

The results of the statistical tests undertaken in Sections 7.2 and 7.3, and as illustrated in Table 7.1, echo this reasoning as it is found that in conditioned environments none of the outdoor environmental parameters have a significant influence on the perception of indoor comfort. The physical environmental variables that have an effect on indoor thermal comfort perception (in conditioned environments) are indoor temperature and indoor wind speed. To gauge the strength of their influence on thermal comfort perception in both hot and cold conditions, two sets of parametric statistical tests were undertaken and presented in the following sections.

Explaining statistical tests used:

A summary explanation of the statistical tests used in the proceeding section is provided in Section 7.5 in order to clarify the interpretation of the particular measures and their values. The statistical texts referred to for this data include SPSS Survival Manual (Pallant, 2013), Discovering Statistics Using IBM SPSS Statistics (Field, 2014), and Research Skills (Hole, 2015).

7.6.1 Physical environmental parameters effecting the influence of hot discomfort in conditioned environments

None of the physical environmental variables, indoor or outdoor, were found to have a significant influence on thermal comfort perception in hot environments (within which either comfort or discomfort from heat is reported). This result is counterintuitive as one would expect indoor thermal comfort to be influenced (at the very least) by indoor temperature. However given that conditioning of indoor environments in hot climatic conditions refers to modifying the environment to induce a cooling effect, the likelihood of occupants experiencing hot environmental conditions leading to the perception of discomfort is not high. A perusal of the dataset on which this research is based shows this explanation to hold true and that in conditioned environments surveyed there are very few cases of occupants

reporting discomfort due to high temperatures (N=1072 of which hot discomfort reported by 10 individuals).

7.6.2 Physical environmental parameters: the influence on cold discomfort.

7.6.2.1 Outdoor Variables:

Statistical analysis showed none of the outdoor environmental parameters to have a significant effect on the indoor thermal comfort perception of occupants.

While the practice of active conditioning of indoor spaces involves minimising the influence of outdoor environmental parameters on the indoor climate, the prolonged exposure to climatic conditions and the nature of thermal transference may result in a measurable or even a significant effect on the indoor environment due to the outdoor conditions. The focus of the tests undertaken in this section however was on determining the effect on thermal comfort perception of immediate change in outdoor environmental parameters which explains why no significant influence of the outdoor environment on indoor comfort was reported.

7.6.2.2 Indoor Variables: Temperature & Wind Speed

Of the indoor environmental parameters, temperature and wind speed have been shown to have an influence on thermal comfort perception in cold environments (where comfort or discomfort from the cold is reported). To gauge the effect of these variables, a hierarchical logistic regression was conducted the results of which are discussed below and recorded in Appendix 7.19.

The test showed that the inclusion of indoor temperature improves the model with the omnibus test showing a significant chi square ($\chi^2=19.24$, $p<0.001$). The effect of indoor temperature is however only reported to account for 3.2% of the perception of comfort in these conditions. The inclusion of wind speed to the model shows a significant increase in the chi square by 18.75 ($p<0.001$), with the wind speed bringing about the 6.3% of the change in thermal comfort perception which is almost twice the effect of temperature.

The odds ratio shows that in conditioned environments an increase in indoor temperature results in an increase in comfort, while the increase in wind speed results in an increase in discomfort. The effect of both these environmental parameters are therefore diagrammatically opposite each other which is reflected in a non-significant effect being reported for the inclusion of the interaction of Indoor Temperature and Wind Speed in the model ($p=.059$).

These results indicate that in conditioned environments where temperatures are quite low (the lowest recorded temperature in Lahore was 19°C in this dataset), and in which an occupant perceives discomfort because it is too cold, an increase in the temperature will aid the regulation of body temperature and increase comfort levels. Similarly, when the wind speed increases, the rate of heat loss through conduction skin due to the human thermo-regulatory system increases which increases the perception of discomfort.

7.6.3 Inferences

The study presented in this section focussed on the effect of indoor environmental parameters on indoor thermal comfort perception, specifically on the perception of cold discomfort in

conditioned environments. The statistical analysis undertaken showed that indoor temperature and wind speed are the primary influencing factors in thermal comfort perception. These results also confirmed the anecdotal inferences of thermal comfort perception which were made through the observations of occupant behaviour in mechanically conditioned environments, such as the reporting of discomfort due to low temperature (the state of being too cold or cold discomfort) and not discomfort due to high temperatures, and also the reporting of an increase in discomfort as temperatures decreases. It can be inferred therefore that in cold climatic conditions a lower boundary or threshold (than in hot climatic conditions) to acceptable indoor temperature exists above which comfort is perceived and beyond which discomfort increases. The results have also shown that in cold conditioned environments the effect of wind speed is opposite to that in hot or warmer thermal environments where an increase in wind speed generally helps alleviate discomfort. This is primarily due to the effect of air movement in increasing the rate of heat loss through conduction and sweat evaporation, which in hot environments is desirable and hence more comfortable to the occupants while the same effect in cold environments is undesirable and hence results in increased discomfort.

The dataset did not contain an adequate number of reports of hot discomfort within conditioned environments for the results of the analysis to have a tangible significance for this study. This does not mean that hot discomfort within conditioned environments is not influenced by environmental parameters, but that within this particular study there were inadequacies in the data for this particular condition to be adequately assessed. It is therefore possible that a more conclusive understanding regarding the perception of hot discomfort in conditioned environments may be achieved with a larger dataset of such cases.

The statistical tests also indicated that indoor thermal comfort in conditioned environments cannot be predicted from the outdoor environmental parameters. Although this seems to be at odds with our understanding of building physics, the laws of which state that there remains a constant system of heat transfer through the building envelope, in conditioned buildings where apertures are usually kept tightly closed (generally within such environments, and especially within the climatic context of Lahore) this reduces and slows down the influence of outdoor environmental parameters on the indoor environment. The focus of the statistical analysis was on the modelling of variations in indoor comfort perception with the immediate outdoor environmental parameters, hence the time-lagged effect of these parameters on the indoor environment was not included in the statistical modelling.

The disassociation of the indoor comfort from the outdoor thermal conditions may also be due to the occupant's expectations of indoor comfort in conditioned environments, which somehow seems to relate to their exposure to a constant and unvaried indoor climate. The practices of maintaining a standard thermal environment year round and the consequence on expectation have been discussed in the Section 4.4. This raises the question of the effectiveness of the traditional thermal comfort equation for conditioned environments as this relies on estimating indoor thermal parameters based on prevalent outdoor conditions.

7.7 Indoor temperature and thermal comfort perception

Through the analysis in the preceding sections (7.5.1.2 and 7.5.2.2), indoor temperature has been established as an influencing variable to thermal comfort perception. However, the range of indoor temperature at which thermal comfort is reported has not been specified.

A perusal of the sample sets limited to indoor environments and the reporting of comfort in either conditioned or unconditioned environments shows that the indoor temperatures at which comfort occurs are very similar for both environments; within unconditioned environments, comfort is reported between 22°C to 40°C, while 80% of responses (as is traditionally used margin in thermal comfort studies) fall between 29°C to 34°C. The range of indoor temperature in conditioned environments in which thermal comfort is reported is very similar to that of unconditioned spaces being from 19°C to 38°C of which 80% of responses are between 25°C to 32°C. This is represented in Figure 7.1:

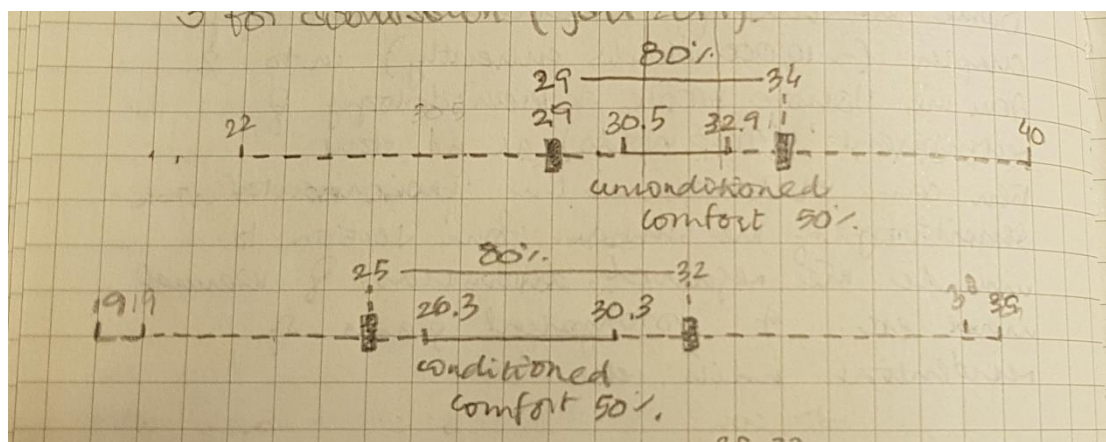


Figure 7-1

Image of thermal comfort temperatures for conditioned and unconditioned environments. The temperatures within which 80% of responses are reported are highlighted.

Thus, the condition of thermal comfort temperatures for conditioned and unconditioned environments being disparate entities which are influenced by varying degrees of different environmental parameters is reinforced.

7.8 Unconditioned environments

Based on the analysis presented in this chapter thus far, all further investigation into thermal comfort perception and the environmental parameters that inform it will focus on unconditioned environments.

7.9 The thermal comfort equation: The relationship between Outdoor Temperature, Indoor Temperature, and Thermal Comfort.

The results of the parametric analyses presented in the previous sections shows that thermal comfort perception in unconditioned environments is a function of the outdoor

environmental parameters of temperature and can be accurately represented by the indoor environmental parameter of temperature.

Conventional practice has been to use a linear model to describe the relationship between outdoor prevalent temperature and indoor comfort temperature. Based on this formula, an assessment of the dataset for the city of Lahore provides the linear predictive thermal comfort equation for unconditioned indoor environments.

$$T_{\text{comf}} = 29.62 + 0.07T_o \quad \text{Equation 7-1}$$

Equation 7-1

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the prevalent outdoor temperature.

The accuracy of the thermal comfort equation is based on the relevance of the reference outdoor temperature used, and the strength of the relationship between this outdoor temperature and the indoor thermal environment.

7.9.1 Specificity of outdoor temperature in thermal comfort equations ⁶

The predictive formula in its linear form such as the thermal comfort equation in the preceding section (Equation 7-1) is predicated on the convention established by previously conducted field studies including those compiled by Humphreys (1975; 1978), de Dear and Aucliemis (1988), the European Smart control and thermal comfort (SCATS) (Mccartney and Nicol, 2002), and the ASHRAE commissioned RP-884 (de Dear and Brager, 2002). These studies laid the groundwork for and developed the adaptive model of thermal comfort, however, there exists large discrepancy between the outdoor reference temperatures used within the equations developed with the reference temperature ranging from the outdoor monthly mean air temperature (ASHRAE), the running mean outdoor air temperature (EN15251) and the weighted mean running outdoor temperature (M A Humphreys, 1978).

In many instances the outdoor reference temperature used is of coarse granularity and has weak geographic and temporal links with the recorded indoor temperature often having been collected from archived government sources and from weather stations located at a considerable distance from the field study site. Secondly, there exists a conventional assumption that indoor thermal comfort parameters that are linked to outdoor climatic conditions as described through the adaptive thermal equations will remain uniform throughout the extent of the climatic classification. Because of this a comfort equation developed for a hot-arid climate through a study in Arizona USA is assumed to apply equally well to hot-arid climates in other parts of the world. There is thus a disregard for the local variations in thermal comfort perception that may occur due to differences in culture, urban form, and local thermal comfort practices.

In order to assess the regional and climatic specificity of the outdoor temperature that can be accurately used as a reference within a predictive equation, an analysis of a sub-set of the world database of thermal comfort field studies, the RP-884, which focuses on field study data from a single climatic classification, is undertaken.

⁶ Part of this section has been previously presented at the PLEA 2017 Design to Thrive conference – listed in bibliography under: Siddiq & Hanna 2017.

The RP-884 has been divided according to climatic classification by Toe & Kabota (2013) with an adaptive equation developed for each climate. A perusal of the hot-dry climatic area shows the inclusion of the field study site of the Pakistan Project (1994-95, undertaken by Oxford Brookes University and referenced in detail in Section 5.4.2 and 2.7 as well as the city of Athens. Of these field study sites both Athens and Karachi are coastal in location and as such are climatically different from the remaining land-locked cities of Multan, Peshawar, Quetta and Saidu Sharif⁷, and are therefore removed from the RP-884 dataset and a new comfort equation developed for hot-dry climatic regions as shown in Equation 7-1.

$$T_{\text{comf}} = 22.51 + 0.22T_o \quad \text{- Equation 7-2}$$

Equation 7-2

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the prevalent outdoor temperature.

7.9.1.1 An assessment of outdoor reference temperatures for comfort equations

As discussed in the preceding section, the outdoor reference temperature used in the development and use of thermal comfort equations has weak geographic and temporal links with the recorded indoor temperature, as it has often been collected from archived government sources and from weather stations that are located at a considerable distance from the field study site. Furthermore, in hot climates, there is often a significant diurnal change in temperature which may not have been taken into account. One could assume, the use of such reference temperatures may compromise the accuracy of the predicted comfort temperature.

In order to assess the time-based specificity of outdoor temperature used in adaptive thermal equations that provides the most accurate prediction of indoor thermal comfort parameters, the predictive formula developed for hot-dry climates (Equation 7-2) is used with three different outdoor reference temperatures of varying temporal quality and the subsequent predicted indoor comfort temperatures is compared to those empirically measured in each of the four field study sites to gauge their accuracy.

The outdoor reference temperatures used were the outdoor maximum daily temperature, the outdoor daily mean temperature, and a temperature range representative of the diurnal range (in the absence of an hourly outdoor temperature, the temperature used is the 6am as minimum temperature used for readings taken during the cooler times of the day from 1am to 11am, and a 3pm maximum temperature used for readings taken during the hotter times of the day from 11am to 1am). A series of one-sample t-tests are undertaken for each field study site.

When the **maximum daily temperature** was used as outdoor reference temperature, a significant difference was found between the predicted and empirical comfort temperatures in Multan [$M=29.74$, $SD=1.38$; $t(12)=3.9$, $p=.002$], Peshawar [$M=29.54$, $SD=1.5$; $t(9)=3.64$,

⁷ The city of Saidu Sharif is included in the dataset despite its geographic location particularly its altitude, its short summer season, and also as the mean high temperature of 36.8°C is considerably lower than the summer high temperatures of the other cities within the dataset. This raises concerns that the city is not of the hot-dry climatic classification, and more importantly that the residents of the city do not experience the same variations in climatic conditions and will therefore have different thermal comfort preferences to the residents of other cities within the dataset.

p=.005], and Quetta [M=29.3, SD=1.06; t(9)=4.33, p=.001], while no significant difference was recorded for the city of Saidu Sharif. This result indicates (at least within this regional context), that the maximum daily temperature cannot be used with confidence, in the adaptive thermal equation in hot-dry climatic conditions as it fails to provide accurate predictions of indoor comfort temperatures for most of the regions tested.

In using the **mean daily temperature** as outdoor reference temperature, a significant difference in the predicted and empirically measured means was found to exist in Multan [M=29.74, SD=1.58; t(14)=2.8, p=.04] and Peshawar [M=30.4, SD=1.79; t(18)=4.4, p=.000] while the result for Quetta was non-significant at p=.061 and no significant difference was found for Saidu Sharif.

The use of the reference temperature that is reflective of the **diurnal variations in temperature range** resulted in no significant difference in the means of predicted and empirically measured indoor comfort temperatures in the 4 cities of Multan, Peshawar, Quetta and Saidu Sharif indicating that both sets of temperatures were similar.

The results of these tests reveal that the most accurate prediction of indoor comfort is achieved through the use of an outdoor reference temperature that is reflective of daily variations in temperature. This result also indicates that the residents of hot-dry climatic regions are more sensitive to immediate fluctuations or changes in their thermal environment than the traditional use of an outdoor monthly mean, running mean outdoor air temperature, or even a weighted mean outdoor air temperature in thermal comfort equations would allow.

7.9.1.2 Regional specificity of adaptive comfort equations:

Adaptive equations developed with the climatic and comfort data of a region are typically considered to be suitable for use in other regions that have a similar climatic classification (Toe and Kubota, 2013). The assumption being that the relationship between outdoor environmental parameters and indoor comfort is based on exposure to climate and is not influenced by regional variations in cultural and social norms. To assess if this assumption is valid, an analysis of the field study sites climatically classified as hot-dry (as described in Section 7.9.1) was undertaken where adaptive equations developed for each site are used to predict the comfort range of the other sites and the accuracy of the prediction assessed.

The Pakistan Project dataset was divided into its composite field study sites of: Multan, Peshawar, Quetta and Saidu Sharif and individual adaptive equations developed for each city and listed in Equation 7-3, Equation 7-4, Equation 7-5, Equation 7-6 below.

$$T_{\text{comf}} = 19.54 + 0.34T_o \quad \text{Multan} \quad \text{Equation 7-3}$$

$$T_{\text{comf}} = 23.91 + 0.18T_o \quad \text{Peshawar} \quad \text{Equation 7-4}$$

$$T_{\text{comf}} = 25.49 + 0.12T_o \quad \text{Quetta} \quad \text{Equation 7-5}$$

$$T_{\text{comf}} = 20.64 + 0.27T_o \quad \text{Saidu Sharif} \quad \text{Equation 7-6}$$

Equation 7-3, Equation 7-4, Equation 7-5, Equation 7-6

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature most representative of diurnal range, and if available, with an hourly interval.

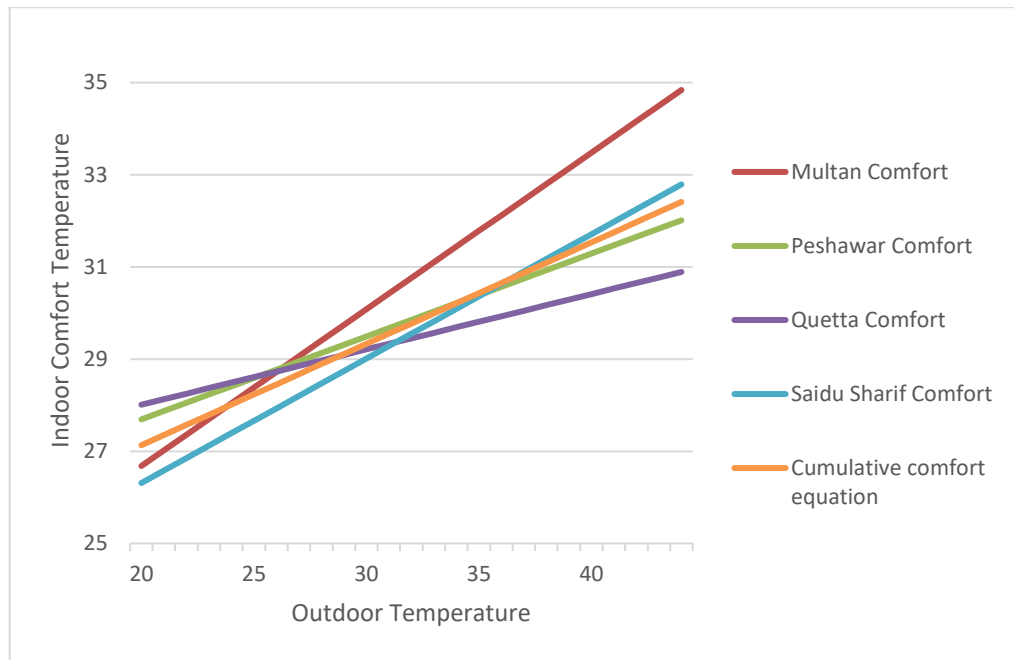


Figure 7-2

Visual representation of the predictive comfort temperatures for each of the component cities of the Pakistan Project, as well as the cumulative comfort equation developed from the entire dataset.

A simple line plot of the various equations, and the predictive equation developed by this thesis from the whole dataset is represented in Figure 7.2, which clearly indicates the variations in predictive comfort temperatures between the different formulae. The range between the comfort temperatures predicted for each location vary from 0.8°C to 3.9°C for the same outdoor temperatures (20°C to 45°C). The accuracy of a single formula to provide accurate predictions of comfort temperatures for a diverse range of expectations can thus be called in to question. This is expanded on and explored below.

A series of single-sample t-tests performed to assess the differences between the means of predicted thermal comfort temperatures of the four cities with the empirical data of the other cities showed no significant difference between the two sets of values, indicating that a single adaptive formula could provide an accurate prediction of the indoor comfort temperatures for the entire climatic region. The data along which these t-tests were conducted were compiled from a wide range of outdoor temperatures ranging from 25°C to over 40°C. Given our understanding of thermal comfort being a non-linear entity, further tests are conducted to determine if the adaptive equation(s) remain accurate throughout the entire range of outdoor temperature.

The analysis of the **Multan adaptive formula** (Equation 7-3) showed a significant difference between the predicted mean and the empirical data (sourced from the Pakistan Project dataset) for the temperature range of 25°C to 30°C with the city of Peshawar [$M=30.47$, $SD=1.03$; $t(5)=4.15$, $p=.009$; 95%CI: .67 to 2.84] while no significant difference was recorded for Saidu Sharif and there was insufficient data for the analysis of Quetta. Between 30°C to 35°C a significant difference was recorded for Peshawar [$M=28.48$, $SD=1.38$; $t(3)=-3.3$, $p=.045$; 95%CI: -4.48 to .09] and Quetta [$M=29.46$, $SD=.91$; $t(9)=-4.5$, $p=.001$; 95%CI: -1.95 to -.65] while Saidu Sharif was not significantly different. For the temperature range 35°C to

40°C, no significant difference was recorded for Peshawar and Saidu Sharif while there was insufficient data for analysis of Quetta.

The analysis of the **Peshawar adaptive formula** (Equation 7-4) for the temperature range 25°C to 30°C showed a significant difference with the Multan empirical data [$M=30$, $SD=.68$; $t(5)=4.6$, $p=.006$; 95%CI: .564 to 1.99] while Saidu Sharif was non-significant and there was insufficient data for the analysis of Quetta. In the 30°C to 35°C temperature range, no significant difference was recorded for any of the three cities while in the 35°C to 40°C temperature range Saidu Sharif was again recorded as being not-significantly different while both Multan and Quetta were not analysed due to insufficient data available.

The analysis of the **Quetta adaptive formula** (Equation 7-5) for the range of 25°C to 30°C shows a significant difference between the predicted mean and the empirical data of the cities of Multan [$M=30.05$, $SD=.68$; $t(5)=4.48$, $p=.005$; 95%CI: .604 to 2.03] and Peshawar [$M=30.47$, $SD=1.03$; $t(5)=4.13$, $p=.009$; 95%CI: .66 to 2.83] while Saidu Sharif was not significantly different. No significant differences were recorded for any of the three cities in the temperature range 30°C to 35°C while in the 35°C to 40°C Saidu Sharif and Quetta were recorded as not-significant and Multan had insufficient data for analysis.

The analysis of the **Saidu Sharif adaptive formula** (Equation 7-6) showed the predicted mean of the outdoor temperature range 25°C to 30°C was significantly different from the mean of the empirical data of Multan [$M=30.05$, $SD=.68$; $t(5)=7.63$, $p=.001$; 95%CI: 1.4 to 2.83] and Peshawar [$M=30.4$, $SD=1$; $t(5)=5$, $p=.002$; 95%CI: 1.46 to 3.63] while there was insufficient data for the analysis for Quetta. No significant differences were recorded for the cities of Multan, Peshawar and Quetta in the outdoor temperature range 30°C to 35°C. In the temperature range 35°C to 40°C, no significant difference was recorded for the city of Peshawar while there was insufficient data for analysis for both Multan and Quetta.

City of which adaptive formula used (predicted mean)	City of which empirical dataset was compared											
	25°C -to- 30°C				30°C -to- 35°C				35°C -to- 40°C			
	Multan	Peshawar	Quetta	Saidu Sharif	Multan	Peshawar	Quetta	Saidu Sharif	Multan	Peshawar	Quetta	Saidu Sharif
Multan	-	Sig.	Insuf. data	Non. Sig	-	Sig.	Sig.	Non. Sig	-	Non. Sig	Insuf. data	Non. Sig
Peshawar	Sig.	-	Insuf. data	Non. Sig	Non. Sig	-	Non. Sig	Non. Sig	Insuf. data	-	Insuf. data	Non. Sig
Quetta	Sig.	Sig.	-	Non. Sig	Non. Sig	-	-	Non. Sig	Insuf. data	Non. Sig	-	Non. Sig
Saidu Sharif	Sig.	Sig.	Insuf. data	-	Non. Sig	Sig.	Non. Sig	-	Insuf. data	Non. Sig	Insuf. data	-

Table 7.2 – Summary of single-sample T-test analysis of adaptive equations predicted mean and empirical data of various cities with similar climatic classification.

(Where Sig.= significant; Non Sig. = non-significant; insuf.data = insufficient data)

The analysis described above and summarised in Table 7.2, shows the variations in thermal comfort perception of the residents of the different cities despite being classified within the same climatic zone (hot-dry). This hints at the contextual nature of thermal comfort perception where the thermal comfort equation developed from a particular region cannot be confidently applied to predict thermal comfort temperatures for other regions even if they fall

within the same climatic zone. The reasons for this difference in thermal comfort perception could likely be related to the social and cultural differences within the regions that influence housing, building materials, clothing, and cooling or conditioning practice. These tests have further reinforced the non-static nature of thermal comfort perception highlighting a change in the relationship between outdoor temperature and indoor comfort when outdoor temperature increases. This questions the conventional representation of the adaptive equation as a linear relationship between indoor and outdoor environmental parameters, which clearly negates the use of a single predictive formula to represent the thermal comfort perceptions of populations from differing climatic and cultural backgrounds.

7.9.1.3 Inferences

The analysis carried out in this section focused on the outdoor reference temperature used in the adaptive equations to establish the temporal and geographic qualities that provide the most accurate predictions of indoor comfort. This analysis has provided a solid basis for the acceptance or rejection of three conventionally used *assumptions* of the adaptive theory and its adaptive equations.

The **temporal quality of outdoor reference temperature** shown to provide the most accurate predictions for indoor comfort, is one that is reflective of the immediate changes to the outdoor environment, i.e. hourly or daily maximum and minimum temperatures that are reflective of the diurnal range. The assumption can therefore be made that while the residents of any climatic zone become acclimatised to the prevalent environmental conditions and while these may be well represented through the use of the average monthly temperature, a running mean temperature, or even a weighted mean temperature (to incorporate the effects of the variations throughout a week), this study has shown that in hot-dry climatic regions the thermal comfort perception of residents is influenced by sudden or immediate changes to the thermal environment.

The **regional specificity of thermal comfort perception** was assessed whereby the convention of establishing thermal comfort equations based on climatic classification was found to compromise its accuracy and its predictive power when used in other regions with similar climates but that may be culturally and socially different. The use of an adaptive formula developed from a particular dataset can therefore only be used with confidence for the same population. This was also found to be true for situations where a dataset from similar climatic regions but culturally different field study sites is used to develop an adaptive equation, resulting in predictive comfort parameters that are not as accurate for each of the initial field study sites within the dataset.

The **linear relationship between outdoor temperature and indoor comfort** in relation to thermal comfort perception was explored. It was found that although the perception of thermal comfort is typically defined as linear in adaptive equations, the relationship between outdoor temperature and indoor comfort is not constantly linear and varies with change in temperature.

Therefore these tests have established that within the hot-dry climatic scenario, the need is for developing thermal comfort equations that are not only climatically sensitive but also specific to regions where populations are culturally different and may consequently have different thermal comfort practices and hence variations in their thermal comfort perception. It has

also been confirmed that within such climates, a variation in outdoor conditions results in an immediate change in indoor comfort perception for residents which reinforces the need for the outdoor reference temperatures used in adaptive equations to be reflective of diurnal changes in outdoor conditions. Finally, the definition of thermal comfort as a linear relationship between indoor comfort and outdoor parameters (within a particular outdoor temperature range) was found to be incorrect.

7.9.2 The thermal comfort equation of Lahore, Pakistan

In order to establish a conventional thermal comfort equation for the unconditioned indoor spaces in Lahore in Pakistan, a scatterplot of the data collected correlating outdoor temperature (measured at hourly intervals) and indoor temperature at which comfort is reported is produced. A linear relationship between the two variables is plotted at the best fit to produce the Equation 7-1 below:

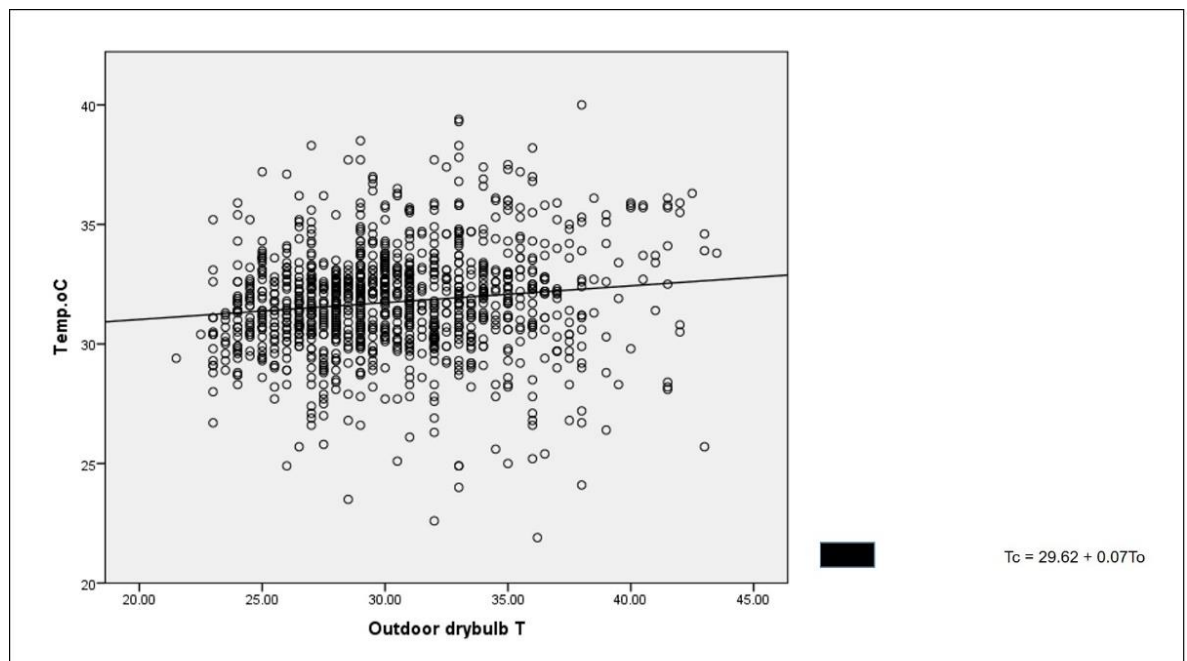


Figure 7-3

Scatterplot of Outdoor Temperature (Outdoor drybulb T) against Indoor Temperature at which thermal comfort is reported (Temp °C) showing linear equation of thermal comfort.

In light of the non-linear and variable nature of thermal comfort perception purported earlier (Section 7.9.1.2) which shows that the indoor temperature at which thermal comfort is reported varies in a non-linear manner due to changes in outdoor temperature, an investigation in to the form of the relationship between the two variables is undertaken. In order to assess the extent of this variation within a population, the dataset is divided into smaller packets of data so that the range of outdoor drybulb temperature in each is of 5°C. Thus 5 datasets are formed from the original (that had a 20°C outdoor drybulb temperature range from 20°C to 45°C), and independent thermal equations are developed for each dataset.

The thermal comfort equations thus developed are illustrated along with their numeric formula in Figure 7.4.

An examination of these equations raises two issues. First, as expected there is a marked difference in the pitch and angle (between the gradients and constants) of each linear equation

confirming a non-linear relationship between indoor comfort and outdoor temperature. Secondly the gradients of the central outdoor temperature range, between 25°C to 40°C are similar, raising the possibility that a linear equation could accurately represent the thermal comfort for this range.

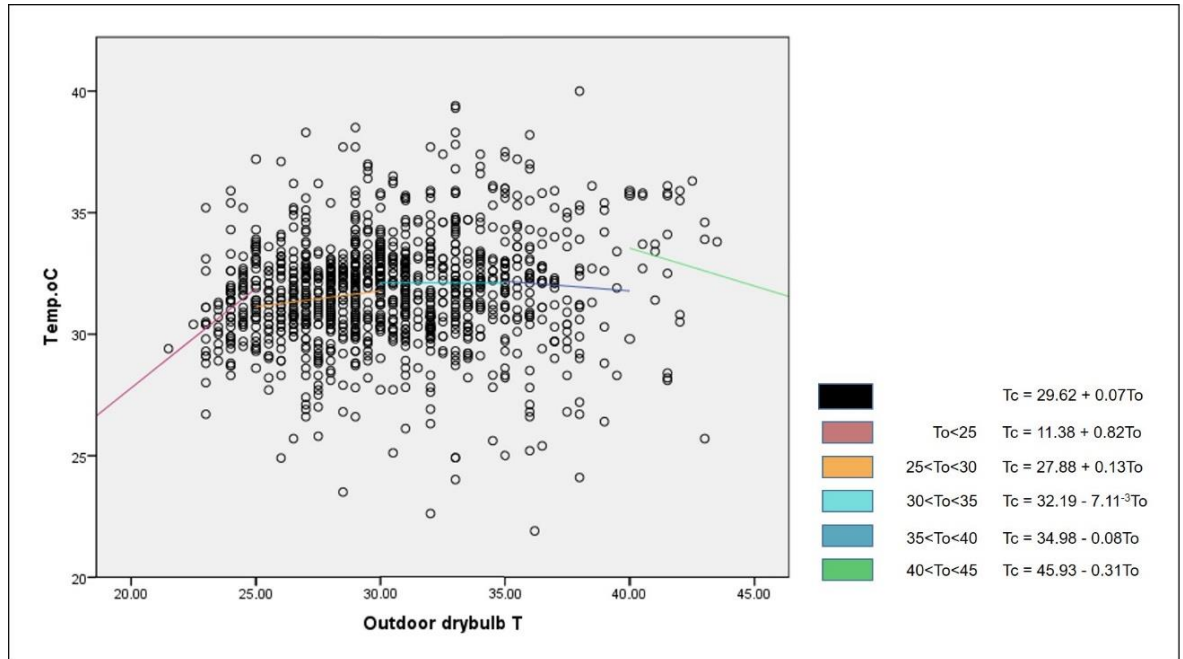


Figure 7-4

Scatterplot of Outdoor Temperature (Outdoor drybulb T) against Indoor Temperature at which thermal comfort is reported (Temp °C) showing linear thermal comfort equations for the 5° temperature ranges to highlight variations in gradient.

The linear equation that is developed from the dataset when outdoor temperatures are limited to between 25°C and 45°C is

$$T_{\text{comf}} = 30.53 + 0.04T_o \quad \text{Equation 7-7}$$

Equation 7-7

Linear thermal comfort equation for the outdoor temperature range between 25°C and 45°C.

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval.

7.9.2.1 Quadratic fit

As a means of developing the thermal comfort equation for the unconditioned spaces in the city of Lahore that reflect the variations in gradient for the outdoor temperature ranges below 25°C and above 40°C, the best fit equation was considered. It was found that a quadratic formula is the best fit for the data as represented.

$$T_{\text{comf}} = 25.84 + 0.32T_o - 3.91E^{-3}T_o^2 \quad \text{Equation 7-8}$$

Equation 7-8

Quadratic thermal comfort equation for the outdoor temperature range as empirically measured from 21.5°C to 43.5°C.

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval.

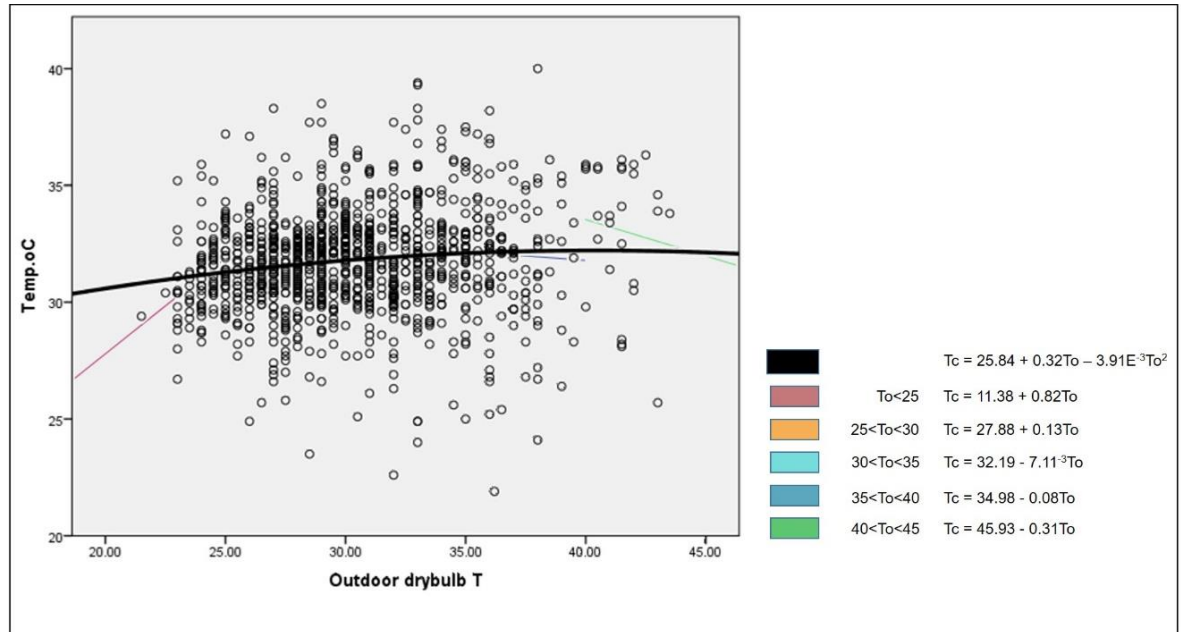


Figure 7-5

Scatterplot of Outdoor Temperature (Outdoor drybulb T) against Indoor Temperature at which thermal comfort is reported (Temp °C) showing the quadratic thermal comfort equation as best fit for the data.

7.9.2.2 The argument for a logarithmic thermal comfort equation

The scatterplot representing the thermal comfort relationship between indoor comfort temperatures and outdoor hourly temperatures (Figure 7.4) shows a steeper gradient of the linear equations for the temperature ranges below 25°C and above 40°C, and which has been represented in quadratic thermal equation developed earlier. While the higher positive gradient at the lower outdoor temperature range can be explained through our conventional understanding of thermal comfort perception. The negative gradient of the equation at the higher temperature range (above 40°C) is not as easy to explain through the traditional understanding of thermal comfort perception.

This may be due to the empirical nature of the data collection as a perusal of the dataset shows that the instances of very high outdoor temperatures were limited in number (in comparison to outdoor temperatures of less than 40°C), and that the occupants that reported comfort temperatures during those times were within cooler indoor conditions than those recorded at lower outdoor temperatures.

The correlation between outdoor temperature and indoor comfort temperature is largely positive with an increase in outdoor temperature resulting in an increase in acceptable indoor comfort temperatures. In unconditioned environments, this increase in indoor comfort temperature would be expected to taper off as the outdoor temperature increases, until at a given outdoor temperature, the indoor comfort temperature ceases to increase and remains constant irrespective of outdoor temperature. Such correlation of indoor comfort and outdoor temperatures could be represented with a logarithmic scale. However due to the limitations of the dataset (and the necessity to base the predictive formula on empirically gathered data), it is difficult to confirm the use of a logarithmic thermal equation as the best fit for thermal comfort studies in hot-dry climates as the whole assumption remains a scientific speculation.

7.9.2.3 Comparing equations – compromising on linear

A comparison of the predictive strength or accuracy of the three formulae developed in the preceding sections was undertaken and the results showed that within the outdoor temperature range between 25°C to 40°C, the predicted indoor comfort temperatures are more or less similar to within a maximum of 0.29°C. At 5°C below this range (at 20°C < T_o < 25°C) the difference increases to 0.65°C while above the range (at 40°C < T_o < 45°C) the maximum difference in predicted temperature is 0.45°C.

Outdoor Reference Temperature (°C)	Linear comfort equation –whole dataset (°C)	Linear comfort equation - 25°C < T _o < 40°C in (°C)	Quadratic comfort equation (°C)
20	31.02	31.33	30.68
25	31.37	31.53	31.4
30	32.72	31.73	32.92
35	32.07	31.93	32.25
40	32.42	32.13	32.38
45	32.77	32.33	32.32

Table 7.3 - Comparison of predicted indoor comfort temperatures through the use of three thermal comfort equations developed by this thesis for the dataset of Lahore, Pakistan.

The differences in the predicted temperatures are not large enough to recommend a drastic change in the adoption of a different comfort equation from the conventionally used linear equation. The differences in the indoor comfort temperatures are such that the human body can adapt to such variations through its thermo-regulatory system maintaining thermal equilibrium.

The stark gradient of the linear comfort equation at the outdoor temperature range of below 25°C, as well as the relatively large difference between the thermal equation predictions in Table 7.3, provides credence to the use of either the quadratic equation (Equation 7-8) or the linear equation developed for this temperature range (T_o < 25°C) (in Figure 7.4) for low temperatures.

7.10 Conclusions

The work in this chapter has focussed on statistically assessing and understanding the influence of the environmental parameters of temperature, relative humidity, and air movement on thermal comfort perception. This type of predictive analysis is the first of its kind for Lahore. These environmental parameters both influence and define thermal comfort, therefore the analysis undertaken has focused on quantifying their relative influence in order to develop a model that would provide the most accurate representation of thermal comfort perception –within the limitations of the empirical dataset of the population and the climatic environment of Lahore Pakistan, and the ‘Pakistan Project’ subset of the RP-884 dataset.

The analysis undertaken has quantified the relative influence of various physical environmental parameters on thermal comfort perception and has found the commonly used relationship between outdoor temperature and indoor comfort temperatures to be the most sound representation of indoor thermal comfort. This relationship between indoor comfort and outdoor temperature has traditionally been represented as a linear entity, however through the analysis assessing the relationship of thermal comfort perception with the environmental parameters in conditioned and unconditioned environments separately, the practice of

equating hot discomfort (as reported by persons experiencing hot environmental conditions) with cold discomfort (as reported by persons experiencing cold environmental conditions) was not found to be an accurate representation of comfort perception. This understanding of differing comfort perception due to variations in temperature helps to further our understanding of the changes in perception due to seasonal variations in environmental parameters, which were previously attributed to seasonal acclimatisation, and also the variations in comfort perceptions and consequent thermal comfort requirements in conditioned and unconditioned environments.

An original thermal comfort equation for the city of Lahore in Pakistan was developed by this research from the empirical dataset and through an iterative process the best fit equations for the thermal data was assessed for predictive power and accuracy. The non-linear form of thermal comfort perception was observed in the dataset hence an assessment of quadratic and logarithmic equations was undertaken to determine best fit, concluding that both are more reflective of the relationship between outdoor temperatures and indoor comfort than the linear form. Further assessment of the use of alternate comfort equations is however required to determine which is most practical to develop and use.

This chapter also included an analysis of part of the archived meta-dataset RP-884 of similarly climatically classified urban spaces within the larger geographic region of Pakistan. This was used to conduct a comparative analytical study of the popularly used reference temperatures through which the consequent predictive strength of the adaptive equations was compared. This analysis showed that the use of an immediate (or as close as possible) outdoor reference temperature provided the most accurate predictions of indoor comfort. This necessitates a change in the current practice of thermal comfort field studies requiring the collection of climatic data alongside thermal comfort data in order to reduce the reliance on historic records and the use of less accurate weekly or monthly mean temperatures.

The 'Pakistan Project' data was also used to establish the extents to which thermal equations developed for a particular climatic and cultural specification can be used with confidence in other regions. It was found that thermal comfort is both climatically and culturally specific, which means that the practice of developing comfort equations for climates and not specific populations is flawed as such an equation does not provide as accurate prediction across the range of outdoor temperatures for each culturally varied populations within it.

The analysis undertaken in this chapter, summarised above, has looked at current practices of measuring and predicting thermal comfort perception. The assessments of these analyses have developed a good understanding of the physical aspects of thermal comfort which include the objective measures of comfort sensation. This chapter has thus laid the groundwork to move the investigation in to the subjective aspects of thermal comfort perception.

The thesis seeks to determine the influence that prior exposure to a thermal environment, as would be experienced due to a person's socio-economic background, has on the thermal comfort perceptions of a population. To this end, this chapter, as the first of two analysis chapters, is the first step in this investigation. Through determining the physical parameters within which thermal comfort is achieved, and by establishing the most accurate temporal and geographic distance of measuring and predicting thermal comfort, the work presented in this

chapter establishes a framework for environmental variables that could help in testing the research hypothesis.

Chapter 8

Subjective aspect of thermal comfort perception

8.1 Introduction

The hypothesis presented in Chapter 5 (Research Design) proposes that within regions of high socio-economic inequity such as in the developing world, the populations from different socio-economic backgrounds will differ in their level of access and exposure to different thermal environments, which could inform their thermal comfort expectations and preferences. This chapter presents part of the analysis undertaken in order to assess and quantify this influence within the case study region of Lahore Pakistan.

The proceeding paragraphs of this section provide a brief summary of the existing literature around current knowledge and practice that is presented in detail in Chapter 2, 3 and 4. Section 8.2 outlines aspects of thermal comfort and socio-economic position in both conditioned and unconditioned environments. This is further elaborated on in Section 8.3 where the constituent parts of socio-economic position, income, occupation, and education, are each individually correlated with thermal comfort. Section 8.4 presents work undertaken in assessing the effect of exposure to different thermal environments on thermal comfort perception while additional variables that potentially influence thermal comfort perception are discussed in Section 8.5. The thermal comfort equation for the case study site of Lahore Pakistan are re-visited in Section 8.6, where the accuracy of prediction and sensitivity to variations in exposure and socio-economic position of the various arrangements are discussed.

Thermal comfort is understood to be the subjective assessment of the thermal environment which comprises the physical environmental variables of temperature, humidity and air movement. The traditional methods of measuring thermal comfort perception have focused on the influence of outdoor environmental conditions on the indoor environments and has been limited in representation as a measure of indoor temperature (defined for a particular climatic zone) as a function of the outdoor environmental conditions primary of which is the outdoor temperature (described in detail in Chapter 2 and Chapter 7).

The study of thermal comfort in real life situations (through field studies and surveys) has improved our understanding of the field immensely since the early days of thermal comfort studies when the reliance was purely on physiological measurements. Currently the understanding of the subject is reflective of the real life perceptions of comfort for the regions that have been studied, and include a recognition of the subjective influences of thermal comfort perception. Many of the parameters that form the basis of the subjective influence to thermal comfort perception have been identified but their respective influence on the perception have not been quantified. This may be due to the existing adaptive thermal equations accurately predicting thermal comfort ranges for 80% of the population despite considering only the physical parameters.

Recent assessment of thermal comfort perception has reinforced its being a climatically specific entity with variations in thermal comfort perception existing between populations

residing in different climatic zones (Toe and Kubota, 2013). This means that if the thermal perception responses of populations from diverse climatic backgrounds are collated (such as in the RP-884) the predictive strength of the thermal equation decreases. The findings in the preceding chapter (Chapter 7) have shown that even within a particular climatic zone there exist differences in thermal comfort perception between populations of varied cultural backgrounds (Siddiq and Hanna, 2017). The parameters that are responsible for the variations in thermal comfort perception between the different socio-cultural groups of a single (climatically and culturally defined) population have not yet been identified, and it is this gap in thermal comfort knowledge that the work presented in this chapter addresses.

The enquiry undertaken examines the subjective aspect of thermal comfort perception, if it can be quantified, and whether its contribution to predictive thermal equations would make a significant difference to the accuracy of the equation. Therefore this analysis will also provide a definitive answer to the question of variation in thermal comfort perception within the population of a single climatic and cultural region.

The parameters that form the basis of subjective influence cannot be measured in a traditional manner, as in most instances, the translation from the objective parameter to its subjective influence is undefined and there are additional unquantifiable variations in subjective value due to each individual participant in the study. One notable exception to this is the socio-economic position of a person or population that exerts a subjective influence but could primarily be assessed through the objective parameters of income, occupation, and education. A significant body of academic work has been undertaken to establish the effect of socio-economic position and its influences in several fields including on attainment, health, infrastructure development and the perception of one's self-worth, (discussed in detail in Chapter 2), and as such there exists a strong precedent to conduct the investigation of thermal comfort perception along socio-economic lines.

The discussion undertaken in the literature review presented in Chapter 3 and Chapter 4 highlighted greater levels of social and economic inequity within developing world scenarios. The discussion also identified the discrepancy in scholarship regarding the interaction of socio-economic position and thermal comfort perception. It is therefore important to investigate the effect of socio-economic position on thermal comfort perception in these regions. The urban region of Lahore in Pakistan as detailed in Chapter 6 is a good case with which to explore this.

8.1.1 Representation of socio-economic position in the dataset

The socio-economic scale developed in this thesis for the residents of Lahore was based on the ranking system popularly used in the developing world that involves an 11 point scale for occupation against a 7 point scale for education (P.A.S., 2015; Gallup-Pakistan, 2016) and described in detail in Section 3.5.1. The resulting ranking is divided into a 5-point rank of socio-economic position that includes the ranks: low / low-mid / mid / upper-mid / high. This can further be collapsed into a 3-point rank with low / mid/ high as required.

The socio-economic position has been coded as SEP in analysis, and is referred to as *high SEP* for populations of higher socio-economic position, *mid SEP* for middle socio-economic positions and *low SEP* for populations of low socio-economic position etc. in reporting the results of analysis.

8.1.2 Limitations to the dataset

The dataset is limited to assessing indoor conditions from which the occupants have not recently entered or exited (within the previous 10 minutes) so as to filter out responses from participants whose thermal comfort perception may be skewed due the residual effects of sudden change in climate. The dataset is also limited to those cases where the occupants of the space are sedentary in activity (sitting and/or standing) so as to preclude the effect of increased metabolic activity on their thermal comfort perception.

8.2 Thermal comfort and socio-economic position

In order to evaluate the effect of socio-economic background on the perception of the thermal environment, the socio-economic strata within the dataset that are most different, the low and high are assessed. The participants that are at the middle socio-economic grouping are excluded from this analysis in order to avoid any ambiguity in the results.

The thermal comfort parameters of these two socio-economic groups are measured through statistical analysis techniques and any difference between them is highlighted. Both conditioned and unconditioned spaces are assessed separately in order to determine if thermal comfort perception is dependent on the expectation of environmental conditions within a space, which may result in a variation in comfort perceived in conditioned and unconditioned spaces. This dealing of conditioned and unconditioned spaces is of special concern in the context of socio-economic differences between occupants of a space as the expectation of thermal comfort is based largely on prior experiences of thermal environments, which may vary due to privilege and opportunity afforded by ones' socio-economic position.

The conditions of comfort and discomfort due to the thermal environments are also examined independently, recognising that people of different socio-economic backgrounds may experience comfort at similar temperatures, however the differences at which they report discomfort may not be the same and this needs to be identified.

8.2.1 Unconditioned Environments

Unconditioned indoor environments are those where no means of artificial management of the indoor climatic parameters (such as evaporative cooling or artificial air conditioning) is undertaken, and adjustments to achieve and maintain thermal comfort are based on adaptations through change in clothing, or the opening and closing of windows. The cases where mechanically assisted air movement through the use of ceiling and wall mounted fans are included in unconditioned environments for the purposes of this study.

8.2.1.1 Comfort

An assessment of the indoor temperatures at which the two socio-economic population groups perceive thermal comfort in unconditioned environments was undertaken through an independent sample t-test (Appendix 8.22). This showed that the average temperatures experienced by members of low SEP ($M=32.30$, $SE=.147$) and high SEP ($M=31.69$, $SE=.121$) are similar, however this difference of .609, 95% CI [.230, .989] is significant with $t(596)=3.152$, $p=.002$. Thus the occupants of unconditioned environments of both

populations of low SEP and high SEP reported experiencing comfort at very similar temperatures with the mean of their respective ranges being different by just over 0.5°C. This difference in comfort temperatures has been measured empirically, and has been reported to be statistically significant, however it may be considered to be too small a difference to account for a meaningful conversation in comfort studies.

While the results of this analysis indicate that there is a significant difference in the thermal comfort temperatures between the low and high socio-economic populations, this difference may be explained by the temperatures to which the participants were exposed to during the course of the survey, rather than a difference in the comfort perception of the participants of the two socio-economic groups. A perusal of the dataset showed that the ranges of temperatures at which comfort is reported by participants of the two socio-economic populations is very similar, with the low socio-economic population reporting comfort between 24°C and 40°C, and of which 80% of comfort responses were between 29.8°C to 35.7°C; while the high-socio-economic population reports comfort between 22°C and 39°C of which 80% of comfort responses were between 29.3°C to 34.4°C. It can therefore be said that in the case of unconditioned environments it appears that there is little variation in the temperatures to which the two populations are exposed and therefore little variation at which they report comfort. It is also possible that the differences in comfort exposed may be due to a chance exposure during the course of the data collection, and does not mean that if a low socio-economic population had been exposed to such temperature they would not have reported comfort.

8.2.1.2 Discomfort

The analysis of the temperatures at which the population group with low socio-economic position and population group with high socio-economic position experience discomfort has shown that these temperatures do not vary significantly between the groups in both hot discomfort and cold discomfort situations (Appendix 8.23).

8.2.2 Conditioned Environments

Conditioned environments are those where indoor spaces are controlled through artificial means such as with the use of air conditioners and desert coolers. The environmental parameters in a conditioned indoor environment are maintained within a set range, and are only minimally influenced by variations in outdoor environmental conditions.

8.2.2.1 Comfort

An independent sample t-test conducted in conditioned environments showed that the mean of the temperatures at which comfort was reported by the low SEP ($M=28.24$, $SE=.309$) and high SEP ($M=28.21$ $SE=.150$) are not significantly different (Appendix 8.24). This result indicates that within conditioned environments both low and high socio-economic populations find similar temperatures comfortable.

This result implies that in conditioned environments one's socio-economic position has no influence on their thermal comfort perception, however the standard error mean reported for the low SEP indicates that the sample is not a good representation of the population group. It

is therefore necessary to examine the dataset further in more depth to forge a better picture of participants' thermal responses.

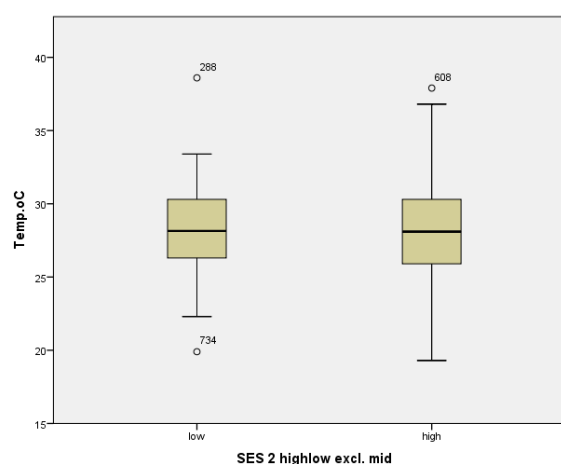


Figure 8-1

Boxplot of comfort temperature distribution for low socio-economic population group and high socio-economic population group in conditioned spaces.

This data in a boxplot distribution (Figure 8.1) shows that the mean of the two socio-economic populations is similar, however the range of temperature to which both populations are exposed is considerably different with the members of high socio-economic positions being exposed to a larger range of temperatures within conditioned spaces than members of low socio-economic populations. A possible explanation of this could be that the high socio-economic position participants may occupy conditioned spaces at times when the conditioning is not yet complete (as the air conditioning may have just been turned on), while members of the low socio-economic population group may spend shorter periods of time in such spaces, for example entering a conditioned space to retrieve items etc. and would thus experience only a smaller range of indoor temperature in conditioned spaces.

The analysis thus indicates that within the sample, both low and high socio-economic position populations had a similar mean comfort temperature, this may be coincidental however due to the small sample size, there results may not be representative of the comfort preferences of the entire population.

It is pertinent to note that despite the mean comfort temperatures of both the socio-economic population groups assessed being similar, the differences in extents of thermal comfort temperatures indicate either a difference in exposure or an actual difference in the ranges at which comfort is perceived. If the latter is the case, the results of this study lean towards proving the hypothesis this study set out to test. In order to do this, assessing the temperatures at which thermal discomfort is perceived is explored.

8.2.2.2 Discomfort

In order to assess if the different socio-economic populations perceive discomfort at different temperatures within a conditioned environment, independent t-tests are undertaken for both hot discomfort (discomfort reported due the environment perceived as being *too hot*) and cold discomfort (where the environment is perceived as being *too cold*). The t-test provides a

comparison between the means of the two types of discomfort (results are in Appendix 8.24 and Appendix 8.25 respectively).

The sample data did not provide an adequate number of participants who reported experiencing hot discomfort within conditioned environments from either of the low socio-economic population and the high socio-economic population for an analysis to be undertaken.

For the cases where discomfort due to the cold was reported, there was found to be a significant difference between the means of low SEP participants ($M=25.95$, $SE=.572$) and high SEP participants ($M=27.77$, $SE=.486$) with a difference of -1.819 between the two means ($95\%CI[-3.527, -.111]$) where $t(8.67)=-2.423$. $p=.039$. This result indicates that the two populations of low socio-economic position and high socio-economic position perceive thermal discomfort in cold environments at different temperatures.

However it is to be noted that although the means of the discomfort temperatures are different, there are only 4 cases of reported cold discomfort from the low socio-economic population, which is too small a sample to regard as a representative example of the population. Furthermore, the cold discomfort readings that form the upper range of the high socio-economic population's data includes three separate temperature entries at 38°C , 37°C and 37°C that originate from one participant. In order to assess the effect of these two *irregularities* in the data on the results of the t-test, the outliers were removed from the dataset and a bootstrapping t-test was run, which yielded similar results to those reported above with a significant difference in the means of the discomfort temperatures of the two socio-economic populations.

8.2.3 Inferences

The independent assessment of the thermal comfort (and discomfort) temperatures for the two socio-economic populations, the low and the high, has led to an understanding of socio-economic status of an individual having a significant influence on their thermal comfort perception.

These results indicate that within unconditioned environments, there exists a small but statistically significant difference in the temperatures at which comfort is reported however both populations experience discomfort at similar temperatures. Interestingly, in conditioned environments the opposite is found to hold true, with a significant difference existing in cold environments where discomfort temperatures are reported and both populations reporting comfort at similar temperatures. The ranges of comfort temperatures for both populations (as depicted in the boxplots in the preceding sections) when summarised collectively for both conditioned and unconditioned environments show a similar distribution as hypothesized in the Research Methodology (Chapter 5 Figure 5.2) and replicated below in Figure 8.2.

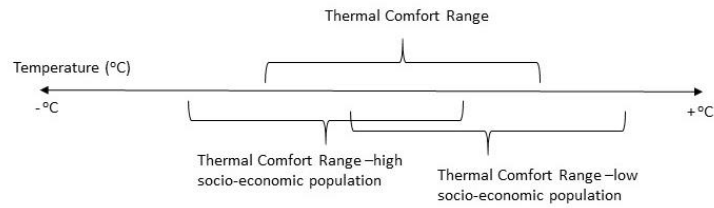


Figure 8-2

Diagrammatic representation of hypothesis: showing different extents of comfort temperature ranges between members of low socio-economic position and high socio-economic position.

The analysis of the thermal comfort preferences and perception of the low and high socio-economic population groups of Lahore, Pakistan that has been presented in this section was undertaken to assess the primary hypothesis of this thesis (Section 5.4.1) as below:

There will be a significant difference between the range of environmental parameters within which populations of low(er) socio-economic position perceive thermal comfort and the range of environmental parameters within which populations of high(er) socio-economic position perceive thermal comfort.

The analysis has shown that the hypothesis holds true for the population sample used in this study with both populations reporting discomfort temperatures that were significantly different from the other.

8.3 Deconstructing the socio-economic position re thermal comfort

The socio-economic position is defined for the purposes of analysis as a sum of the income, occupation, and education status (ranked as lowest to highest) of the individual (as detailed in Chapter 3). The analysis explained in the preceding section has shown that the socio-economic position of a population has a significant effect on the thermal comfort perception, however provides no clarity as to which of the variables that define socio-economic position have more of an influence. The work presented in this section seeks to provide an assessment of thermal comfort perception with respect to the different variables that are markers of socio-economic position and may have an influence.

The thermal comfort perception of the socio-economic groups has been shown to be significantly different for comfort in unconditioned environments and for cold discomfort in conditioned environments. The analysis undertaken in this section is therefore limited to these two scenarios.

Note on statistical procedures used:

Independent sample t-tests are the statistical tests used in this section. These are parametric tests that provide a comparison of the means across two groups. The assumptions required of the data in order to conduct the t-test are all met (continuous dependent variable, categorical independent groups, independence of observations and no significant outliers) with the

exception of two which are only partially met (normal distribution of the samples, homogeneity of variance). The assumptions are met for the majority of the groups in each of the sections of income, education, and occupation, and the strength and accuracy of the p-values has been reported accordingly.

In some of the smaller sub-sets in each category the sample size becomes quite small, though there is no minimum prescribed sample size for the t-test, very small samples compromise the power of the test. As the parametric t-test is a robust statistical procedure and the results of the larger sub-sets for each category are relevant to the study, all the results including those with compromised validity are presented so as to provide a complete picture of thermal comfort perception across all categories of socio-economic position.

8.3.1 Income

The income of an individual may have an effect on their thermal comfort perception as it may determine which thermal adaptive methods or systems can be afforded, and may, through place of work or lifestyle provide access to various thermal environments.

The effect of income on thermal comfort perception is assessed independently for conditioned and unconditioned environments and presented below.

Unconditioned environments:

The assessment of thermal comfort temperatures across different income levels is undertaken through a series of independent sample t-tests between different income groups. The results of the statistical analysis is recorded in Appendix 8.26, and laid out below in Table 8.1.

The results show that there exists a significant difference in the mean temperatures at which comfort is reported between the different income groups. This difference appears to increase in significance as the difference between the income groups increases, with income groups closer together having the lower significant differences, and in some instances non-significant differences. The lowest income group does not seem to have a significant difference in comfort temperatures with any of the other income groups, a possible reason for this may be a comparatively small sample size of $N=3$ that does not provide adequate data for a wholesome analysis (as per the assumptions required for t-tests).

Therefore it can be inferred that within the case study area of Lahore Pakistan, in unconditioned environments, the temperatures at which comfort is reported varies with a change in income level. This correlation may be due to the affordability of mechanical ventilation and conditioning methods to people of higher income levels, which in turn appears to lead to the expectation of those temperatures to ensure comfort. However these results may have been influenced by the temperatures that the participants were exposed to during the course of the data collection; that it is possible that persons of higher income groups were largely exposed to lower temperatures while those of lower income groups were exposed to slightly higher temperatures, and this difference in lifestyle (or opportunity) would appear as a significant difference in the mean temperatures at which comfort was reported. There is therefore a possibility that exposing people of different financial status to the same temperatures will show that there is no or little differences to their perceptions of the thermal environment.

In order to assess the potential effect of this, the temperature range of reported comfort was limited to between 30°C –to- 35 °C (the most populated of the temperature ranges) and the statistical analysis was re-run. A summary of the results is provided in Table 8.2 and the detailed results of the significance tests are recorded in Appendix 8.27.

It is found that the results of the restricted temperature range are considerably different from those recorded through the whole dataset. The most noteworthy difference is the non-significant difference in the mean temperatures for income groups at the higher end and that are closer together which would imply that the experiences of comfort temperatures of the populations are similar. For the lower-middle, and middle range income groups, the results show significant differences in the mean comfort temperatures and this may be due to the difference in financial stability between these and the higher income groups.

Income groups		1	2	3	4	5	6	7	8
		<3000 N=3	3001-7000 N=2	7001-15,000 N=65	15,000-30,000 N=151	30,001-50,000 N=216	50,001-100,000 N=282	100,001-300,000 N=438	>300,000 N=34
1	<3000								
2	3001-7000	x							
3	7001-15,000	x	.011						
4	15,000-30,000	x	.003	.032					
5	30,001-50,000	x	.004	.007	x				
6	50,001-100,000	x	.002	.000	.026	x			
7	100,001-300,000	x	.000	.001	x	x	.047		
8	>300,000	x	.042	x	.016	.005	.000	.006	

Table 8.1 – Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different income groups.
Number = significant difference = p; x= not significant.

Income groups		1	2	3	4	5	6	7	8
		<3000 N=3	3001-7000 N=0	7001-15,000 N=51	15,000-30,000 N=119	30,001-50,000 N=153	50,001-100,000 N=219	100,001-300,000 N=368	>300,000 N=23
1	<3000								
2	3001-7000	●							
3	7001-15,000	x	●						
4	15,000-30,000	x	●	x					
5	30,001-50,000	x	●	.030	.026				
6	50,001-100,000	x	●	.005	.002	x			
7	100,001-300,000	x	●	.008	.003	x	x		
8	>300,000	x	●	x	x	x	x	x	

Table 8.2 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different income groups where indoor temperature is restricted to between 30°C –to- 35 °C.
Number = significant difference = p; x= not significant.

There is a change to the significance levels when limiting the comfort temperature range (to between 30°C –to- 35 °C) which indicates that the differences in mean temperatures are not as distinct at higher outdoor temperatures. Despite this, it is clear that there is a correlation between the financial status of a population and their comfort perception, and that in situations where populations have markedly different financial positions, this translates to the

affordability of conditioned environments and their mean comfort temperatures remain significantly different.

Conditioned environments

The assessment of cold discomfort temperatures within conditioned environments that are reported by the various income groups was conducted through a series of independent t-tests. The tests were conducted sequentially through the income groups increasing the difference between them in order to determine a correlation between discomfort and a change in income. The results of these tests are recorded in Appendix 8.28 and in Table 8.3 below.

Income groups		1	2	3	4	5	6	7	8
		<3000 N=0	3001-7000 N=0	7001-15,000 N=1	15,000-30,000 N=3	30,001-50,000 N=24	50,001-100,000 N=31	100,001-300,000 N=65	>300,000 N=4
1	<3000								
2	3001-7000	●							
3	7001-15,000	●	●						
4	15,000-30,000	●	●	x					
5	30,001-50,000	●	●	x	x				
6	50,001-100,000	●	●	x	.023	.01			
7	100,001-300,000	●	●	x	x	.051	.000		
8	>300,000	●	●	.039	.017	x	x	.015	

Table 8.3 - Results of independent samples t-test conducted comparing means of cold discomfort temperatures in conditioned environments between different income groups. (Number = significant difference = p; x= not significant).

The results of these assessments show no directional correlation between the presence of cold discomfort and income group of the participants. There was insufficient data for analysis for the lower two income groups as none of the participants reported cold discomfort, which may also be due to the very small number of people with low incomes who have access to conditioned spaces. The significant results in the analysis do not appear to follow a pattern or direction, however, the significant differences are found between the three higher income groups and the lower groups. It is possible that a directional correlation does exist between the two groups (income and discomfort temperature due to cold) but this has not been evidenced through this analysis due to the unequal distribution and small sample size of the income groups that report cold discomfort in the dataset.

8.3.2 Occupation

Occupation could be expected to have an effect on thermal comfort perception of a person if the nature of the occupation required their presence in a particular thermal environment for prolonged periods of time which may result in a familiarization to that thermal environment consequently informs the expectation of comfort for that individual. For example, if a factory worker is required to work near a furnace, or within an open-to-air shed, or in an air-conditioned office, they would over time acclimatise to that thermal environment while also expecting it, and thus differ in their thermal comfort perception from the rest of the population including their office cohort who are exposed to different thermal environments. Such an influence of occupation environment on the thermal comfort perception would not be expected to occur in unconditioned environments where indoor conditions are effected by

outdoor climatic changes and occupants are largely in control of adaption of self and the environment to maintain comfort.

The analysis to assess the influence of occupation on thermal comfort perception is undertaken separately for conditioned and unconditioned environments and presented below.

Unconditioned environments:

A directional and random cross comparison of the indoor temperatures at which the participants of the various occupation groups reported comfort, in unconditioned indoor environments, was undertaken through a series of independent sample t-tests. The results of these tests are summarised in Table 8.4 (and in Appendix 8.29), do not indicate that the existence of a correlation between change in occupation and comfort temperatures.

As comfort is a non-linear and non-static entity (as previously established in Chapter 7 Section 7.9), dealing with the average of comfort temperatures across the whole range of outdoor temperature may provide inaccurate results. In order to counteract this, the dataset is restricted to the comfort temperatures between 30°C to 35°C (which received the most participant responses of the temperature ranges) and the tests re-run (summary of results is in Table 8.5 and detailed results in Appendix 8.30). The results of these tests are similar in the distribution of significant differences (between the means of the various occupation groups), and there is a little variation in the significance values of the two tests.

Occupation groups		1	2	3	4	5	6	7	8	9	10	11
		Unskilled worker N=83	Petty trader N=38	Skilled worker N=74	Non-executive staff N=382	Supervisory level N=184	Small shopkeeper /businessman N=91	Lower middle executive officer N=147	Self-employed / employed professional N=168	Medium businessman N=1	Senior executive officer N=16	Large businessman / factory owner N=7
1	Unskilled worker											
2	Petty trader	x										
3	Skilled worker	x	.003									
4	Non-executive staff	x	x	x								
5	Supervisory level	x	x	.004	x							
6	Small shopkeeper /businessman	x	x	.003	x	x						
7	Lower middle executive officer	x	x	.000	.014	x	x					
8	Self-employed / employed professional	x	x	.057	x	x	x	.019				
9	Medium businessman	x	x	x	x	x	x	x	x			
10	Senior executive officer	x	x	.003	x	x	x	x	x	x		
11	Large businessman / factory owner	x	x	x	x	x	x	x	x	x	x	

Table 8.4 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different occupation groups.
Number = significant difference = p; x= not significant.

It can be inferred therefore, that there is no effect of variation of occupation on thermal comfort perception in unconditioned spaces within the case study region of Lahore which is a typical example of a developing world region within a hot climatic zone.

Occupation groups		1	2	3	4	5	6	7	8	9	10	11
		Unskilled worker N=54	Petty trader N=38	Skilled worker N=57	Non-executive staff N=314	Supervisory level N=128	Small shopkeeper /businessman N=77	Lower middle executive officer N=113	Self-employed/ employed professional N=132	Medium businessman N=1	Senior executive officer N=15	Large businessman / factory owner N=7
1	Unskilled worker											
2	Petty trader	x										
3	Skilled worker	.044	.014									
4	Non-executive staff	x	x	x								
5	Supervisory level	x	x	.001	.002							
6	Small shopkeeper /businessman	x	x	.012	x	x						
7	Lower middle executive officer	x	x	.033	x	x	x					
8	Self-employed / employed professional	x	x	.055	x	x	x	x				
9	Medium businessman	x	x	x	x	x	x	x	x			
10	Senior executive officer	x	x	x	x	x	x	x	x	x		
11	Large businessman / factory owner	x	x	x	x	x	x	x	x	x	x	

Table 8.5 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different occupation groups where indoor temperature is restricted to between 30°C –to- 35°C.

Number = significant difference = p; x= not significant.

Conditioned environments:

Independent sample t-tests were conducted to determine the effect of variation in occupation on thermal comfort perception in conditioned environments (reported in Table 8.6 and detailed in Appendix 8.31). These show no directional correlation between the mean comfort temperatures of the different occupation groups (which range from 23.40°C to 28.63 °C). However the small sample size of the lower three and highest two occupation groups with $N \leq 2$ may result in a limited accuracy in their representation.

Given the small dataset, the validity of the test may be questioned. Bearing this in mind, the significant results reported could be due to the coincidental exposure to different environmental conditions for (some of) the participants from one of the groups (possibly the self-employed/employed professional category). It is equally possible however that with a larger sample size a more meaningful correlation may become visible, which would nullify (or severely reduce) the possibility of a chance significant recording.

Thus it would appear that the occupation of a person has little influence on their perception of thermal comfort in conditioned environments.

Occupation groups		1	2	3	4	5	6	7	8	9	10	11
		Unskilled worker N=2	Petty trader N=0	Skilled worker N=1	Non-executive staff N=44	Supervisory level N=44	Small shopkeeper /businessman N=15	Lower middle executive officer N=1	Self-employed / employed professional N=17	Medium businessman N=42	Senior executive officer N=2	Large businessman / factory owner N=2
1	Unskilled worker											
2	Petty trader	●										
3	Skilled worker	x	●									
4	Non-executive staff	x	●	x								
5	Supervisory level	x	●	x	x							
6	Small shopkeeper /businessman	x	●	x	x	x						
7	Lower middle executive officer	x	●	x	x	x	x					
8	Self-employed / employed professional	.003	●	x	.020	.015	x	.017				
9	Medium businessman	x	●	x	x	x	x	x	x			
10	Senior executive officer	x	●	x	x	x	x	x	x	x		
11	Large businessman / factory owner	x	●	x	x	x	.052	x	.003	x	x	

Table 8.6 - Results of independent samples t-test conducted comparing means of cold discomfort temperatures in conditioned environments between different occupation groups.
Number = significant difference = p; x= not significant.

8.3.3 Education

The education level of an individual may have an influence on thermal comfort perception, as it is possible that a higher level of education could provide access to higher level occupations which may result in greater income making different thermal environments and conditioning systems within financial reach. The effect of education on thermal comfort perception is assessed below for both conditioned and unconditioned environments.

Unconditioned environments

The effect of education level on thermal comfort perception in unconditioned environments is assessed through a series of independent sample t-tests that compare the means of comfort temperature between different sets of education level groups. The results of this analysis is summarised in Table 8.7 and detailed in Appendix 8.32.

The results show that for most of the different education level groups there is a significant difference between the mean temperature at which comfort is reported with the mean comfort temperatures of other groups. This difference is non-significant for education groups that are adjacent to each other in ranking (with the exception of Intermediate and Graduate levels), and it appears that in most instances, the significance of the difference increases as the distance in education ranking increases. This increase levels off at approximately the Matric (10th Grade) education level.

Education levels		1	2	3	4	5	6	7
		No formal schooling N=3	School class 1-5 N=10	School class 5-9 N=59	Matric N=154	Intermediate N=359	Graduate N=339	Post-graduate N=277
1	No formal schooling							
2	School class 1-5	x						
3	School class 5-9	x	x					
4	Matric	.029	.033	x				
5	Intermediate	.024	.018	.018	x			
6	Graduate	.020	.008	.000	.008	.017		
7	Post-graduate	.018	.011	.009	x	x	x	

Table 8.7 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different education groups.

Number = significant difference = p; x= not significant.

Given the non-static nature of thermal comfort perception, and in order to more accurately assess the effect of education level, the t-tests are re-run within a restricted comfort temperature range of between 30°C to 35°C (the most populated of the temperature ranges). The results are summarised in Table 8.8 and detailed in Appendix 8.33.

A perusal of the table indicates that within this temperature range, the population of the education group 2 ‘School class 1-5’ reported a mean comfort temperature that was significantly different from all the other education groups. Upon further examination of the dataset, it was found that the majority of the participants to the survey that make up this group worked in a factory setting (on the ‘shop floor’) which may explain the significance. It is also worth noting that the sample size of the lowest ranked education group ‘No formal training’ is very small at N=1, and it is possible that had a larger sample been obtained within this temperature range, the results of the t-tests for this group could have been different.

As things stand, the analysis indicates that at indoor temperatures between 30°C to 35°C, the perception of indoor comfort is not influenced by the education level of the participants.

Education levels		1	2	3	4	5	6	7
		No formal schooling N=1	School class 1-5 N=7	School class 5-9 N=39	Matric N=127	Intermediate N=272	Graduate N=265	Post-graduate N=225
1	No formal schooling							
2	School class 1-5	x						
3	School class 5-9	x	.020					
4	Matric	x	.000	x				
5	Intermediate	x	.001	x	x			
6	Graduate	x	.045	x	x	.032		
7	Post-graduate	x	.005	x	x	x	x	

Table 8.8 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different education groups where indoor temperature is restricted to between 30°C to- 35°C

Number = significant difference = p; x= not significant.

Conditioned environments

The independent sample t-tests undertaken to assess the mean temperatures at which persons from various education levels report cold discomfort (in conditioned environments) show that there is a negligible effect of change in education level with the perception of the thermal discomfort environments (summary in Table 8.9 and detailed results in Appendix 8.34). The accuracy of the assumptions inferred from these results is compromised due to the small size of the dataset where both of the lower two education rankings were unpopulated. The results do however show that within the large cross-section of Lahore's population that is represented within the dataset, only the higher three categories that comprise college and university educated persons are exposed to temperatures low enough to warrant a recording of cold discomfort in conditioned environments.

Education levels		1	2	3	4	5	6	7
		No formal schooling N=0	School class 1-5 N=0	School class 5-9 N=1	Matric N=3	Intermediate N=37	Graduate N=35	Post-graduate N=52
1	No formal schooling							
2	School class 1-5	●						
3	School class 5-9	●	●					
4	Matric	●	●	x				
5	Intermediate	●	●	x	x			
6	Graduate	●	●	x	x	x		
7	Post-graduate	●	●	x	.034	x	.016	

Table 8.9 - Results of independent samples t-test conducted comparing means of cold discomfort temperatures in conditioned environments between different education groups.

Number = significant difference = p; x= not significant.

8.3.4 Inferences

The component parts of socio-economic position, education, income, and occupation level, all interact and have an element of co-dependency in their making up the socio-economic position of a person. For example, a person's education level will, in all probabilities, pave the way for their occupation, and that occupation will (to a certain extent) determine their financial status, which in turn (particularly in the developing world) may dictate the extent to which one has access to education (discussed in detail in Chapter 3).

The exposure to different thermal environments is largely dependent on the access of conditioning devices and spaces either through being able to afford the initial outlay and running costs, or through the access of conditioned environments available through occupation and lifestyle (public libraries/shopping areas etc.). The thermal comfort perception of an individual could potentially, therefore, be correlated to their socio-economic position within society. Section 8.3 deconstructs the influence of the parameters that make up socio-economic positions and through a series of statistical analysis (presented in sections 8.3.1 to 8.3.3), provides insight to the effect of the component parameters of a populations' socio-economic position on their thermal comfort perception.

The results indicated that within unconditioned spaces the income and education of an individual had a significant effect on thermal comfort perception while occupation did not appear to influence thermal perception. In the case of income levels, an increase in the income

largely resulted in a greater difference to thermal comfort perception from the lower earners. The effect was not as pronounced in the case of education levels, but even then it was found that people with similar education levels perceived comfort at similar temperatures. These results can be explained by the potential of education and income levels of a person determining the types of home and work environments a person would have access to. The occupation of a person on the other hand does not have as much of an influence possibly due to people of various roles working in similarly unconditioned environments perceive comfort at similar temperatures.

The analysis conducted did not provide indication of cold discomfort in conditioned environments being effected by either income, education, or occupation levels of the individuals. A possible explanation for this could have been that the majority of participants who reported discomfort in conditioned environments were of higher socio-economic categories (of income, occupation, or education groups), as it was mostly these individuals who had access to conditioned environments. We can surmise from this that though the collective effect of these three parameters shows an effect of socio-economic position on thermal comfort perception, the sample sizes that were obtained after isolating each parameter may not have been large enough to conduct a robust analysis.

8.4 The effect of exposure to different thermal environments on thermal comfort perception

Following on from the previous analysis that quantified the effect of change in socio-economic status on thermal comfort perception (Section 8.2), and the effect of the individual parameters of socio-economic position on thermal comfort perception (Section 8.3), the variation in thermal comfort perception within an individual's socio-economic group has not previously been established. Such an investigation is essential in highlighting the potential influence that exposure to different thermal environments has on a person's expectations and perceptions of their thermal environment.

The effect of exposure to different environments is examined through an assessment of the lower income group that generally does not have access to conditioned environments in their home environments, although some members of this group are exposed to conditioned environments during work hours. The possibility of this sub-group of the low socio-economic category to potentially perceive their thermal environment differently to other members of the low socio-economic population and an assessment of their thermal comfort perception in both conditioned and unconditioned environments may therefore provide an accurate indication of the effect of exposure to conditioned environments on thermal comfort perception.

Two sets of analysis are thus conducted, one within unconditioned environments looking to assess differences in comfort temperatures and the second in conditioned environments to assess differences in cold discomfort temperatures. The possibility of a significant result due to the participants having recently transitioned from a different thermal environment which would result in a residual physiological effect has been minimised by the exclusion of all cases where the participant have recorded a change in their previous location.

8.4.1 Unconditioned environments

An independent sample t-test was undertaken to determine if members of the lowest socio-economic group that were exposed to conditioned work environments perceived their unconditioned environments differently to the other members of the group. The test showed there is a significant difference of $p < .05$ between the two sub-groups of lower socio-economic position populations, those who experienced unconditioned office environments ($M=32.48$, $SD=2.394$) and those who experienced conditioned environments ($M=31.51$, $SD=2.332$) (Appendix 8.35). The Mean difference of .972, 95% CI [.129, 1.815] with $t(137)=2.279$, $p=.024$ (two-tailed).

In order to reduce the chance of the significant result being due to some of the participants exposed to higher or lower than average temperatures, the indoor comfort range was fixed at 30°C to 35°C and the test re-run. This test (Appendix 8.36) showed that when restricted to similar high temperatures, the members of the lower socioeconomic group who work in unconditioned spaces ($M=32.39$, $SD=1.252$) and those who are exposed to conditioned work environments ($M=31.39$, $SD=1.089$) were significantly different with $p < .001$ (two-tailed) where $t(105)=4.233$ and the mean difference = .998 95% CI [.531, 1.466]. The effect size is large with Cohen's $d=.852$ which confirms that the difference in mean temperatures was not a chance occurrence.

The difference between the average comfort temperatures of the two groups was a little over 1°C, which though may not be considered large enough to warrant the development of an independent comfort equation, it is substantial enough to have implications and consequences for the calculation and prediction of thermal comfort perception and therefore cannot be ignored.

8.4.2 Conditioned environments

In order to assess the effect of exposure within conditioned environments, independent sample t-tests were undertaken that compared the mean temperature at which cold discomfort is reported by people who only have access to conditioned spaces during working hours (which is approximately 8 hours/day) and those members of the same socio-economic group who experience conditioned environments regularly. Due to the limited size of available sample from the lowest socio-economic group that fits the criteria of exposure to and reported discomfort from conditioned environments, the analysis was undertaken on the lower-middle socio-economic group (where socio-economic groups are ranked as five: low, lower-middle, middle, upper-middle, high).

The test (Appendix 8.37) showed that people within the socio-economic group that were not exposed to conditioned home environments ($M=26.52$, $SD=2.551$) reported cold discomfort at a temperature significantly higher than those people who were regularly exposed to conditioned environments throughout their day ($M=24.04$, $SD=3.002$). The mean difference is 2.486 (95% CI [.756, 4.216]) where $t(41)=2.9$, $p=.006$ (two-tailed). The effect size of this result as measured through Cohen's d of this is .89 which indicates a very large effect.

In order to provide a more robust assessment of the differences in the temperatures at which discomfort is reported, the temperatures were restricted to between 21°C to 26°C and the test re-run (Appendix 8.38). This results show that persons who did not have access to

conditioned environments outside of working hours ($M=24.75$, $SD=.984$) reported feeling discomfort from cold at a temperature significantly higher than those persons who have access to conditioned environments outside of work ($M=23.29$, $SD=1.808$) with their mean difference being 1.55 (95%CI[.383, 2.717]) where $t(20.63)=2.765$, $p=.012$ (two-tailed). The effect size is a very strong 1 (Cohen's d).

8.4.3 Inferences

The result of these tests indicate that regular daily exposure to a conditioned environment even for a limited time such as during working hours results in a change in the perception of thermal environments. It can be inferred that such a change in thermal comfort perception may be due to acclimatization to the thermal environment, but is more likely to be due to an *expectation* of what thermal comfort should or could be. The relationship between *expectation* based on previous (or in this case regular) exposure and the consequent *perception* of the thermal environment has been discussed in detail in Chapter 2 (Section 2.2) and Chapter 4.

The scenarios tested were in conditioned and unconditioned environments with both tests demonstrating a shift in the preferred comfort temperature by people who were exposed to a different thermal environment during part of their normal daily routine such as during working hours (which are approximately 8 hours of the day).

In unconditioned environments the results showed that people who were exposed to conditioned environments during part of their day (approximately 8 hours, in their working environment) reported a preference for comfort at lower temperatures than those exposed to unconditioned environments constantly. The range at which both populations reported comfort were similar indicating that a change in acclimatisation is not the reason for the shift in the mean comfort temperature, but the regular (daily) exposure to cooler conditioned environments appears to have affected the preference of comfort temperatures. This is particularly interesting as there is no change in the reporting of discomfort temperatures for both populations.

Similarly, in conditioned environments, the participants who only experienced conditioned environments for part of their day (during work hours) reported mean cold discomfort temperatures that were on average 2.5°C higher than those occupants of the space who have access to and experienced conditioned environments during most of their day, both at work and at home. This result therefore implies that regular exposure to cooler conditioned environments does not result in a physiological change in thermal comfort requirements and it appears that the participants remain acclimatised to the thermal environment to which they are normally exposed to during their day.

Anecdotal evidence collected during the field survey showed that people who slept outdoors during the night, as was once traditional to avail of lower diurnal temperatures, were more accepting of higher daytime temperatures. These results confirmed the reason for this could be a regular exposure to cooler night time conditions. The potential influence of limited but regular exposure to conditioned environments is quite substantial and warrants further investigation to establish how regular the exposure to conditioned environments has to be for it to effect the expectation of comfort, and how long does this expectation continue to last once the exposure to conditioned environments has been discontinued.

The expectation of a comfortable thermal environment could therefore be said to vary due to the lifestyle (time spent outdoors, the clothing type, material, covering etc.), cultural practices (night time cooling, local adaptations, and construction materials and techniques etc.), and exposure to different thermal environments (conditioned or unconditioned environments) within a climatic region. This expectation has been shown through the investigation presented in this chapter, to vary even within a specific sub-group of the local population, particularly those members of the population that are affected directly by lifestyle and cultural practices because of their socio-economic position. This investigation thus lays the groundwork for understanding of the effect of short term changes in environment that give one the *taste* of what things could be like that effects their desire or ability to settle for less. This result also has the potential for informing our understanding of the effect of lived experiences and application to other fields of study.

8.5 Additional influencing variables of thermal comfort perception

Thermal comfort perception has been shown to be influenced, to varying degrees, by numerous variables including age, gender, and metabolism (Fanger, 1970; de Dear, 2004; van Hoof, 2008; Nicol, Humphreys and Roaf, 2012), while this study has shown that the regular daily exposure of different thermal environments influences thermal comfort perception. In this vein, the effect of exposure to different thermal environments over the course of a person's life is the next step in this investigation, which can be conducted through an assessment of change in comfort perception for different age groups. The particular conditions of the developing world case-study (Lahore, Pakistan) are ideal for this investigation, as the technological advancements including the common use of air conditioning, and the potential of social mobility, (such as where upward mobility has resulted in populations of lower socio-economic status to become a part of the higher socio-economic group in their old age), are both factors that affect thermal exposure and may potentially influence thermal comfort perception, and are more pronounced in the developing world (discussed in detail in Chapter 4 and Chapter 6).

8.5.1 Age – the effect of social mobility/technological advancements.

The influence of age on thermal comfort perception was gauged through a series of independent sample t-tests that compared the mean temperatures at which persons of different age groups reported thermal comfort in unconditioned environments.

It was found that in the case study region of Lahore Pakistan within the hot-dry climatic zone and in the hot summer season, age does not seem to have an influence on the mean comfort temperature that was reported in unconditioned environments. Of the different population groups tested, only the persons of the highest age group (65+years) consistently reported significantly different temperatures from the other population (age) groups (summary of results in Table 8.10 with the detailed results in Appendix 8.39). This result could be a reflection of older persons perceiving the thermal environment differently from younger populations, however the result may also have been due to the small size of this group in comparison to the others as it is possible that with a larger sample size the mean comfort temperature of the group may have been similar to the other groups.

In order to ensure the results were not influenced by the range in temperature the population groups were exposed to, that would include variation due to their occupations and lifestyles, the comfort temperature range was restricted to between 30°C-to-35°C and the tests re-run. The results as summarised in Table 8.11 (detailed in Appendix 8.40) show that all the population age groups report comfort at similar temperatures with the exception of the oldest age group (65+years). The sample size of N=2 is very small particularly in comparison to the other population group sizes and the results of this age group are therefore not credible. It is possible that with a larger group, the results might have been different.

A point to note from both sets of these tests is that the mean comfort temperatures of the highest (oldest) age group are lower than those of the other age groups, this raises interesting points for further investigation regarding the comfort preferences of the elderly in hot climatic conditions. If the difference in the mean comfort temperatures of older members of the population was due to social mobility or technological advancements, their preferred comfort would have been at a higher temperature than the younger population groups. As this is not the case we can assume that the variation is due to age related to lifestyle, activity and metabolism differences.

Age groups		1	2	3	4	5	6
		18-24 N=423	25-34 N=422	35-44 N=189	45-54 N=113	55-64 N=37	65+ N=7
1	18-24						
2	25-34	x					
3	35-44	x	x				
4	45-54	x	x	.023			
5	55-64	x	x	.037	x		
6	65+	.003	.005	.001	.009	.079	

Table 8.10 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different age groups.
Number = significant difference = p; x= not significant.

Age groups		1	2	3	4	5	6
		18-24 N=364	25-34 N=339	35-44 N=156	45-54 N=90	55-64 N=31	65+ N=2
1	18-24						
2	25-34	x					
3	35-44	x	x				
4	45-54	x	x	x			
5	55-64	x	x	x	x		
6	65+	x	x	.000	.000	.003	

Table 8.11 - Results of independent samples t-test conducted comparing means of comfort temperatures in unconditioned environments between different age groups, where comfort temperatures are restricted to between 30°C-to-35°C.
Number = significant difference = p; x= not significant.

The differences in mean of the lowest 2 age groups (18-24 and 25-34) with the oldest (65+) is very close to being statistically significant however are not reported as in order to maintain the rules against which all the tests have been undertaken.

8.6 (Re)-examining the thermal comfort equation of Lahore

Having established that thermal comfort perception in addition to being climatically sensitive, is also regionally specific with variations between populations due to the particular cultural

context of each region (Section 7.9). Further analysis in this chapter has established that within a regionally and culturally defined population, differences in the thermal comfort temperatures do exist between different socio-economic populations.

This section seeks to establish thermal equations for different socio-economic population groups as a means to compare the effective accuracy of the predictive formula developed for the entire population of the region.

8.6.1 Linear thermal comfort equations for different socio-economic groups

Following the traditional representation of thermal comfort in a linear format, Equation 8-1 is developed for the lowest socio-economic group and Equation 8-2 for the highest socio-economic group.

$$T_{c \text{ (lowSEP)}} = 27.59 + 0.15T_o \quad \text{Equation 8-1}$$

Equation 8-1

Where $T_{c \text{ (lowSEP)}}$ is the indoor temperature at which persons of low socio-economic position perceive comfort and T_o is the prevalent outdoor temperature.

$$T_{c \text{ (high SEP)}} = 30.8 + 0.05T_o \quad \text{Equation 8-2}$$

Equation 8-2

Where $T_{c \text{ (highSEP)}}$ is the indoor temperature at which persons of high socio-economic position perceive comfort and T_o is the prevalent outdoor temperature.

A comparison of these two equations developed from different socio-economic sub-sets of the same regional and cultural population shows a stark difference in the outcome comfort temperatures for the same outdoor temperature range (30°C to 45°C or summer temperatures) with persons of lower socio-economic position expected to perceive comfort at a much wider temperature range of 2.25°C (32.09°C to 34.34°C) than the higher socio-economic position group with a range of 0.75°C (31.58°C to 32.33°C).

The differences between the thermal temperatures predicted from these equations range from 0.31°C to 2.01°C (at $T_o = 30^\circ\text{C}$ and $T_o = 45^\circ\text{C}$). While at an outdoor temperature of 35°C the predicted comfort temperature for the two socio-economic groups are only 0.23°C different.

The predictive thermal equations along with their comfort temperatures are in Appendix 8.41.

8.6.1.1 Comparison with the linear comfort equation for the entire population group

When compared to the comfort temperatures produced from the linear thermal comfort equation for the whole population of Lahore developed in the preceding chapter (Section 7.9.2, Equation 7-7 and below as Equation 8-3), it was found that the equation is more representative of the thermal comfort temperatures for higher socio-economic persons with the differences between the Lahore equation and the higher socio-economic equation ranging between 0°C to 0.2°C (for the outdoor range (25°C to 45°C) while the difference between the Lahore equation and the lower socio-economic equation ranges from 0.03°C to 2.01°C for the same outdoor temperature range.

$$T_{\text{comf}} = 30.53 + 0.04T_o \quad \text{Equation 8-3}$$

Equation 8-3

Linear thermal comfort equation for the outdoor temperature range between 25°C and 45°C. Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval.

This result may be due to the greater incidence of persons of higher socio-economic position groups than the lowest socio-economic position group within the population sample from which this equation was developed as such persons may have been exposed to and consequently show a preference for lower comfort temperatures in unconditioned environments as established in Section 8.4.

The use of the whole of Lahore equation (Equation 8-3) for predicting comfort temperatures for the different socio-economic populations of the city, results in predictive temperatures that are not as accurate for low socio-economic populations.

8.6.2 Quadratic thermal comfort equations for different socio-economic groups

The discussion around the best fit predictive thermal equation in the preceding chapter (Section 7.9.2) indicated that quadratic equations are most representative of the relationship between indoor comfort temperatures and prevalent outdoor temperatures producing lower residuals (distance of the predicted from the empirical) and hence greater accuracy. Following on from this the predictive thermal comfort formulae for the lowest and highest socio-economic groups are developed

$$T_{c(\text{low SEP})} = 23.08 + 0.44 T_o + 4.67E^{-3} T_o^2 \quad \text{Equation 8-4}$$

Equation 8-4

Where $T_{c(\text{low SEP})}$ is the indoor temperature at which persons of low socio-economic position perceive comfort and T_o is the prevalent outdoor temperature.

This quadratic equation for the lowest socio-economic group (Equation 8-4) is judged by this research to be more sympathetic to the plateauing of the indoor thermal comfort temperatures at higher outdoor temperatures (greater than 40°C) in comparison to the linear equation for the same socio-economic group. For the outdoor temperature range of 25°C to 39°C, the predicted comfort temperatures from both the linear and quadratic equations are within 0.15 °C difference. Even at higher outdoor temperatures from 40°C to 45°C, the difference in predicted temperatures does not exceed 0.71°C. These results indicate that while the quadratic equation is more representative of thermal comfort perception the difference between the linear and quadratic comfort temperatures is small enough for the traditionally used linear equation to be considered accurate specifically in the case of lower socio-economic populations in the hot climatic conditions in developing world urban region.

$$T_{c(\text{high SEP})} = 31.14 + 0.02 T_o + 3.26E^{-4} T_o^2 \quad \text{Equation 8-5}$$

Equation 8-5

Where $T_{c(\text{high SEP})}$ is the indoor temperature at which persons of high socio-economic position perceive comfort and T_o is the prevalent outdoor temperature.

A review of the predictive equation for the high socio-economic population group which is in quadratic equation format (Equation 8-5), shows that for the outdoor reference temperatures

of between 25°C to 45°C, the variation in comfort temperature is only 0.86°C. The variation in comfort temperature obtained from the linear equation format for the same outdoor reference temperature range was 1°C. The difference in the predicted comfort temperatures from both linear and quadratic equations are almost similar with a maximum difference of 0.51°C between their values. Therefore, we could assume that as thermal comfort is neither exact for given outdoor conditions nor a static entity, the use of the linear comfort equation may be considered to be within acceptable accuracy for the higher socio-economic population in unconditioned environments in hot climatic developing world regions.

The predictive thermal equations along with their comfort temperatures are in Appendix 8.41.

8.6.2.1 Comparison with the quadratic comfort equation for the entire population group

The quadratic comfort equation for unconditioned environments developed for the whole population group of Lahore (Chapter 7 Equation 7-8 and below as Equation 8-6).

$$T_{\text{comf}} = 25.84 + 0.32T_o - 3.91E^{-3}T_o^2 \quad \text{Equation 8-6}$$

Equation 8-6

Quadratic thermal comfort equation for the outdoor temperature range as empirically measured from 21.5°C to 43.5°C.

Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval.

A comparison of the predicted thermal comfort temperatures from the composite (whole of Lahore) equation above (Equation 8-6) and the quadratic equation for low socio-economic groups (Equation 8-4) for the temperature range 25°C to 45°C shows a maximum difference of 1.3°C. While a comparison of the predicted temperatures (at the same outdoor reference temperature range) from the whole-of-Lahore equation with those from the quadratic equation for the high socio-economic population (Equation 8-5) shows a maximum difference in temperature of 0.45°C. The predicted temperatures from the composite equation are thus closer to those of the higher socio-economic group however this may be due to a larger number of participants from higher socio-economic groups that are exposed to and consequently show a preference for lower comfort temperatures in unconditioned environments as established in Section 8.4.

8.6.3 Inferences

It would appear from the above discussion that while the quadratic equation is judged to provide a more accurate prediction of thermal comfort perception especially at higher temperatures (over 40°C), the predicted values are not very different from those predicted by linear equations which (in part) justifies the continued use of linear comfort equations.

Furthermore, while the results of the preceding sections have shown that there was a significant difference in the thermal comfort perception of populations from low and high socio-economic backgrounds, the use of a *composite* linear or quadratic predictive equation (that includes data from all socio-economic population groups) provides results that are biased towards the high socio-economic population which, it can be conjectured, is due to the lasting influence of exposure to different (cooler) environments that persons of middle and higher socio-economic population groups would experience. Of both of these composite equations,

the quadratic provides more accurate predictive temperatures for both the low and high socio-economic populations. However the difference between the comfort temperatures generated from the composite quadratic equation and from the quadratic equation for the low socio-economic group above 40°C outdoor temperature was quite large going from 1°C to 1.3°C at 45°C.

Of the population groups assessed above, the least accurately predicted is the low socio-economic position. As thermal comfort values that are predicted through even the most accurate of the composite comfort equations (the quadratic) are not reflective of those experienced by members of this group (as represented by the quadratic equation generated through the groups' empirical data).

The best way to check the validity and accuracy of the comfort equations developed through this analysis would be to check the predicted comfort temperatures from these equations against empirically measured data from the local (Lahore Pakistan) population, or to conduct a similar analysis on data collected from a different case study site of similar climatic and economic qualities. Both these validity checks are at present beyond the scope of this thesis, and therefore, currently we can only state that these results are valid for this particular population group of Lahore Pakistan.

8.7 Conclusions

This chapter set out to investigate the influence of subjective parameters on thermal comfort perception within the hot-dry climatic environment in the developing world urban region of Lahore, Pakistan, the geographic focus of this thesis. The parameter selected was the socio-economic position of a person or a population group as the established measures traditionally used to define it are quantifiable and would therefore lead to a robust analysis of its relative influence on thermal comfort perception.

In earlier studies, many of which have laid the groundwork for our current understanding of thermal comfort, the variations in thermal comfort perception examined and identified were based on the objective parameters of age, metabolism, gender etc. while the subjective parameters have at most been acknowledged and no rigorous empirical studies on their influence have been undertaken. This study has therefore filled an important gap in knowledge through its focus on the subjective parameters of thermal comfort. The use of empirical data to identify and statistically quantify variations due to their influence on thermal comfort perception, adds a significant dimension to this investigation.

The analysis, in this chapter, of the effect of socio-economic status on thermal comfort perception showed a correlation with persons of low socio-economic backgrounds who preferred warmer comfort temperatures and found a larger range of temperatures comfortable than persons from the higher socio-economic group. Prior to this study such a variation in thermal comfort values within a regional mono-cultural population had not been established.

A further investigation to establish the effect of exposure to a regular (daily) change in thermal environment on thermal comfort perception was also undertaken and the analysis described in this chapter. The expectation from this investigation was to determine whether a continued exposure to a particular climate results in the population being acclimatised to those climatic

parameters, would a regular, daily exposure to a different thermal environment have a similar long-lasting effect on their thermal comfort perception? The exposure that was tested was of limited but regular duration in the everyday routine experiences of the participants such as during working hours and office environment. The analysis yielded some very interesting results that indicated that such exposure does indeed influence the perception of the thermal environment, and such people go on to have a significantly different expectation of comfort under normal (routine) conditions than their counterparts who have not been exposed to different thermal conditions.

This is the first time that the long-term effect of a physical environmental change on subjective choice (based on expectation and consequent perception) has been empirically measured and assessed. The potential influence of this study within the realm of thermal comfort studies is in providing an increased sense of understanding of the effect of exposure to conditioned environments, and in particular the cumulative effect of uniform indoor temperatures, prescribed through building standards, on the occupants thermal comfort perception and demand for similar environmental conditions in other times.

The work presented in this chapter also addressed the argument of replacing the traditionally used linear thermal comfort equation with a quadratic equation as it has been shown to best fit the empirically measured thermal comfort temperatures especially at higher temperatures. The assessment of the thermal equations developed for the different socio-economic population groups and for the whole of Lahore population showed that though the quadratic equations for each socio-economic group was a more accurate predictor of thermal comfort temperatures than the composite (whole of Lahore) equation in both the quadratic and linear equation forms, the difference in the predicted temperatures was not large enough for a case to be made advocating the adoption of the quadratic form, or calling for separate equations to be used within a climatic and culturally specific region.

It must be said however, that the opinion adopted here is that in both the worst-case scenarios where climate change is not tackled resulting in extreme temperatures, and the socio-economic inequity within the developing world is not tackled, resulting in a greater divide in the thermal comfort perception of the different socio-economic groups, it will become necessary for building standards and guidelines for unconditioned building design to be more climatically sensitive providing an indoor environment that brings thermally comfort conditions (as defined by the users) within an achievable limit. As such the continued study of variations in thermal comfort perception within a climatically and culturally unified region is essential.

The focus of this thesis has been to determine if variations in socio-economic position within a population that consequently results in variations in exposure and access to different thermal environments results in an effect on the thermal comfort expectations and preferences of the population groups. The analysis presented in this chapter has shown with a degree of certainty that within the case study region of Lahore Pakistan there exists a difference in the thermal comfort perception between the various socio-economic groups.

Chapter 9

Discussion – Translating analysis, deciphering results. Clarifying the extents of climatic and cultural influence on thermal comfort perception

The purpose of this chapter is to provide a translation of sorts of the work presented in this thesis, as a corollary to the two previous analysis chapters with reference to the original premise and hypotheses and through this to define the original contribution to scholarship that this thesis presents.

9.1 Introduction

This study has focussed on defining thermal comfort perception.

The work undertaken in Chapter 7 went towards understanding how thermal comfort has traditionally been defined as an objective entity, hard-bound by environmental parameters, and also through an in-depth analysis, toward understanding the extents to which this traditional definition remains accurate.

In Chapter 8 the study has also looked at thermal comfort as a subjective entity and attempted through the statistical analysis of the case study site to determine the extents to which the subjective influence of thermal comfort perception can be quantified.

These two lines of analysis have together, led to some rather interesting insights regarding thermal comfort perception and the influence of physical environmental parameters on the perception of the environment. The results of the analyses are linked back to the psycho-physiological phenomenon of alliesthesia defined in the introductory chapter (Chapter 1) that describes the relationship of the physiological state of the body with the perceived pleasure or displeasure i.e. comfort or discomfort from the thermal environment. The analysis that focused on thermal alliesthesia, and the influence of physical variables on thermal comfort perception was presented in Chapter 7 and is discussed in Section 9.2 below.

The second line of investigation was directed at understanding the difference between the objective and subjective aspects of thermal comfort perception. This focused on an investigation into the effect of regular short-term exposure to a thermal environment (such as during an 8-hour work day), where its effect has not yet become part of an automated physiological response (such as occurs due to acclimatisation). The parameter chosen for this was socio-economic position of an individual or population group as, particularly in the developing world scenario where there is large social and economic inequity, population groups of different socio-economic backgrounds do not always have access to the same thermal environments. This difference in exposure of thermal environments which is based on socio-economic position was hypothesized to result in variations in thermal comfort perception of the populations. It was anticipated that confirming this through a statistical analysis based on empirical data would enable an assessment of the variations in thermal comfort perception due to the subjective influence of a non-environmental parameter.

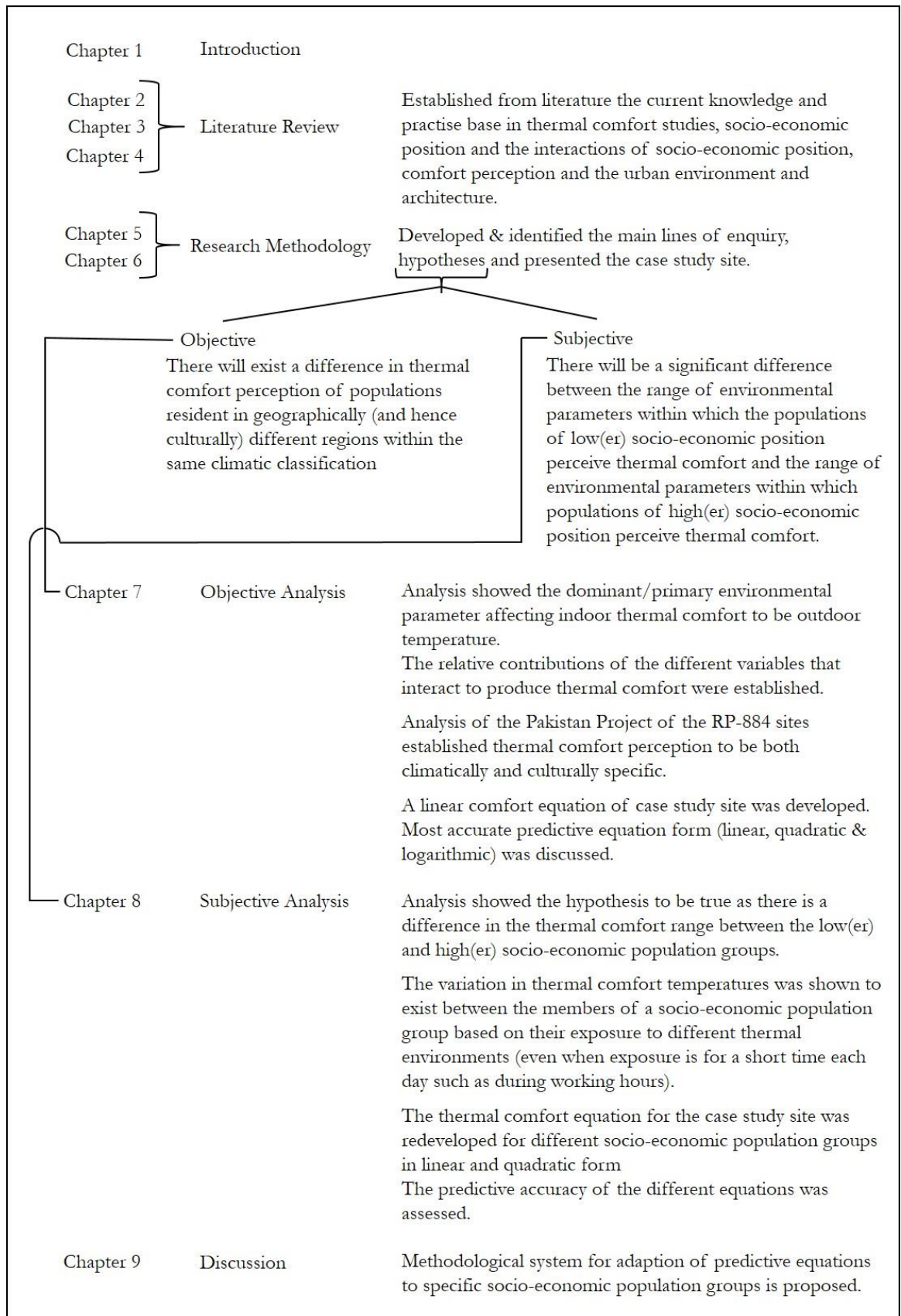


Figure 9-1

Summary diagram of thesis (sans conclusion chapter) highlighting the links between the constituent parts of the thesis.

The research was based on a case study site of an urban settlement within the hot-dry climatic zone. The expectation was that in such climates the general thermal comfort practice does not

involve the use of increased insulation through clothing which means that the thermal environment, as experienced by the resident population, is easier to measure than in cold climatic conditions. The case study site chosen for this study was Lahore in Pakistan as it fits the specifications of climatic classification and measure of economic-development. The site is also particularly appropriate as the locations of previously studied hot-dry climatic field study sites which are now part of the RP-884 meta-dataset are within the same geographic region and provide a basis for the analysis into variations in thermal comfort perception due to social or cultural context. The case study site and the reasons for its selection have been provided in detail in Chapter 5 and Chapter 6.

The following section of this chapter (9.2) provides an overview of the thesis, highlighting the links between the primary research objective, the development of the hypotheses, and the results achieved through their testing. The following two sections (9.3 and 9.4) deal with each of the two analysis chapters, the objective and subjective aspects of thermal comfort perception individually, linking the reasons behind the investigations with the existing literature in the field, examining results and discussing the implications of the findings. The limitations and uncertainties of the study are also discussed.

A summary diagram of the thesis, highlighting the links between the constituent parts of the research is provided in Figure 9-1.

9.2 Revisiting the hypotheses

The aim of this study has been to establish the subjective influence of the regional, cultural, and socio-economic positions of the population on thermal comfort perception. In order to conduct a comprehensive investigation into thermal comfort perception, two hypotheses were presented in the Research Design (Chapter 5).

The first hypothesis posited that thermal comfort perception is regionally specific. The hypothesis states:

There will exist a difference in thermal comfort perception of populations resident in geographically (and hence culturally) different regions within the same climatic classification.

The analysis conducted on the existing comfort data set of the hot-climatically classified areas in the RP-884 showed that this **hypothesis holds true**. And that the **Null Hypothesis can be rejected**.

The results of this investigation have been elaborated further, and the implications discussed in Section 9.3.

The second hypothesis posited that variations that exist in the thermal comfort perception of a regional population could be due to the socio-economic position of the population groups and consequently be dependent on the thermal environments they have previously been exposed to. The hypothesis states:

There will be a significant difference between the range of environmental parameters within which populations of low(er) socio-economic position

perceive thermal comfort and the range of environmental parameters within which populations of high(er) socio-economic position perceive thermal comfort.

The analysis undertaken on original data (collected for the purposes of this research) showed that this **hypothesis holds true**, and that the **Null Hypothesis can be rejected**. The results of this investigation as well as the implications of the findings have been discussed in detail in Section 9.4.

9.3 Thermal comfort as an objective entity: a climatical variable

Thermal comfort is recognised and acknowledged as a feeling, but one that is primarily induced by, and measured through, objective parameters. These include the environmental parameters of temperature, relative humidity, and wind speed, as well as the characteristics of building elements that inform the indoor environmental conditions such as the building envelope, the construction materials, dimensions, and their thermal behaviour. The buildings, materials used, and lifestyle of a regional population are usually formed within a particular climatic environment, and it is within these environmental parameters that the thermal comfort parameters of the population are determined. Thus the behaviour and lifestyle which is formed within a particular cultural and climatic environment may have a long lasting influence on the physiology of an individual, which when established as the individual's identity can be considered to be objective parameters effecting their thermal comfort perception.

Given the formation of comfort perception (as well as built environment and culture) within a particular climatic context, the study of thermal comfort perception has revolved around understanding the relationship between the outdoor climatic environment and indoor acceptable conditions. The predictive equations developed through the steady state chamber based studies as well as those conducted through the field studies that informed the adaptive method, have taken the predominant relationship between the outdoor environmental conditions and indoor thermal comfort to be through the variable of temperature.

The study presented in this thesis has expanded on this, resulting in the defining of three characteristics of thermal comfort perception:

Physical factors: confirming objective thermal comfort variables.

The analysis conducted in this thesis provided confirmation of this; that the most influential of the environmental variables on comfort perception is indeed the variable of outdoor temperature, and that the most indicative of comfort perception is indoor temperature. The work provided explanations of predominant interactions of the environmental variables that together create thermal comfort.

Establishing thermal comfort as a climatic variable: The investigation has shown that there exist differences in the comfort perception of residents of different settlements within the same climatic classification. This result indicates that variations in comfort perception exist due to either regional micro-climatic differences (within the larger climatic zone) or due to cultural variations in thermal comfort practice which would include the built form (material, construction technique) or lifestyle (clothing, behaviour) etc.

Establishing thermal comfort as a cultural variable: In investigating these reasons, the

study looked at the specificity of the outdoor reference temperature used in the thermal comfort equations, and discovered that the most accurate predictive equation was developed with reference temperatures that were taken from data that was both climatically proximate to the region (or regional population) as well as temporally close to the time of day being predicted for. This showed that in hot climatic regions, residents' thermal comfort perception is linked to or influenced by the diurnal change in climate. And that while thermal comfort is a climatic variable, it is prone to differences due to regional and temporal variations in climate.

9.3.1 Implications of findings

The implications of these findings relate back to the method by which the climatic data is collected where historically archived meteorological data that is often of coarse granularity is used, and which would therefore effect the accuracy of the predictive equations as the correlations between indoor comfort temperatures and outdoor climatic conditions found through these cannot be accurate. This does not mean that these studies should be discounted, but that it needs to be accepted that earlier field studies may have provided information regarding the physiological aspects of thermal comfort perception that included acclimatization as well as an element of acceptance due to expectation of seasonal differences. In such a scenario, the correlation between the outdoor prevalent temperatures and indoor comfort found in these studies was accurate, but does not actually cater to the adaptive method per se that sees residents adapting to daily as well as seasonal variations.

The understanding of variations in comfort temperature perception due to long-term (over days or months) and short-term exposure (over a few hours) to thermal environments leads to questions regarding the influence of exposure to artificially conditioned indoor environments. The results of the analysis showed a significant difference in the environmental variables defining the thermal comfort experienced in conditioned and unconditioned environments. Previously researchers had commented on the homogeneity of conditioned environments the world over irrespective of outdoor climatic conditions or cultural context, with the acknowledgment that this preference may have been due to the HVAC industry fuelled promotion of comfort. However, one wonders then if the change in the perception of the occupants of such spaces is physiological, that is, akin to acclimatization, or, if there is a difference in their perception due to the *expectation* of a conditioned environment, or, if these comfort temperatures are reported as a *resignation* (due to lack of control) to such an environment.

The consensus has been that occupants of conditioned environments all over the world *prefer* comfort in similar environmental conditions (Kempton, Feurmann and McGarity, 1992; Healy, 2008; Nicol, Humphreys and Roaf, 2012), which it appears, to me, is a conflation of preference of a temperature (or range of environmental conditions) with the reporting of comfort. It is perhaps possible that one may find themselves thermally comfortable yet have a preference for a different environment. Furthermore, one may also wonder if the reporting of comfort (in conditioned environments) is due to their desire or preference for such an environment or due to an acceptance of what is available and must be what put up with possibly due to a result of lack of control over the environment. These two concepts have not been differentiated between and the reporting of thermal comfort and thermal preference is considered to mean the same thing.

This idea has implications in our current understanding of variations in comfort in

conditioned and unconditioned indoor environments, where currently the evidence from empirical studies conducted in many different regions of the world has shown that the variation in indoor temperatures with respect to outdoor conditions is greater in unconditioned environments than in conditioned environments (M A Humphreys, 1978; de Dear and Brager, 1998; Nicol, Humphreys and Roaf, 2012), could this difference be a reflection of the environmental conditions the occupants of such spaces are exposed to rather than their preferences? This is a particularly pertinent question as it has been established that thermal comfort preferences of a population develop within the climatic context to which they are exposed, should the assumption be that occupants of conditioned environments within the same climatic context have developed their thermal comfort preferences in a different, artificially controlled/maintained, climatic context? In which case the preference is due to the expectation rather than what they really want or desire.

An alternate way of viewing the differences in thermal comfort perception for different population may be to focus on the notion of thermal discomfort instead. The analysis conducted in this research found that the relative contributions of the different environmental parameters that formed thermal perception were different when comfort was reported from when discomfort was reported in the same environmental conditions (conditioned or unconditioned environments). Thus the change of perception from thermal comfort to discomfort is not due to a change in a single environmental parameter but rather due to a *mix* of environmental variables, and we can see that thermal comfort and discomfort are not different ends of the same scale, and should therefore be treated as different entities. Thermal discomfort is likely similar to thermal comfort in that the way the dependence of indoor comfort is on outdoor climatic conditions, however the precise composition of discomfort variables may change between different climatic regions and populations. Thus while the condition of discomfort being the opposite of comfort is not contested, and it is safe to say that the absence of one usually indicates the presence of the other, both entities are significantly more nuanced than is reflected in their current usage. It is possible that discomfort, like comfort, is not a purely physiological variable and is subject to variation and gradation due to psychological factors. Nevertheless, discomfort is currently not measured in comfort studies with the general focus being on identifying comfort and that too through physical environmental parameters. The work presented in this thesis thus raises the argument that neither comfort nor discomfort are the diagrammatical inverse of the other.

The non-static, non-linear nature of thermal comfort perception is reinforced by the graphical representation of comfort temperatures against outdoor temperatures in the original data of this thesis (and presented in Chapter 7), and has also been confirmed by Humphreys (1978)'s representations of comfort temperatures collated for several climatic zones. The plateauing of acceptable indoor temperatures at high outdoor temperatures is understandable from a physiological point of view: there is a ceiling to the extreme environmental conditions within which the human body is able to maintain core temperatures essential to survival, and the higher the external temperatures the more difficult it is to achieve and maintain core temperatures. The assessment of the different graphical representations of comfort found that a non-linear, quadratic or logarithmic equation provided a more accurate depiction of the thermal comfort temperatures (with respect to outdoor temperatures), however the range of acceptable temperatures is wide enough, particularly with the acceptability level of 80% of the population falling within the range, that it was found linear equations provided *adequate* predictions of comfort.

In the analysis conducted to identify the environmental parameters of thermal comfort perception an interesting angle of assessment of thermal comfort was brought to light. Steemers and Steane (2004) talk about the concept of comfort being an ‘absence of discomfort’ (pg.6) as there being a deficiency in the traditional definition of comfort, referencing the general absence of pleasure and delight that contrasting temperatures and environmental parameters may induce.

A focus on the additional aspects of comfort (beyond the absence of discomfort) which include pleasure and delight may provide the option of identifying nuances in comfort perception, with the potential of defining adequate comfort and pleasurable or desirable comfort conditions. A step toward this was taken during the data collection part of this study where comfort data was collected on a 5 point Likert scale that identified 3 parts to comfort: comfortably hot, comfortable, and comfortably cool, and also asked participants to identify what they desired in comfort (prefer to be colder/warmer). Although for the purposes of the research presented in this thesis the three comfort perception points were collapsed to indicate comfort, a further study could utilise the data to investigate this.

It is possible that examining differences in comfort or discomfort perception within a regional population, and the moving beyond a purely physical understanding of thermal comfort perception may provide a truer representation of comfort variables for different population groups. This may enable the development of comfort equations that provide accurate predictions for higher percentages than the current standard of 80%.

9.4 Subjective influences on thermal comfort – a cultural variable

While the predictive equations developed from steady state studies enabled a comprehensive investigation of the various environmental parameters and their effect on thermal perception, as well as enabling the use and incorporation of complex arrangements of the variables in the predictive equations, concerns have been raised regarding their applicability, and accuracy in real life scenarios. Thermal chambers are controlled environments, which mean that even if occupants are exposed to the same thermal environmental conditions as in their normal lives, their reactions to that thermal environment will not be subject to the same stresses and decision making schema of real life situations. Thermal studies undertaken in climate controlled chambers are thus more of a study of alliesthesia and the automated perception based on physiological changes to the human body than the perception based on subjective choice influenced by psychological responses. As the predictive equations that were based on the adaptive field study methodology focussed on identifying thermal comfort parameters in real life scenarios, they can be assumed to include the psychological influencing variables of thermal comfort perception.

The discussion provided in Chapter 3 and Chapter 5 established the use of socio-economic position as an appropriate variable with which to ascertain the existence of subjective influence on thermal comfort perception as an individual’s socio-economic position provides or limits access and exposure to different thermal environments.

Variations in thermal comfort due to socio-economic position: The variations in thermal comfort perception due to socio-economic position is due to both the material quality of the

buildings that people occupy which includes the thermal qualities of the building envelope and reflects on the cultural usage of the spaces, as well as access to conditioned and unconditioned indoor spaces. The analysis focused on identifying the differences in comfort temperatures between the populations of low socio-economic status and high socio-economic position.

Variations in comfort perception in conditioned and unconditioned environments: An assessment of the comfort temperatures reported by the different socio-economic population groups in conditioned and unconditioned environments was presented. Through this it was established that there were differences between the mean comfort temperatures of members of the different population groups in unconditioned environments but not in conditioned environments.

Variations due to exposure: The possible influence of exposure to different thermal environments was investigated through isolating the comfort temperatures reported by members of each socio-economic group who spent part of their day (working hours) in a different thermal environment. This showed that people who spend part of their day (approximately 8 hours) in different thermal conditions report comfort at similar temperatures but the mean temperatures at which they report discomfort is different from those that are not exposed to varied thermal environments.

9.4.1 Implications

The implications of these findings looking into the subjective aspects of thermal comfort perception are complex and far-reaching, potentially influencing the way that objective entities are defined in the future being more sensitive to the inclusion of subjective variables.

The study found that while thermal comfort is most certainly a climatically specific entity, it is formed within a particular regional or cultural context and is therefore also culturally defined. This difference in regional variation had been acknowledged in earlier studies however the majority of these studies were predominantly descriptive focussing on either regional differences in comfort practices or building form and lifestyle. The quantifying of variations in comfort temperatures due to differences in regional variations in lifestyle mean that the current practice of assessing and predicting preferred comfortable conditions based on the comfort temperatures for large population groups may need to be reassessed, as this study has shown that more precise predictions can be made using regionally specific data. There may also be an opportunity to look into which aspects of culture: the built environment, lifestyle, or comfort practices have more influence on comfort perception. In fact, given the increasingly homogenous built environment in most of the world it may be feasible to understand how regional variations in thermal comfort perception are effected, and further, the thermal behaviour of these non-indigenous buildings may be modified to reflect the needs of the local populations.

The study involved an assessment of the variations in thermal comfort perception within the population along socio-economic lines where it was found that different population groups find different temperatures comfortable. This showed that the variations in thermal comfort perception within a population are not arbitrary variations but are based on either subjective choice: expectation or prior exposure to an environment, or both.

Prior to this investigation the influence of subjective choice on thermal comfort perception had been acknowledged but was largely based on conjecture (Givoni, 1992; de Dear, 2004;

Humphreys, Rijal and Nicol, 2010; Nicol, Humphreys and Roaf, 2012). The adaptive theory of thermal comfort in particular was sensitive of the influencing variables of status, position, and exposure to different environmental conditions on an individual's comfort temperatures. However little speculation is found in literature pertaining to the variations in comfort perception within a regional population group being defined enough to warrant being considered a separate population group. This research has shown that previous conjecture holds true, and that variations in social status, economic standing, and accesses to different environmental conditions have a tangible and significant influence on thermal comfort perception.

The most significant contribution of this study however is in the identifying and quantifying of the variations in the thermal comfort perception of a regional population along the objective lines of socio-economic position. This has shown that the thermal comfort perception variations in a population are not due to the random arbitrary influences of access or exposure, rather, within a developing world scenario where social and economic inequity exists, the variations in thermal comfort exist along the very lines of status, position, and exposure. This means that predictive equations that have previously been developed for entire (similarly classified) climatic regions can be confidently developed for different population groups in a city. The resulting predictive equations would be more precise and could be directed at designing better environments not just based on the use or type of the building but also the people using it. This is not to say that people of low socio-economic status should be restricted to experiencing warmer environments than the more privileged, but that understanding the thermal requirements of a population group would lead to better design standards for that group.

Ideally, this would also be used to improve industry standards to work towards better design solutions that reflect the needs and perceptions of occupants of unconditioned spaces. At present much of the focus of the building industry has been toward designing for air-conditioned environments, forming an impervious barrier between the indoor and outdoor environments and maintaining the indoor environment within a set *comfort* parameter. The urban spaces that are a product of these design practices are also, often not conducive to adaptive methods of thermal comfort as the urban heat island effect and lack of open spaces etc. aggravate the thermal environment and result in an insensitivity to regional thermal comfort practices. Based on the understanding of the long-term effect of the urban form that people are exposed to on their thermal comfort perception, the urban planning guidelines could also potentially be improved to provide spaces that are more conducive to the adaptive methods to afford a thermally comfortable lifestyle.

This finding also means that the development of comfort preferences could potentially be traced through the available building stock and its thermal properties. It may then be possible to trace backwards and predict the range of indoor temperatures at which the users of a particular type of building stock may find comfort.

Hence we find that currently the thermal guidelines have been developed based on the understanding that users of different spaces have different thermal expectations and hence different thermal preferences, and that the users of the similarly conditioned spaces will have similar expectations of the thermal environment and thus find similar thermal environments comfortable. The quantitative analysis of the data collected showed that this logic holds true with there being a difference in the temperatures at which occupants of both conditioned and

unconditioned spaces perceive comfort, however, within each environment, the over-arching parameter that defines the variation in thermal preference is their socio-economic position. But within each of socio-economic class, variations in thermal comfort preference, or more precisely, variations in thermal discomfort acceptance exists based on their previous exposure to different thermal environments.

9.4.2 Implications to predictive comfort equations

The purpose of the predictive comfort equation has been to provide a framework of the thermal environments people require in different types of climatic conditions, and that aid in the development of urban bye-laws, building guidelines, and inform the industry development of building materials. It is thus essentially with the data generated through the predictive equations that appropriate indoor thermal environments can be provided to the users or occupants. The need for predictive equations to be reflective of the specific climatic and cultural properties of the local residents in order to more accurately define the environment needs of the users is therefore undeniable.

This has been discussed in detail in Chapter 7 (Section 7.9) with predictive equations developed for the case study site of Lahore. The Lahore comfort equation is presented in the traditional linear equation format (Equation 7-7, pg.135) as well as the more precise quadratic equation format (Equation 7-8 pg.135).

The inclusion of the effect of socio-economic position on thermal comfort perception in these regional comfort equations is the next logical step in achieving accurate comfort equations.

This thesis thus proposes the development of a methodology for extending regional and culturally specific thermal comfort formula through which accurate predictive comfort ranges for different socio-economic populations can be predicted.

The methodology proposed involves the incorporation of a coefficient in the regional predictive equation for each socio-economic population group that would modify the thermal ranges to reflect their thermal comfort perception. So, for example, the comfort equation for the whole population of Lahore developed in this thesis (Equation 7-7), can be modified as a formula to represent the thermal perception of a specific socio-economic population group, with the incorporation of the coefficient μ as the variable representing the relative change in comfort perception or *coefficient of socio-economic variation* and a as a constant of socio-economic variation. This is represented as Equation 9-1.

$$T_{\text{comf}} = 30.53 + 0.04T_o \quad \text{Equation 7-7}$$

Linear thermal comfort equation the whole of Lahore population, for the outdoor temperature range between 25°C and 45°C. Where T_{comf} is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval.

$$T_{\text{comf-SEP}} = \mu [30.53 + 0.04^a T_o] \quad \text{Equation 9-1}$$

Equation 9-1

Linear thermal comfort equation for a specific socio-economic population group of Lahore, for the outdoor temperature range between 25°C and 45°C. Where $T_{\text{comf SEP}}$ is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval. And μ is the coefficient of socio-economic variation (for the socio-economic group) and a is the constant for socio-economic variation (for the socio-economic group).

The thermal comfort equation for the low socio-economic population group derived through this methodology from the whole of Lahore thermal comfort equation thus becomes Equation 9-2 where the constant of socio-economic variation is 0.55 and the coefficient of socio-economic variation is 0.904.

$$T_{\text{comf-Low SEP}} = \mu [30.53 + 0.04^{0.55\mu} T_o] \quad \text{Equation 9-2}$$

Equation 9-2

Linear thermal comfort equation for low socio-economic populations of Lahore, for the outdoor temperature range between 25°C and 45°C. Where $T_{\text{comf-Low SEP}}$ is the indoor temperature at which comfort is achieved, and T_o is the outdoor temperature recorded at an hourly interval. And μ is the coefficient of socio-economic variation which for low socio-economic position is 0.904 while the constant a for the low socio-economic population is 0.55.

This methodological system means that it may be possible that the coefficient of socio-economic variation developed for a particular cultural region (such as in this case a developing world urban region) may be applied with reasonable accuracy to the comfort equations of other regions (within the same climatic zone and which are similarly classified with respect to their developed world status and/or with similar socio-economic inequity), to provide the comfort temperatures for the same socio-economic population group. Thus, for example, the coefficient of socio-economic variation for the low socio-economic group in the city of Lahore in Pakistan may be applied to the comfort equation of the city of Delhi in India to provide an indication of the thermal expectations of low socio-economic populations of Delhi.

Different coefficients of socio-economic variation could be developed through which the regional comfort formula could be modified to represent the comfort temperatures of a particular socio-economic group. This has been presented in Equation 9-1 for the population of Lahore. It is pertinent to note that the variation in comfort perception of the different socio-economic groups may be so distinct that the regional formula may have to be modified before a coefficient can be applied.

The quadratic form of thermal comfort equations was found to be more representative of the variations in comfort temperature with the change in outdoor reference temperature (discussed in detail in Section 7.9.2.1, pg136). The quadratic comfort formula of a regional population could also be modified to reflect the comfort preferences of a particular socio-economic population group with an appropriate coefficient of socio-economic variation, and this would provide more accurate comfort predictions for the population across a wider range of outdoor temperature than the linear comfort equation. The development of such a formula and its subsequent testing is beyond the scope of this thesis, however the potential for this research and its development has been highlighted through this work.

9.5 Uncertainties, inadequacies, and improvements

While care was taken that the research conducted would be a comprehensive and robust investigation that led to concrete conclusions, the process of research design, data collection and subsequent analysis brought insights regarding particular areas of the work that could have been approached differently. These insights have highlighted the uncertainties in the results and are discussed below along with potential means for the improvement of the work.

The main concern raised through the research design was the potential of an inadequate sample of participants that was not representative of the thermal comfort perceptions of the larger population of the case study region. The only way to minimise the chance of this occurring, was to ensure that the dataset was of a reasonably large size. Care was therefore taken to recruit an adequate number of participants, and to ensure, as far as was possible, to recruit from a diverse cross-section of society. The downside of a very large dataset however is that very small effects or correlations in the data can be flagged up as being significant. The analysis and subsequent inferences were therefore presented with care acknowledging this, and presenting conclusions based on a logical understanding of comfort practices rather than rigidly following numerical analysis.

The second uncertainty is more of an improvement that could have been made with regards to the data collected. The focus of this research was on the perception of thermal comfort of the residents' population groups and did not assess the building physics that created the thermal environments, therefore while the questionnaire collected detailed information about the participants location, thermal practices and thermal environment, no information was collected regarding the building type or thermal envelope at the time of each reading. This lack of data has no bearing on the results achieved from the analysis, however, having access to such information would have enabled an interesting line of investigation leading on from this thesis. We know from this research the variation in thermal comfort perception due to the differences in previous exposure (and) due to the socio-economic position, but with this additional data the comfort perception could be linked with the building envelope and potentially also the urban form.

Nevertheless, the lack of this data regarding the urban building, and the uncertainty relayed above with respect to the dataset size, does not detract from the focus of this investigation nor the comprehensive contribution to thermal comfort scholarship this thesis has made.

9.6 Conclusions

This chapter has provided an end discussion to the analysis, furthering the inferences and interpretation of the results presented in the previous two chapters, and developing a methodological system to further the applicability of predictive thermal comfort equations. As well as moving the results beyond their numerical strengths and providing an assessment with respect to their influence and implications in real life.

The central premise of this thesis has been that the thermal comfort perception of a population is a subjective choice that varies based on their exposure to different thermal environments, and that the social and economic disparity between different population groups that exist in Lahore (as a prototypical developing world city) manifests itself to an unequal exposure to various indoor thermal environments for individuals of different socio-economic backgrounds. The analysis, as discussed in this chapter, has shown that the thermal comfort perception of a regional population does indeed vary along socio-economic lines which indicates that exposure to different thermal environments has a long-lasting influence on comfort perception.

An original contribution to the field of thermal comfort studies has therefore been made through the work presented in this thesis.

This research has shifted the conversation of comfort in indoor thermal environments from the purely technological that dealt with conditioning systems and building physics toward one that revolves around the human factors as focal point, with the field of comfort studies thus being aligned within the social science domain. The quantifying of the subjective aspect of thermal comfort perception undertaken in this thesis has bridged the gap between the two fields, and it is anticipated, that this will enable a more wholesome interaction and collegiate atmosphere in comfort studies.

The work has also raised interesting questions regarding the artificially induced variation in thermal comfort perception due to the HVAC industry influencing urban lifestyles (and possibly through their funding of thermal comfort research), and whether populations could be de-acclimatised to higher (more naturally occurring) temperatures, and if this would be a useful exercise. This research has thus also laid out the case for improvement of policy and design guidelines to reflect real users' expectations of thermal conditions.

The implications of these findings on the development of improved sustainable design guidelines and government policy that is sensitive to the restrictive parameters of urban form and economic position have also been discussed in this chapter. The understanding that a sustainable lifestyle which includes access to the building materials and urban form that would enable it, is dependent on ones' socio-economic position has been brought forward by this research and highlights the need for a holistic approach to the subject and its application in real life scenarios to ensure technological advancements and improvements are practicable and do not result in untenable conditions for those they are meant for.

Most importantly, this thesis has brought about an understanding that the effect of socio-economic position is not limited to an individual or population groups' prospects with regards to the infrastructure and facilities available to them, but also has the potential to change their views and expectations of the physical environment. Such an implication can have profound impact on a person's development, colouring their viewpoints and becoming a restrictive and disabling parameter to social mobility across generations.

The discussion presented in this chapter has brought the analyses to conclusion providing a summary of the main findings of the research undertaken as part of this thesis and elaborating on the potential applications and implications of this work within the field of comfort studies.

Chapter 10

Conclusion: research findings, original contributions, and wider implications

This chapter provides a bird's-eye view of this work, placing the research methodology, findings and their implications in perspective.

The discussion in Section 10.1 highlights the development of the research questions, employed methodology and findings. Significant conclusions and original contribution to scholarship is outlined in Section 10.2, while the wider implications of the work and its potential application in further research is presented in Section 10.3.

10.1 The research, development, methodology, and findings

The research presented in this thesis has been an enquiry in to the field of thermal comfort perception.

The established scholarship in the field of thermal comfort recognised indoor comfort temperatures to be correlated with prevalent outdoor environmental parameters, and as such, thermal comfort has traditionally been defined as a climatically specific entity. Thermal comfort perception has consequently been understood to vary seasonally, and to be different for occupants of different thermal environments (such as artificially conditioned and unconditioned spaces).

Simultaneously, there has been a tacit acknowledgment in the field of comfort studies that the variations in comfort perception within a population group are likely due to the influence of subjective variables such as cultural background, the effect of regional thermal comfort practices, and social status etc. though few, if any, attempts to quantify this have been undertaken.

The research presented in this thesis has attempted to address this void in the scholarship through an evaluation of the extent of influence of subjective variables on thermal comfort perception.

The analysis was conducted in two phases. The first phase situated the investigation within the context of existing scholarship in the field, eventually establishing the footing upon which further analyses were conducted.

In the first instance, original empirical comfort data was used to conduct a quantitative assessment of thermal comfort through which the objective definition of thermal comfort perception was determined. The data showed that the main influencing variable to indoor thermal comfort (as measured through temperature) is outdoor temperature, and as such, the existing mode for the measurement of comfort is valid. This alignment of the findings with existing definitions of comfort established, with high confidence, the validity of this study.

This exercise also enabled the subsequent inquiry to be more focused, and without the confounding effect of the numerous other environmental variables.

The objective of the second part of this phase was to investigate the variation in thermal comfort perception due to subjective variables. This was assessed through a comparison of the temperature ranges at which the residents of a single climatic region having different socio-cultural backgrounds perceive comfort.

The thermal comfort data analysed was the existing (open-source) data from the Pakistan Project of ASHRAE RP-884. This included the thermal comfort data of the residents of several cities within the hot-dry climatic classification. The analysis showed the variation in thermal comfort temperatures between different regional populations resident within the same climatic zone are statistically significant. This led to two conclusions: first, that defining thermal comfort at the climatic level is too coarse a granularity to adequately describe comfort perception for a population; and secondly, that the regional variations in thermal comfort preference may be ascribed to culturally determined subjective variables such as cultural identity.

This investigation thus laid the groundwork for the second phase of the project wherein the influence of subjective variables within a regional population group was determined.

The influence of the subjective variables was undertaken through an assessment of the parameter socio-economic position on thermal comfort perception. The socio-economic position of an individual is a cumulative reference to their income, education, and occupation, and also reflects on their social class and position within their society. It is thus quantifiable despite being considered a primarily subjective variable and was therefore ideal for the purposes of this investigation.

This phase of the project was conducted with original empirical data collected from the city of Lahore Pakistan which is within the hot-dry climatic zone but is independent of the Pakistan Project dataset. The analysis showed that there is a statistically significant variation in thermal comfort ranges between the members of the low and high socio-economic population groups. This variation in discomfort temperatures is inferred to be associated with the expectation of comfort that residents have which is based on their experiences of the thermal environments they typically occupy.

In fact, further analysis revealed that even regular exposure to a different thermal environment, such as during daily working hours, can bring about a lasting change in thermal expectation in members of a particular socio-economic group that would otherwise have similarly aligned thermal comfort perception.

This work has thus established that the experiences of individuals, their exposure to different thermal environments, can have a long-lasting influence on their perception of their environment. It is also inferred that the effect of subjective variables on objectively defined entities may be so significant that their exclusion from the definitions may render any conclusions deficient, and even inaccurate for some purposes.

The research also included an analysis of the use of the thermal comfort equation through which thermal comfort parameters are typically defined and predicted. It was found that the

main correlation between indoor and outdoor temperature as used in traditional comfort equations is true and adequate for purpose. However the prevalent representation of this complex relationship in a simplified linear form is misleading. The empirical analysis undertaken as part of this research indicated that this relationship is better represented through a quadratic form. Furthermore, there are also reasonable grounds to hypothesize that the best fit for comfort data is logarithmic.

A considerable amount of work has thus been undertaken as part of this research to clarify existing scholarship in the field of thermal comfort studies and to further advance the field. Of the numerous findings and outcomes, several have been significant in their potential contribution to the field and beyond. Some of these are mentioned in the following.

10.2 Significant findings and original contributions to scholarship

This thesis built upon existing knowledge of thermal comfort and also yielded several insights to thermal comfort perception. Of these, the main contributions that have made a significant contribution to scholarship in the field of thermal comfort include:

i

Thermal comfort perception is culturally variable.

Thermal comfort has been established as a variable that is influenced and affected by multiple factors including regional variations in lifestyle, clothing, the built environment as well as local comfort practices. Thus, while the different population groups of a particular climatic zone living in different, culturally disparate regions experience similar thermal environments and may perceive thermal comfort in similar ranges of indoor condition, the regional cultural differences in comfort perception between them measures as statistically significant. Thus indicating that different regional populations resident within a single climatic zone can, and should be, identified as having significantly different thermal preferences.

The incorporation of cultural variability of comfort perception in the measurement and prediction of acceptable comfort ranges could potentially achieve a higher acceptability rate within local populations. It would also enable the development of more sensitive and applicable comfort predictors, as well as having the potential to improve thermal sensitivity of the built environment and reduce energy costs.

The implications of establishing thermal comfort as a cultural variable include the need to reassess current climatically specific predictive comfort equations to include regional variations in comfort perception. This also necessitates a more sensitive approach in design and policy development that acknowledges regional socio-cultural practices of thermal adaption and building form. As well as adapting building guidelines to include regionally suitable insulative values of the building envelope, and the design of heating, ventilation, and air conditioning (HVAC) systems.

ii _____

Socio-economic status is a predictor of cultural and subjective aspects of thermal comfort perception.

The thermal comfort perception within a regional population varies between different socio-economic classes, likely based on the cultural variations that exist between them due to access to environments, building materials, and variations in lifestyle etc.

Such variations in thermal comfort perception based on the access and affordability of thermal environments imply that the building guideline and urban planning policies for a region should be accommodating to differences in thermal perception along socio-economic lines. Additionally, a modification of comfort recommendations that are currently specific to type of thermal environment (artificially conditioned or unconditioned) toward centring the occupant's thermal needs may also be beneficial.

iii _____

Thermal comfort perception has strong psychological bearings which significantly alter an individual's physiological response.

The study showed that occupants of artificially conditioned spaces and unconditioned spaces report thermal comfort at temperatures different from each other. Furthermore, the thermal preferences of the occupants is not restricted to the type of thermal environment they are occupying but is also influenced by their previous experience and exposure to different thermal environmental conditions.

The effect of previous exposure is not restricted to immediate prior exposure to different environmental conditions, which is a primarily physiological reaction to change in thermal conditions. Rather, the study established that preferences for different thermal ranges are based on their regular exposure to different thermal environmental conditions such as experiencing different thermal environmental conditions during regular working hours.

The effect of regular exposure to thermal environments upon thermal comfort perception of individuals has therefore been shown to be long-lasting.

The research has thus established that the psychological influence of regular exposure to a thermal environment is greater than the physiological influence of current exposure.

iv _____

A methodological system for adaption of thermal comfort equations with respect to socio-economic position.

The study developed predictive comfort equations along the lines of socio-economic position and proposed a methodological system by which the predictive formulae for a particular regional population could be modified to address variations in thermal perception for different socio-economic strata of society.

This included the introduction of a *coefficient of socio-economic variation* through which the comfort equation of a regional population group can be modified to suit different socio-economic population groups. The use of such a methodological system to modify existing measurement

or assessment criteria in order to accommodate variations due to socio-economic position is a potential extension of this outcome.

10.3 Wider implications

The research presented in this thesis may have potentially far reaching implications beyond the direct application on policy and changes to the comfort studies indicated in Chapter 9. The main implications and applications of this study outside of the field of scholarship include:

i

The granularity at which a study looking at the behaviour of population groups, similar to the research focus in this thesis, may need to be reassessed based on the findings of this research.

The establishing of the influence of subjective parameters on thermal comfort perception as part of this thesis brought to light the practice of assessing behavioural choices and patterns at a regional and even climatic level, thus missing out the many nuances in preferences and behaviour that exist due to regional cultural variations between, and indeed, within, populations.

It is clear that in such studies, the focus has to move from the larger socio-economic or socio-cultural region to the more defined in order to achieve an understanding that involves, at the very least, a gradation that recognises the social and economic inequity within the urban spaces of a city, and through the understanding of which tangible solutions can be sought.

ii

The study has also highlighted the importance of the argument that the subjective assessment of variables is not a mechanical system that is unaffected by other influencing variables. As such the treatment of such parameters as a static entity or that varies along a predictable constant scale may not always be accurate. A case in point has been the treatment of thermal comfort and discomfort discussed in Chapter 9 which though defined by similar objective parameters, are radically different in that they are polar opposites but vary in scale and proportion. The continued treatment of comfort and discomfort as different ends of the same scale has led to imprecise scholarship that is not applicable to technological or policy amendments by dint of inaccurately reflecting subjective human perception.

A more holistic approach to the assessment of subjective entities as well as the influence of subjective choice is required. It is only by understanding how subjective choice works, and the variations within it, can the variables be understood enough to be effectively managed.

iii

Possibly the most significant of the outcomes from this research is the potential change in methodological approach to research looking at subjective entities such as perception. The findings of this study, though focused on thermal comfort perception, imply that we cannot, and should not, simplify complex psycho-physiological interaction to a sum of a few of the influencing parameters. The work undertaken to understand the forces that influence and shape thermal comfort have shown that although thermal comfort is defined through the

objective environmental parameters with reasonable accuracy, by excluding the subjective influences from the models defining it, an incomplete impression of thermal comfort is achieved that excludes the many interactions between the subjective and objective parameters.

In fact, based on the influence of short-term exposure to a different thermal environment on comfort preference, it may be pertinent to say that the subjective aspects of perception that are based on exposure and expectation have considerably more influence than the objective parameters. The inclusion of subjective aspects in the assessing of objective aspects of the physical environment is thus necessary for developing a holistic understanding of the human psyche through providing concrete connections between exposure, expectation, and perception.

These connections have been evidenced through the research presented in this thesis that assessed the effect of socio-economic position on the perception of the built environment. When interpolated with existing studies that have investigated the correlations between socio-economic position and attainment, health, the availability of and access to infrastructure etc., the effect of socio-economic position is understood to be more extensive than merely influencing the perception of the environment, and is seen to have the potential to change people in a psychological as well as physiological manner.

It is anticipated that the knowledge of the long-lasting and profound influence an individual's socio-economic position has through the built and social environment will provide the basis toward development of policy that is more sensitive to the particular circumstances of the user and formed in a way so as to be more applicable.

10.4 Concluding comments

This thesis presented, as its first sentence, a statement regarding the quantifying of feelings or emotions. This statement reflects the foundational query of this thesis.

‘You can’t express a feeling in an equation’ –Dr. Lexi Earl -(2018)

This statement, though an obvious paradox, is referring to the common practice of assessing subjective entities (emotions and/or feelings) through objective parameters. The quality of quantitate measures being determinate is convenient but tends to dominate the narrative and to mask or overshadow the subjective aspects in assessments and definitions of subjective entities. It is for this reason, the research questions and the research objectives of this thesis have been directed towards understanding the extents to which the practice of measuring subjective entities such as feeling, emotion, or perception, through objective parameters is accurate and appropriate.

The research undertaken in this thesis sought to further the conversation regarding the measurement and assessment of thermal comfort data, particularly so as to highlight the influence of subjective parameters on the perception of the thermal environment.

The research focused on the subjective influence of socio-economic position of an individual or population group on thermal comfort perception, and it is through this that thermal comfort has been shown to vary within a population due to differences in exposure to

different thermal environments. – This research has therefore irrevocably defined thermal comfort perception as a climatical and cultural variable.

The work presented in this thesis has shown that the simplification of a complex psycho-physiological phenomenon such as thermal comfort into a numerical equation is possible, but that the study and use of the numerical formulae cannot be separated from the theory that defines it. In the case of thermal comfort perception, such an equation would have to be in constant revision mirroring the dynamic nature of thermal comfort perception as a non-static entity that is influenced by objective parameters of climate, as well as the numerous fluid parameters that form culture, rather than the current popular model that is climatically specific but remains uniform across different social and cultural populations.

Though the focus of this research has been on thermal comfort perception, the importance of this work with regards to increasing our understanding of the interactions between the subjective and objective aspects of human perception is significant and has the potential to inform research, scholarship, and policy in many fields.

THE END.

Appendices

Appendix 2.1 – Chronological development of indices related to thermal comfort (Epstein and Moran, 2006; Taleghani *et al.*, 2013; Schweiker and Wagner, 2017)

Year	Index Acronym	Index	Author(s)
1897		Theory of heat transfer	Hill L, Barnard H, Sequiera JH. (1897) The effect of venous pressure on the pulse. The Journal of Physiology 1897; 17(21); pp147-159
1905	T _w	Wet-bulb temperature	Haldane Js (1905) The influence of high air temperature Journal of Hygiene 5 pp494-513
1916		Katathermometer	Hill L, Griffith OW, Flack M. (1916). The measurement of the rate of heat-loss at body temperature by convection, radiation, and evaporation Philosophical Transactions Research Society London B 1916; 207; pp183-220.
1923	ET	Effective temperature	Houghton FC, Yaglou CP. Determining equal comfort lines. American Society of Heating & Ventilation Engineers 1923: pp165-729 1923: pp165-176
1929	T _{eq}	Equivalent temperature	Dufton AF. (1929). The eupatheostat. Scientific Instruments 1929 pp249-251.
1932	CET	Corrected effective temperature	Vernon HM, Warner CG (1932). The influence of the humidity of the air on capacity for work at high temperature. Hygiene 1932;32(3) pp431-463.
1937	T _{op}	Operative temperature	Winslow CA, Herrington LP, Gagge AP (1937). Physiological reaction of the human body to varying environmental temperature. American Journal of Physiology 1937;120. Pp1-22.
1945	TAR	Thermal acceptance ratio	Robbinson S, Turrel ES, Gerking SD. Physiologically equivalent conditions of air temperature and humidity. American Journal of Physiology 1945;143. Pp21-32.
1945	E _p	Index of physiological effect	Robbinson S, Turrel ES, Gerking SD. Physiologically equivalent conditions of air temperature and humidity. American Journal of Physiology 1945;143. Pp21-32.
1946	CET	Corrected effective temperature	Bedford t (1946). Environmental warmth and its measurement. Med Res Council Memo 17. HMSO, London.
1947	P4SR	Predicted 4-h sweat rate	McArdle, B. et al (1947) The prediction of the physiological effects of warm and hot environments In Medical Research Council 1947, London RNP Report 47/391: London
1948	RT	Resultant Temperature	Missenard A. (1948) A thermique des ambiances: equivalences de passage, equivalences de sejours. Chaleur Industry 1948;276: pp159-172 in French
1950	I	Craig index	Craig (1950). Relation between heat balance and physiological strain in walking men clad in

			ventilated impermeable envelope. Fed Prod 9, 26.
1955	HIS	Heat stress index	Belding HS, Hatch TF.(1955). Index for evaluating heat stress in terms of resulting physiological strain. Heating, piping and air conditioning 1955:129-3627 1955:129-36.
1957	WBGT	Wet bulb globe temperature	Yaglou CP, Minard D.(1957) Control of heat casualties at military training centres. AMA Archives of Industrial Health 1957; 16:302-16
1957	WD	Oxford index	Lind AR, Hallon RF (1957) Assessment of physiologic severity of hot climate. aPplied Physilogy 1957;11:35-40.
1957	DI	Discomfort index	Thom EC (1959) The discomfort index. Weatherwise 1959;12(2);57-61.
1958	TSI	Thermal strain index	Lee, HDK., Proprioclimates of man and domestic animals, in Climatology, Arid zone research. 1958: UNESCO, Paris 102-125
1960	CumDI	Cumulative discomfort index	Tennenbaum, J. et al (1961) The physiological significance of the cumulative discomfort index (CumDI). Harefuah 1961; 60:315-9
1960	I _s	Index of physiological strain	Hall JFK, Polte W (1960) Physiological index of strain and body heat storage in hyperthermia. J Appl Physiol 15, 1027–30
1962	ITS	Index of thermal stress	Givoni, B., The influence of work and environmental conditions on the physiological responses and thermal equilibrium of man. In: UNESCO symposium on environmental physiology and psychology in arid coditions. 1962 Lucknow. 199-204
1966	HIS	Heat strain index (corrected)	McKarns JS, Brief RS., Nomographs five refined estimate of heat stress index. Heating, Piping, and Air Conditioning 1966: 113-6
1966	HR	Prediction of heart rate	Fuller FH, Brouha L., New engineering methods for evaluating the job environment. ASHRAE 1966; 8:39-52
1967	ERF	Effective radiant field	Gagge A, Stolwijk A, Nishi Y (1971) An effective temperature scale based on a simple model of human physiological regulatory response. ASHRAE Trans 77, 247–57
1970	PMV	Predicted mean vote	Fanger P. Thermal comfort: analysis and applications in environmental engineering. Copenhagen Danish Technical Press 1970
1970	TLV	Threshold limit value	Fanger PO (1970) Thermal comfort, Danish Technical Press, Copenhgen.
1970		Prescriptive zone	Lind AR (1970) Effect of individual variation on upper limit of prespective zone of climates. J Appl Physiol 28, 57–62.
1971	ET*	New effective temperature	Gagge AP, Stolwkl JAJ, Nishi Y. Effective temperature scale, based on a simple model of human physiological regulatory response. ASHRAE 1971; 13:1
1971	WGT	Wet globe temperature (°)	Botsford JH. A wet glob thermometer for environmental hea measurement. American Industrial Hygiene Association Journal 1971; 31(1):1-10.
1971		Humid operative temperature	Nishi Y., Gagge AP. Humid operative temperature. Physiology – Paris 1971; 63:365-8
1972		Predicted body core	Givoni B, Goldman RF. Predicting rectal

		temperature	temperature response to work, environment and clothing. <i>Applied Physiology</i> 1972; 32:812-22
1972		Skin wettedness	Kerslake DM. The stress of hot environment. Cambridge: Cambridge University Press; 1972
1973	SET	Standard effective temperature	Gonzalez RR, Nishi Y, Gagge AP. Experimental evaluation of standard effective temperature a new biometeorological index of man's thermal discomfort. <i>International Journal of Biometeorology</i> 1974; 18(1):1-15
1973		Predicted heart rate	Givoni G, Goldman RF. Predicting heart rate response to work, environment and clothing. <i>Applied Physiology</i> 1973; 34:201-4
1978		Skin wettedness	Gonzalez RR, Berglund LG, Gagge AP (1978) Indices of thermoregulatory strain for moderate exercise in the heat. <i>J Appl Physiol</i> 44, 889–99.
1979	FITS	Fighter index of thermal stress	Nunneley SH, Stribley F (1979) Fighter index of thermal stress (FITS): guidance for hot-weather aircraft operations. <i>Aviat Space Environ Med</i> 50, 639–42.
1981	EHSI	Effective heat strain index	Kamon E, Ryan C (1981) Effective heat strain index using pocket computer. <i>Am Ind Hyg Assoc J</i> 42, 611–5.
1982	m _{sw}	Predicted sweat loss	Shapiro Y, Pandolf KB, Goldman RF (1982) Predicting sweat loss response to exercise, environment and clothing. <i>Eur J Appl Physiol Occup Physiol</i> 48, 83–96.
1985	SW _{req}	Required sweating	ISO 7730 (1984) Moderate thermal environments— determination of the PMV and PPD indices and specification of the conditions for thermal comfort. ISO, Geneva.
1986	PMV*	Predicted mean vote (modified)	Gagge AP, Fobelets AP, Berglund LG. A standard predictive index of human response to the thermal environment. <i>ASHRAE Transaction</i> 1986; 92:709-31
1996	CHSI	Cumulative heat strain index	Frank A, Moran D, Epstein Y, Belokopytov M, Shapiro Y (1996) The estimation of heat tolerance by a new cumulative heat strain index. In: <i>Environmental Ergonomics: Recent progress and new frontiers</i> , Shapiro Y, Moran D, Epstein Y (Eds.), 194–7, Freund Pub House, London.
1998	PSI	Physiological strain index	Moran DS, Shitzer A, Pandolf KB (1998) A physiological strain index to evaluate heat stress. <i>Am J Physiol</i> 275, R129–34.
1999	MDI	Modified discomfort index	Morans DS, et al. A modified discomfort index (MDI) as an alternative to the wet bulb globe temperature (WBGT). In: Hodgdon JA, Heany JH, M.J. B., editors. <i>Environmental Ergonomics VIII</i> . San Diego; 1998. pp77-80
1999	PET	Physiological equivalent temperature	Hoppe P. the physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment. <i>International Journal of Biometeorology</i> 1999; 43(2):71-5
2001	ESI	Environmental stress index	Moran DS, et al. An environmental stress index (ESI) as a substitute for the wet bulb globe temperature (WBGT). <i>Journal of Thermal</i>

			Biology 2001; 26(4-5):427-31
2001	UTCI	Universal thermal climate index	Jendritzky, G. Maarouf, A and Henning, S., Looking for a universal thermal climate index UTCI for outdoor applications. In: Windsor conference on thermal standards. 2001, Network for Comfort and Energy Use in Buildings: Windsor, UK.
2002	ePMV	PMV extended with expectancy factor	Fanger, P. O., & Toftum, J. (2002). Extension of the PMV model to non-air-conditioned buildings in warm climates. Energy and Buildings, 34, 533–536.
2005	WBDT	Wet bulb dry temperature	Wallace RF, et al. The effects of continuous hot weather training on risk of exertional heat illness. Medicine & Science in Sports & Exercise 2005; 37(1):84-90
2005	RHDT	Relative humidity dry temperature	Wallace RF, Kriebel D, Punnett L, Wegman DH, Wenger CB, Gardner JW, Gonzales RR (2005) The effects of continuous hot weather training on risk of exertional heat illness. Medicine and Science Sports Exercise 37, 84–90.
2009	aPMV	PMV extended with adaptive factor	Yao, R., Li, B., & Liu, J. (2009). A theoretical adaptive model of thermal comfort: Adaptive predicted mean vote (aPMV). Building and Environment, 44, 2089–2096.
2013	PMV _{adj}	PMV adjusted for cooling effect of elevated air speed using standard effective temperature (SET)	ASHRAE. (2013). Standard 55-2013. Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineering, Atlanta, USA.
2015	ATHB _{pmv}	Adaptive thermal heat balance indices applied to PMV	Schweiker, M., & Wagner, A. (2015). A framework for an adaptive thermal heat balance model (ATHB). Building and Environment, 94(P1), 252–262.
2015	apts	Predicted thermal sensation calculated based on the SET model extended by adaptive factor	Gao, J., Wang, Y., & Wargocki, P. (2015). Comparative analysis of modified PMV models and SET models to predict human thermal sensation in naturally ventilated buildings. Building and Environment, 92, 200–208.
2015	ept	Predicted thermal sensation calculated based on the SET model extended by expectancy factor	Gao, J., Wang, Y., & Wargocki, P. (2015). Comparative analysis of modified PMV models and SET models to predict human thermal sensation in naturally ventilated buildings. Building and Environment, 92, 200–208.
2017	ATHB _{pts}	Adaptive thermal heat balance indices applied to SET model	Schweiker, M., & Wagner, A. (2017). Influences on the predictive performance of thermal sensation indices, Building Research & Information, 45:7, 745-758.

Appendix 5.2 – Questionnaire Part 2

Date: _____ تاریخ _____		Observation Day _____		Thermal comfort in hot climates														
				1	2	3	4	دن نمبر										
I am wearing (the wet / muslin / house net) _____		کپڑے (نموان / مٹیل / ہاؤس نیٹ)																
changes in clothes _____		کپڑے تبدیل کرنے																
Other relevant miscellaneous information _____		کوئی اور ضروری انفارمیشن																
Suggested Reading Time		7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	SAMPLE
Actual Reading Time	ریڈنگ کا ٹائم																	7:55 PM
Wind Speed Reading (max)	بوا کی رفتار																	5.6
In Last 15 Minutes I have been _____		بچھنے پندرہ منٹ میں																
Carrying the logger	لوگر سرے پاس تھا																	✓
Indoors	گھر کے اندر تھا																	
Outdoors	باہر کھڑی جگہ میں تھا																	✓
Sitting / Resting	بیٹھا تھا یا سو رہا تھا																	
Standing	کھڑا ہوا تھا																	✓
Walking	چل رہا تھا																	
Exercising / Running	ورزش کر رہا تھا																	✓
Currently I am _____		اب اس وقت میں																
Indoors	گھر کے اندر ہوں																	✓
Outdoors	باہر کھڑی جگہ پر ہوں																	
In a car	گڈی میں ہوں																	
The space I am in has _____		جس جگہ میں ہوں وہاں																
A/C On	ایئر کنڈیشنر چل رہا ہے																	✓
Ceiling Fan On	چھت کا پنکھا چل رہا ہے																	✓
Wall/Axial Fan On	چھت کے پنکھے چل رہا ہے																	✓
Windows Open	کھڑکیاں کھلی ہوئی ہیں																	
I am currently feeling _____		میں اس وقت محسوس کر رہا ہوں																
Much too warm	بہت زیادہ گرم و جیس																	
Too warm	بہت زیادہ گرم و جیس																	
Comfortable warm	قابل برداشت گرم و جیس																	
Comfortable	مناسب																	✓
Comfortable cool	آرام دہ ٹھنڈا																	
Too cool	بہت زیادہ ٹھنڈا																	
Much too cool	بہت زیادہ ٹھنڈا																	
I would like to be _____		میں چاہتا ہوں کہ ہو جاؤں																
A lot warmer	بہت زیادہ گرم																	
A bit warmer	تھوڑا سا گرم																	
The same	یہی مناسب ہے																	✓
A bit cooler	تھوڑا سا سرد																	
A lot cooler	بہت زیادہ سرد																	
The wind speed is _____		اس وقت بوا کی رفتار																
Too slow	بہت سست ہے																	✓
Comfortable	مناسب ہے																	
Too fast	بہت تیز ہے																	
Causing quite a breeze	کام میں تنگی کا باعث ہے																	✓

Appendix 5.3– Questionnaire Part 1

**MACKINTOSH SCHOOL
OF ARCHITECTURE
THE GLASGOW
SCHOOL OF ART**

PhD Research Project:
Thermal comfort in hot climates

Gender ☐ Male ☐ Female

Age ☐ 18-24 ☐ 25-34 ☐ 35-44
☐ 45-54 ☐ 55-64 ☐ 65+ _____

Occupation _____

Education ☐ Post-graduate
☐ Graduate
☐ Intermediate
☐ Matric
☐ School class 5-9
☐ School class 1-5
☐ No schooling

Family ☐ Nuclear family ☐ Extended family / joint family
Number of Kitchens _____

Number of dependents _____ Number of wage-earners _____
Number of dependents _____

Income	Household
☐ >50,000 ☐ 30,001 – 50,000 ☐ 15,001 – 30,000 ☐ 7001 – 15,000 ☐ 3001 – 7000 ☐ < 3000	☐ > 100,000 ☐ 50,000 – 100,000 ☐ 30,001 – 50,000 ☐ 15,001 – 30,000 ☐ 7001 – 15,000 ☐ 3001 – 7000 ☐ < 3000

Activity level:

Work	Home	Exercise
Office/Sitting	Sitting/Computer	Rarely
Walk a lot	Move about/busy	Light ex. Long walks
Active most of day	Heavy housework gardening	2-3 times a week
Labour intensive	v.active Rigorous activities	Heavy, intense daily

☐ Sedentary ☐ Light activity
☐ Moderately active ☐ Very active

Current climatic perceptions

☐ موجودہ موسم گرم ہے	☐ جمن میں آپ خود کو ٹھنڈا کرنا چاہتے ہیں
☐ موجودہ موسم ٹھنڈا ہے	☐ جمن میں آپ خود کو گرم کرنا چاہتے ہیں
☐ موجودہ موسم میٹھا ہے	☐ جمن میں عام کیڑوں میں آپ آرام دہ رہتے ہیں

Appendix 5.4– Consent Form

MACKINTOSH SCHOOL OF ARCHITECTURE THE GLASGOW SCHOOL OF ART	PhD Research Project: Thermal comfort in hot climates
Participant Consent Form: Please circle your response to each statement and sign below.	
براءہ مہربانی مندرجہ ذیل سوالات کے جواب کو دائرہ لگا کر منتخب کریں	
- I have read and understood the Information Sheet about the research project and have had the opportunity to ask questions about it. میں نے ریسرچ پراجیکٹ کے بارے میں معلوماتی کاغذ پڑھا لیا ہے، اسے اچھی طرح سمجھ لیا ہے اور اس بارے میں اپنے سوالات کے جوابات حاصل کر لیے ہیں	✓ YES جی ہاں ✗ NO نہیں
- I agree to being a participant for the purposes of the above research project میں اس ریسرچ پراجیکٹ کے مقاصد کی تکمیل کے لیے اس میں حصہ لینے پر راضی ہوں	✓ YES جی ہاں ✗ NO نہیں
- I understand that my participation is voluntary and that I am free to withdraw at any time and without giving a reason. If I withdraw from participation in this project, any information I have given will either be withdrawn from the research or will only be used with my permission.. میں نے یہ جان لیا ہے اس ریسرچ پراجیکٹ میں میری شمولیت رضاکارانہ ہے اور یہ کہ میں کسی بھی وقت بغیر کوئی وجہ بتائے اس شمولیت کو ختم کر سکتا ہوں اگر میں اس پراجیکٹ میں اپنی شمولیت کو ختم کر دوں تو اس صورت میں میری دی گئی معلومات میری اجازت کے بغیر استعمال کیا جائے گا اور اگر میں چاہوں تو ان معلومات کو پراجیکٹ سے خارج کر دیا جائے گا	✓ YES جی ہاں ✗ NO نہیں
- I agree that the data I provide may be used by authorised researchers and other interested parties for the purposes described in the information sheet. میں یہ اجازت دیتا ہوں جو بھی معلومات میں دے رہا ہوں وہ اس پراجیکٹ کے یا دیگر تحقیق کنندگان اس پراجیکٹ کے مقاصد کی مطابقت میں استعمال کر سکتے ہیں	✓ YES جی ہاں ✗ NO نہیں
- I understand the data I provide during the course of this project will remain anonymous, and I will be identifiable by a pseudonym. میں نے یہ جان لیا ہے کہ اس پراجیکٹ کے ریکارڈ میں میری شناخت پراجیکٹ کی اصل ریسرچر تک محدود رہے گی اور اس پراجیکٹ کی کوئی بھی معلومات اس صورت میں شائع نہیں کی جائے گی کہ ان سے میری شناخت ممکن ہو	✓ YES جی ہاں ✗ NO نہیں
- Do you wish to add any other instruction or restriction in relation to your contribution? If yes, please provide details below. کیا آپ اپنی فراہم کردہ معلومات کے حوالے سے کوئی ہدایت دینا چاہتے ہیں یا ان کے استعمال پر کسی قسم کی پابندی لگنا چاہتے ہیں؟ اگر اس سوال کا جواب ہاں میں ہے برہم مہربانی ذیل میں انہیں درج کر دیجئے	✓ YES جی ہاں ✗ NO نہیں
تاریخ _____ Date _____	
Signed _____ Name (please print) _____ Address _____ City _____ Telephone No. _____ Mobile No. _____ Email address _____	
MS 201406 consent form v03	

Appendix 7.5 - Pearsons Point Biserial Correlation for the physical variables of thermal comfort in conditioned and unconditioned spaces

		Correlations		
		Binary comfort	Binary hot comfort	Binary cold comfort
Outdoor drybulb T	Pearson Correlation	-.081**	-.066**	-.054**
	Sig. (2-tailed)	.000	.001	.007
	N	2707	2555	2513
Outdoor RH %	Pearson Correlation	.035	.009	.048*
	Sig. (2-tailed)	.071	.642	.017
	N	2707	2555	2513
Temp.oC	Pearson Correlation	-.023	-.196**	.192**
	Sig. (2-tailed)	.236	.000	.000
	N	2707	2555	2513
% Relative humidity	Pearson Correlation	.028	-.041*	.100**
	Sig. (2-tailed)	.140	.036	.000
	N	2707	2555	2513
Wind speed m/s	Pearson Correlation	-.032	-.001	-.051*
	Sig. (2-tailed)	.094	.977	.011
	N	2703	2551	2509

**, Correlation is significant at the 0.01 level (2-tailed).

*, Correlation is significant at the 0.05 level (2-tailed).

Appendix 7.6 - Pearson Point Biserial Correlation for physical variables of thermal comfort in unconditioned indoor spaces

		Correlations		
		Binary comfort	Binary hot comfort	Binary cold comfort
Outdoor drybulb T	Pearson Correlation	-.127**	-.135**	.020
	Sig. (2-tailed)	.000	.000	.485
	N	1340	1323	1207
Outdoor RH %	Pearson Correlation	.059*	.059*	.002
	Sig. (2-tailed)	.031	.031	.944
	N	1340	1323	1207
Temp.oC	Pearson Correlation	-.113**	-.140**	.080**
	Sig. (2-tailed)	.000	.000	.006
	N	1340	1323	1207
% Relative humidity	Pearson Correlation	.042	.029	.063*
	Sig. (2-tailed)	.126	.288	.030
	N	1340	1323	1207
Wind speed m/s	Pearson Correlation	.014	.008	.031
	Sig. (2-tailed)	.596	.762	.276
	N	1338	1321	1205

**, Correlation is significant at the 0.01 level (2-tailed).

*, Correlation is significant at the 0.05 level (2-tailed).

Appendix 7.7 – Pearson's Point Biserial Correlation for physical environmental variables of thermal comfort in conditioned indoor spaces

		Correlations		
		Binary comfort	Binary hot comfort	Binary cold comfort
Outdoor drybulb T	Pearson Correlation	-.022	.010	-.026
	Sig. (2-tailed)	.438	.748	.374
	N	1201	1072	1191
Outdoor RH %	Pearson Correlation	.004	-.014	.008
	Sig. (2-tailed)	.876	.637	.775
	N	1201	1072	1191

Temp.oC	Pearson Correlation	.116**	-.013	.125**
	Sig. (2-tailed)	.000	.677	.000
	N	1201	1072	1191
% Relative humidity	Pearson Correlation	.013	-.054	.027
	Sig. (2-tailed)	.658	.075	.349
	N	1201	1072	1191
Wind speed m/s	Pearson Correlation	-.098**	.006	-.103**
	Sig. (2-tailed)	.001	.852	.000
	N	1199	1070	1189

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix 7.8 - Independent Samples T-test for physical environmental variables of thermal comfort in unconditioned spaces with grouping variable Binary Comfort (comfort/general discomfort (due to hot and cold conditions))

Group Statistics					
	Binary comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1193	30.3493	4.12256	.11936
	Discomfort	147	32.0272	3.86093	.31844
Outdoor RH %	Comfort	1193	64.78	18.364	.532
	Discomfort	147	61.33	17.261	1.424
Temp.oC	Comfort	1193	31.77	2.240	.065
	Discomfort	147	32.60	2.637	.217
% Relative humidity	Comfort	1193	59.428	12.1642	.3522
	Discomfort	147	57.789	12.9505	1.0681
Wind speed m/s	Comfort	1191	1.234	1.2661	.0367
	Discomfort	147	1.176	1.1754	.0969

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Outdoor drybulb T	Equal variances assumed	.502	.479	-4.688	1338	.000	-1.67792	.35794	-2.38011	-.97574
	Equal variances not assumed			-4.934	189.445	.000	-1.67792	.34008	-2.34875	-1.00710
Outdoor RH %	Equal variances assumed	.937	.333	2.164	1338	.031	3.452	1.595	.323	6.581
	Equal variances not assumed			2.272	189.118	.024	3.452	1.520	.454	6.450
Temp.oC	Equal variances assumed	2.797	.095	-4.163	1338	.000	-.832	.200	-1.224	-.440
	Equal variances not assumed			-3.666	172.945	.000	-.832	.227	-1.280	-.384
% Relative humidity	Equal variances assumed	.011	.916	1.530	1338	.126	1.6388	1.0710	-.4623	3.7399
	Equal variances not assumed			1.457	179.209	.147	1.6388	1.1247	-.5806	3.8582
Wind speed m/s	Equal variances assumed	.478	.489	.530	1336	.596	.0582	.1098	-.1573	.2737
	Equal variances not assumed			.562	190.332	.575	.0582	.1037	-.1462	.2627

Appendix 7.9 - Independent Samples T-test for physical environmental variables of thermal comfort in unconditioned indoor spaces with grouping variable Binary Hot Comfort (comfort/discomfort due to hot conditions)

Group Statistics

	Binary hot comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1193	30.3493	4.12256	.11936
	Hot discomfort	130	32.2038	3.50785	.30766
Outdoor RH %	Comfort	1193	64.78	18.364	.532
	Hot discomfort	130	61.15	16.413	1.440
Temp.oC	Comfort	1193	31.77	2.240	.065
	Hot discomfort	130	32.85	2.470	.217
% Relative humidity	Comfort	1193	59.428	12.1642	.3522
	Hot discomfort	130	58.235	12.0388	1.0559
Wind speed m/s	Comfort	1191	1.234	1.2661	.0367
	Hot discomfort	130	1.199	1.1954	.1048

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Outdoor drybulb T	Equal variances assumed	3.583	.059	-4.938	1321	.000	-1.85456	.37560	-2.59139	-1.11773
	Equal variances not assumed			-5.620	170.335	.000	-1.85456	.33000	-2.50598	-1.20314
Outdoor RH %	Equal variances assumed	2.156	.142	2.158	1321	.031	3.625	1.679	.330	6.919
	Equal variances not assumed			2.362	166.260	.019	3.625	1.535	.595	6.655
Temp.oC	Equal variances assumed	.825	.364	-5.152	1321	.000	-1.077	.209	-1.487	-.667
	Equal variances not assumed			-4.763	153.026	.000	-1.077	.226	-1.524	-.630
% Relative humidity	Equal variances assumed	.634	.426	1.063	1321	.288	1.1933	1.1224	-1.0085	3.3951
	Equal variances not assumed			1.072	159.086	.285	1.1933	1.1131	-1.0050	3.3916
Wind speed m/s	Equal variances assumed	.551	.458	.302	1319	.762	.0352	.1163	-.1930	.2634
	Equal variances not assumed			.317	162.262	.752	.0352	.1111	-.1842	.2545

Appendix 7.10 - Independent Samples T-test for physical environmental variables of thermal comfort in unconditioned indoor spaces with grouping variable Binary Cold Comfort (comfort/discomfort due to cold conditions)

Group Statistics

	Binary cold comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1193	30.3493	4.12256	.11936
	Cold discomfort	14	29.5714	5.86337	1.56705
Outdoor RH %	Comfort	1193	64.78	18.364	.532
	Cold discomfort	14	64.43	25.203	6.736
Temp.oC	Comfort	1193	31.77	2.240	.065
	Cold discomfort	14	30.09	3.139	.839
% Relative humidity	Comfort	1193	59.428	12.1642	.3522
	Cold discomfort	14	52.243	19.9814	5.3403
Wind speed m/s	Comfort	1191	1.234	1.2661	.0367
	Cold discomfort	14	.864	1.0419	.2785

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Outdoor drybulb T	Equal variances assumed	3.270	.071	.698	1205	.485	.77786	1.11434	-1.40841	2.96413
	Equal variances not assumed			.495	13.151	.629	.77786	1.57159	-2.61339	4.16911
Outdoor RH %	Equal variances assumed	2.543	.111	.071	1205	.944	.350	4.960	-9.382	10.082
	Equal variances not assumed			.052	13.162	.959	.350	6.757	-14.229	14.929
Temp.oC	Equal variances assumed	1.765	.184	2.773	1205	.006	1.678	.605	.491	2.865
	Equal variances not assumed			1.994	13.156	.067	1.678	.841	-.137	3.493
% Relative humidity	Equal variances assumed	5.871	.016	2.177	1205	.030	7.1851	3.2999	.7109	13.6592
	Equal variances not assumed			1.343	13.113	.202	7.1851	5.3519	-4.3668	18.7369
Wind speed m/s	Equal variances assumed	.016	.901	1.089	1203	.276	.3701	.3398	-.2965	1.0367
	Equal variances not assumed			1.318	13.455	.210	.3701	.2809	-.2346	.9748

Appendix 7.11 - Independent Samples T-test for physical environmental variables of thermal comfort in conditioned indoor spaces with grouping variable Binary Comfort (comfort/discomfort due to both hot and cold conditions)

Group Statistics					
	Binary comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1062	32.0163	4.56831	.14018
	Discomfort	139	32.3453	5.65104	.47931
Outdoor RH %	Comfort	1062	56.60	21.395	.657
	Discomfort	139	56.29	22.268	1.889
Temp.oC	Comfort	1062	28.44	3.009	.092
	Discomfort	139	27.29	4.037	.342
% Relative humidity	Comfort	1062	51.155	11.4520	.3514
	Discomfort	139	50.701	10.6334	.9019
Wind speed m/s	Comfort	1060	.922	1.3779	.0423
	Discomfort	139	1.375	2.1219	.1800

		Levene's Test for Equality of Variances		Independent Samples Test						
		F	Sig.	t-test for Equality of Means					95% Confidence Interval of the Difference	
				t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Outdoor drybulb T	Equal variances assumed	15.173	.000	-.775	1199	.438	-.32903	.42444	-1.16177	.50370
	Equal variances not assumed			-.659	162.463	.511	-.32903	.49939	-1.31517	.65711
Outdoor RH %	Equal variances assumed	1.280	.258	.155	1199	.876	.301	1.939	-3.503	4.106
	Equal variances not assumed			.151	173.036	.880	.301	2.000	-3.645	4.248
Temp.oC	Equal variances assumed	24.183	.000	4.040	1199	.000	1.146	.284	.589	1.702
	Equal variances not assumed			3.231	158.695	.001	1.146	.355	.445	1.846

% Relative humidity	Equal variances assumed	1.324	.250	.443	1199	.658	.4539	1.0247	-1.5566	2.4644
	Equal variances not assumed			.469	182.533	.640	.4539	.9680	-1.4559	2.3637
Wind speed m/s	Equal variances assumed	16.992	.000	-3.391	1197	.001	-.4537	.1338	-.7161	-.1912
	Equal variances not assumed			-2.454	153.622	.015	-.4537	.1849	-.8189	-.0884

Appendix 7.12 - Independent Samples T-test for physical environmental variables of thermal comfort in conditioned indoor spaces with grouping variable Binary Hot Comfort (comfort/discomfort due to hot conditions)

Group Statistics					
	Binary hot comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1062	32.0163	4.56831	.14018
	Hot discomfort	10	31.5500	3.73013	1.17957
Outdoor RH %	Comfort	1062	56.60	21.395	.657
	Hot discomfort	10	59.80	17.015	5.381
Temp.oC	Comfort	1062	28.44	3.009	.092
	Hot discomfort	10	28.84	4.647	1.469
% Relative humidity	Comfort	1062	51.155	11.4520	.3514
	Hot discomfort	10	57.630	10.8684	3.4369
Wind speed m/s	Comfort	1060	.922	1.3779	.0423
	Hot discomfort	10	.840	.3864	.1222

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Outdoor drybulb T	Equal variances assumed	1.681	.195	.322	1070	.748	.46629	1.44938	-2.37765	3.31023
	Equal variances not assumed			.393	9.256	.704	.46629	1.18787	-2.20958	3.14216
Outdoor RH %	Equal variances assumed	1.619	.204	-.472	1070	.637	-3.204	6.787	-16.521	10.114
	Equal variances not assumed			-.591	9.270	.569	-3.204	5.421	-15.411	9.004
Temp.oC	Equal variances assumed	4.287	.039	-.417	1070	.677	-.401	.962	-2.287	1.486
	Equal variances not assumed			-.272	9.071	.792	-.401	1.472	-3.727	2.926
% Relative humidity	Equal variances assumed	.314	.575	-1.780	1070	.075	-6.4754	3.6369	-13.6117	.6609
	Equal variances not assumed			-1.874	9.189	.093	-6.4754	3.4548	-14.2663	1.3155
Wind speed m/s	Equal variances assumed	1.327	.250	.187	1068	.852	.0816	.4361	-.7741	.9372
	Equal variances not assumed			.631	11.287	.541	.0816	.1293	-.2022	.3653

Appendix 7.13 - Independent Samples T-test for physical environmental variables of thermal comfort in conditioned indoor spaces with grouping variable Binary Cold Comfort (comfort/discomfort due to cold conditions)

Group Statistics

	Binary cold comfort	N	Mean	Std. Deviation	Std. Error Mean
Outdoor drybulb T	Comfort	1062	32.0163	4.56831	.14018
	Cold discomfort	129	32.4070	5.77906	.50882
Outdoor RH %	Comfort	1062	56.60	21.395	.657
	Cold discomfort	129	56.02	22.654	1.995
Temp.oC	Comfort	1062	28.44	3.009	.092
	Cold discomfort	129	27.17	3.981	.351
% Relative humidity	Comfort	1062	51.155	11.4520	.3514
	Cold discomfort	129	50.164	10.4669	.9216
Wind speed m/s	Comfort	1060	.922	1.3779	.0423
	Cold discomfort	129	1.417	2.1954	.1933

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference		Lower	Upper
Outdoor drybulb T	Equal variances assumed	19.384	.000	-.889	1189	.374	-.39069	.43949		-1.25296	.47158
	Equal variances not assumed			-.740	148.066	.460	-.39069	.52778		-1.43363	.65226
Outdoor RH %	Equal variances assumed	2.172	.141	.285	1189	.775	.573	2.008		-3.366	4.512
	Equal variances not assumed			.273	157.017	.785	.573	2.100		-3.574	4.721
Temp.oC	Equal variances assumed	19.000	.000	4.339	1189	.000	1.266	.292		.693	1.838
	Equal variances not assumed			3.492	146.298	.001	1.266	.362		.549	1.982
% Relative humidity	Equal variances assumed	2.184	.140	.936	1189	.349	.9910	1.0583		-1.0852	3.0673
	Equal variances not assumed			1.005	167.504	.316	.9910	.9863		-.9561	2.9382
Wind speed m/s	Equal variances assumed	20.847	.000	-3.569	1187	.000	-.4951	.1387		-.7673	-.2230
	Equal variances not assumed			-2.502	140.528	.013	-.4951	.1979		-.8863	-.1040

Appendix 7.14 – Hierarchical logistic regression of Outdoor parameters drybulb Temperature and Relative Humidity in unconditioned environments with dependent variable hot discomfort.

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	1323	98.7
	Missing Cases	17	1.3
	Total	1340	100.0
Unselected Cases		0	.0
Total		1340	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Hot discomfort	0
Comfort	1

Block 0: Beginning Block

Classification Table^{a,b}

			Predicted Binary hot comfort		
	Observed		Hot discomfort	Comfort	Percentage Correct
Step 0	Binary hot comfort	Hot discomfort	0	130	.0
		Comfort	0	1193	100.0
	Overall Percentage				90.2

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	2.217	.092	576.016	1	.000	9.177

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Outdoor drybulb T	23.975	1	.000
	Overall Statistics		23.975	1	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	23.096	1	.000
	Block	23.096	1	.000
	Model	23.096	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	826.921 ^a	.017	.037

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	10.847	8	.211

Contingency Table for Hosmer and Lemeshow Test

		Binary hot comfort = Hot discomfort		Binary hot comfort = Comfort		
		Observed	Expected	Observed	Expected	Total
Step 1	1	16	22.846	104	97.154	120
	2	25	19.142	109	114.858	134
	3	19	17.001	122	123.999	141
	4	14	12.265	102	103.735	116
	5	15	11.703	109	112.297	124
	6	12	10.188	107	108.812	119
	7	9	10.627	127	125.373	136
	8	10	8.486	110	111.514	120
	9	5	7.411	111	108.589	116
	10	5	10.331	192	186.669	197

Classification Table^a

			Predicted Binary hot comfort		
	Observed		Hot discomfort	Comfort	Percentage Correct
Step 1	Binary hot comfort	Hot discomfort	0	130	.0
		Comfort	0	1193	100.0
	Overall Percentage				90.2

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Outdoor drybulb T	-.105	.022	23.256	1	.000	.900	.863	.940
	Constant	5.500	.703	61.255	1	.000	244.737		

a. Variable(s) entered on step 1: Outdoor drybulb T.

Block 2: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	7.269	1	.007
	Block	7.269	1	.007
	Model	30.366	2	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	819.652 ^a	.023	.048

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	22.036	8	.005

Contingency Table for Hosmer and Lemeshow Test

		Binary hot comfort = Hot discomfort		Binary hot comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	22	25.755	111	107.245	133
	2	21	19.319	112	113.681	133
	3	11	16.023	120	114.977	131
	4	25	14.222	107	117.778	132
	5	15	12.530	116	118.470	131
	6	16	11.062	115	119.938	131
	7	8	9.838	119	117.162	127
	8	6	9.064	124	120.936	130
	9	1	7.348	134	127.652	135
	10	5	4.839	135	135.161	140

Classification Table^a

		Predicted		Percentage Correct
		Binary hot comfort	Comfort	
Step 1	Observed	Hot discomfort	Comfort	
	Binary hot comfort	0	130	.0
	Comfort	0	1193	100.0
Overall Percentage				90.2

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Outdoor drybulb T	-.189	.040	22.430	1	.000	.827	.765	.895
	Outdoor RH %	-.023	.009	6.659	1	.010	.977	.960	.994
	Constant	9.614	1.773	29.403	1	.000	14973.226		

a. Variable(s) entered on step 1: Outdoor drybulb T, Outdoor RH %.

Block 3: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	10.863	1	.001
	Block	10.863	1	.001
	Model	41.229	3	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	808.789 ^a	.031	.065

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	4.778	8	.781

Contingency Table for Hosmer and Lemeshow Test

		Binary hot comfort = Hot discomfort		Binary hot comfort = Comfort		
		Observed	Expected	Observed	Expected	Total
Step 1	1	30	26.398	101	104.602	131
	2	16	21.658	124	118.342	140
	3	17	17.811	115	114.189	132
	4	20	15.420	115	119.580	135
	5	12	12.554	122	121.446	134
	6	10	11.370	130	128.630	140
	7	11	9.238	122	123.762	133
	8	7	7.407	126	125.593	133
	9	5	5.382	127	126.618	132
	10	2	2.762	111	110.238	113

Classification Table^a

Classification Table					
			Predicted		
			Binary hot comfort		
Observed			Hot discomfort	Comfort	Percentage Correct
Step 1	Binary hot comfort	Hot discomfort	0	130	.0
		Comfort	0	1193	100.0
	Overall Percentage				90.2

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Outdoor drybulb T	.043	.085	.248	1	.618	1.043	.883	1.233
	Outdoor RH %	.107	.043	6.046	1	.014	1.113	1.022	1.212
	Outdoor RH % by Outdoor drybulb T	-.004	.001	9.204	1	.002	.996	.993	.999
	Constant	1.834	3.027	.367	1	.545	6.256		

a. Variable(s) entered on step 1: Outdoor drybulb T, Outdoor RH %, Outdoor RH % * Outdoor drybulb T.

Appendix 7.15 – Pearson's Product Moment correlation between Outdoor drybulb Temperature and Outdoor Relative Humidity for conditions of indoor thermal comfort perception (unconditioned environments).

Correlations

		Outdoor drybulb T	Outdoor RH %
Outdoor drybulb T	Pearson Correlation	1	-.751**
	Sig. (2-tailed)		.000
	N	1193	1193
Outdoor RH %	Pearson Correlation	-.751**	1
	Sig. (2-tailed)	.000	
	N	1193	1193

** . Correlation is significant at the 0.01 level (2-tailed).

Appendix 7.16 – Binary logistic regression of Indoor physical environmental parameter of Temperature in unconditioned environments with dependent variable hot discomfort.

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	1321	98.6
	Missing Cases	19	1.4
	Total	1340	100.0
Unselected Cases		0	.0
Total		1340	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Hot discomfort	0
Comfort	1

Block 0: Beginning Block

Classification Table^{a,b}

		Predicted Binary hot comfort		
		Hot discomfort	Comfort	Percentage Correct
Step 0	Observed Binary hot comfort	Hot discomfort	0	130
		Comfort	0	1191
	Overall Percentage			90.2

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	2.215	.092	575.050	1	.000	9.162

Variables not in the Equation

		Score	df	Sig.
Step 0	Variables Temp.oC	25.970	1	.000
	Overall Statistics	25.970	1	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	25.647	1	.000
	Block	25.647	1	.000
	Model	25.647	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	823.957 ^a	.019	.041

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	12.557	8	.128

Contingency Table for Hosmer and Lemeshow Test

		Binary hot comfort = Hot discomfort		Binary hot comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	26	26.242	108	107.758	134
	2	24	17.738	110	116.262	134
	3	16	13.887	107	109.113	123
	4	15	13.526	116	117.474	131
	5	12	13.459	129	127.541	141
	6	11	11.113	117	116.887	128
	7	8	9.578	113	111.422	121
	8	4	9.784	132	126.216	136
	9	4	8.615	132	127.385	136
	10	10	6.059	127	130.941	137

Classification Table^a

		Predicted Binary hot comfort		Percentage Correct
		Hot discomfort	Comfort	
Step 1	Binary hot comfort	Hot discomfort	0	.0
		Comfort	1	99.9
	Overall Percentage			90.1

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1 ^a	Temp.oC	-.203	.040	25.600	1	.000	.816	.754	.883
	Constant	8.777	1.316	44.475	1	.000	6485.186		

a. Variable(s) entered on step 1: Temp.oC.

Appendix 7.17 – Hierarchical logistic regression of Outdoor environmental parameters of drybulb Temperature and Relative Humidity in unconditioned environments with dependent variable cold discomfort.

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	1207	90.1
	Missing Cases	133	9.9
	Total	1340	100.0
Unselected Cases		0	.0
Total		1340	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Cold discomfort	0
Comfort	1

Block 0: Beginning Block

Classification Table^{a,b}

		Predicted Binary cold comfort		Percentage Correct
		Cold discomfort	Comfort	
Step 0	Binary cold comfort	Cold discomfort	0	.0
		Comfort	0	100.0
	Overall Percentage			98.8

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

B	S.E.	Wald	df	Sig.	Exp(B)
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Step 0	Constant	4.445	.269	273.425	1	.000	85.214
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Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Outdoor drybulb T	.488	1	.485
	Overall Statistics		.488	1	.485

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	.505	1	.477
	Block	.505	1	.477
	Model	.505	1	.477

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	152.124 ^a	.000	.004

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	11.883	8	.157

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	4	1.978	126	128.022	130
	2	0	1.545	111	109.455	111
	3	3	1.414	104	105.586	107
	4	1	1.351	106	105.649	107
	5	1	1.614	133	132.386	134
	6	1	1.228	106	105.772	107
	7	0	1.630	151	149.370	151
	8	1	1.073	106	105.927	107
	9	0	1.067	115	113.933	115
	10	3	1.099	135	136.901	138

Classification Table^a

		Predicted		Percentage Correct
		Binary cold comfort	Comfort	
Step 1	Observed	Cold discomfort	Comfort	
	Binary cold comfort	0	14	.0
	Comfort	0	1193	100.0
Overall Percentage				98.8

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Outdoor drybulb T	.048	.068	.486	1	.486	1.049	.917	1.199
	Constant	3.015	2.042	2.180	1	.140	20.397		

a. Variable(s) entered on step 1: Outdoor drybulb T.

Block 2: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	.724	1	.395

Block	.724	1	.395
Model	1.229	2	.541

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	151.400 ^a	.001	.009

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	4.127	8	.845

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	3	2.408	118	118.592	121
	2	1	1.861	120	119.139	121
	3	3	1.537	120	121.463	123
	4	1	1.387	119	118.613	120
	5	1	1.319	119	118.681	120
	6	1	1.277	121	120.723	122
	7	0	1.225	124	122.775	124
	8	2	1.148	122	122.852	124
	9	1	1.017	120	119.983	121
	10	1	.820	110	110.180	111

Classification Table^a

		Predicted		Percentage Correct
		Binary cold comfort	Comfort	
Step 1	Observed	Cold discomfort	Comfort	
	Binary cold comfort	0	14	.0
	Cold discomfort	0	1193	100.0
Overall Percentage				98.8

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Outdoor drybulb T	.103	.091	1.275	1	.259	1.109	.927	1.326
	Outdoor RH %	.018	.020	.761	1	.383	1.018	.978	1.059
	Constant	.221	3.721	.004	1	.953	1.248		

a. Variable(s) entered on step 1: Outdoor drybulb T, Outdoor RH %.

Block 3: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	7.003	1	.008
	Block	7.003	1	.008
	Model	8.232	3	.041

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	144.397 ^a	.007	.057

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	14.463	8	.070

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	5	4.427	117	117.573	122
	2	1	2.286	120	118.714	121
	3	0	1.677	126	124.323	126
	4	4	1.317	115	117.683	119
	5	0	1.117	121	119.883	121
	6	0	.966	131	130.034	131
	7	1	.736	119	119.264	120
	8	2	.589	113	114.411	115
	9	1	.517	120	120.483	121
	10	0	.370	111	110.630	111

Classification Table^a

		Predicted Binary cold comfort		Percentage Correct
		Cold discomfort	Comfort	
Step 1	Binary cold comfort	Cold discomfort	0	14
		Comfort	0	1193
	Overall Percentage			98.8

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1 ^a	Outdoor drybulb T	-.222	.138	2.586	1	.108	.801	.611	1.050
	Outdoor RH %	-.177	.070	6.403	1	.011	.838	.730	.961
	Outdoor RH % by Outdoor drybulb T	.007	.002	8.274	1	.004	1.007	1.002	1.011
	Constant	10.473	5.184	4.081	1	.043	35340.292		

a. Variable(s) entered on step 1: Outdoor drybulb T, Outdoor RH %, Outdoor RH % * Outdoor drybulb T .

Appendix 7.18 - Binary logistic regression of Indoor physical environmental parameter of Temperature in unconditioned environments with dependent variable cold discomfort.

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	1207	90.1
	Missing Cases	133	9.9
	Total	1340	100.0
Unselected Cases		0	.0
Total		1340	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Cold discomfort	0
Comfort	1

Block 0: Beginning Block

Classification Table^{a,b}

		Predicted Binary cold comfort		Percentage Correct
		Cold discomfort	Comfort	
Step 0	Binary cold comfort	Cold discomfort	0	14
		Comfort	0	1193
	Overall Percentage			98.8

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	4.445	.269	273.425	1	.000	85.214

Variables not in the Equation

		Score	df	Sig.
Step 0	Variables Temp.oC	7.652	1	.006
	Overall Statistics	7.652	1	.006

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	7.210	1	.007
	Block	7.210	1	.007
	Model	7.210	1	.007

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	145.418 ^a	.006	.050

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	8.053	8	.428

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	4	4.034	116	115.966	120
	2	4	2.089	124	125.911	128
	3	0	1.673	126	124.327	126
	4	1	1.339	115	114.661	116
	5	0	1.138	114	112.862	114
	6	1	1.066	123	122.934	124
	7	2	.866	112	113.134	114
	8	1	.768	114	114.232	115
	9	0	.663	125	124.337	125
	10	1	.365	124	124.635	125

Classification Table^a

		Predicted		Percentage Correct
		Binary cold comfort	Comfort	
Step 1	Observed	Cold discomfort	Comfort	
	Binary cold comfort	0	14	.0
	Comfort	0	1193	100.0
Overall Percentage				98.8

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1 ^a	Temp.oC	.295	.103	8.234	1	.004	1.343	1.098	1.642
	Constant	-4.687	3.109	2.273	1	.132	.009		

a. Variable(s) entered on step 1: Temp.oC.

Appendix 7.19 - Binary logistic regression of Indoor physical environmental parameter of Temperature and Wind Speed in conditioned environments with dependent variable cold discomfort.

Case Processing Summary

Unweighted Cases ^a		N	Percent
Selected Cases	Included in Analysis	1189	99.0
	Missing Cases	12	1.0
	Total	1201	100.0
Unselected Cases		0	.0
Total		1201	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
Cold discomfort	0
Comfort	1

Block 0: Beginning Block

Classification Table^{a,b}

			Predicted		
			Binary cold comfort		
	Observed		Cold discomfort	Comfort	Percentage Correct
Step 0	Binary cold comfort	Cold discomfort	0	129	.0
		Comfort	0	1060	100.0
	Overall Percentage				89.2

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	2.106	.093	510.173	1	.000	8.217

Variables not in the Equation

		Score	df	Sig.
Step 0	Variables Temp.oC	18.628	1	.000
Overall Statistics		18.628	1	.000

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	19.343	1	.000
	Block	19.343	1	.000
	Model	19.343	1	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	797.158 ^a	.016	.032

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	40.943	8	.000

Contingency Table for Hosmer and Lemeshow Test

Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
Observed	Expected	Observed	Expected	

Step 1	1	33	21.960	84	95.040	117
	2	16	18.957	109	106.043	125
	3	19	16.111	102	104.889	121
	4	12	15.648	120	116.352	132
	5	7	12.295	108	102.705	115
	6	6	12.022	119	112.978	125
	7	6	10.405	115	110.595	121
	8	7	9.973	124	121.027	131
	9	10	7.741	110	112.259	120
	10	13	3.889	69	78.111	82

Classification Table^a

		Observed		Predicted Binary cold comfort		
				Cold discomfort	Comfort	Percentage Correct
Step 1	Binary cold comfort	Cold discomfort		0	129	.0
		Comfort		0	1060	100.0
	Overall Percentage					89.2

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
Step 1 ^a	Temp.oC	.136	.032	18.400	1	.000	1.145	1.076	1.218
	Constant	-1.662	.868	3.663	1	.056	.190		

a. Variable(s) entered on step 1: Temp.oC.

Block 2: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	18.745	1	.000
	Block	18.745	1	.000
	Model	38.089	2	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	778.412 ^a	.032	.063

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	38.534	8	.000

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		
		Observed	Expected	Observed	Expected	Total
Step 1	1	36	27.748	83	91.252	119
	2	22	18.520	97	100.480	119
	3	17	15.811	102	103.189	119
	4	16	13.868	102	104.132	118
	5	4	12.338	115	106.662	119
	6	6	11.122	113	107.878	119
	7	4	9.711	115	109.289	119
	8	2	8.358	117	110.642	119
	9	9	6.878	111	113.122	120
	10	13	4.645	105	113.355	118

Classification Table^a

	Observed	Predicted
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			Binary cold comfort		Percentage Correct
			Cold discomfort	Comfort	
Step 1	Binary cold comfort	Cold discomfort	0	129	.0
		Comfort	4	1056	99.6
	Overall Percentage				88.8

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1 ^a	Temp.oC	.172	.033	26.845	1	.000	1.187	1.113	1.267
	Wind speed m/s	-.229	.049	21.660	1	.000	.796	.723	.876
	Constant	-2.413	.892	7.315	1	.007	.090		

a. Variable(s) entered on step 1: Temp.oC, Wind speed m/s.

Block 3: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	3.578	1	.059
	Block	3.578	1	.059
	Model	41.667	3	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	774.834 ^a	.034	.069

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	42.747	8	.000

Contingency Table for Hosmer and Lemeshow Test

		Binary cold comfort = Cold discomfort		Binary cold comfort = Comfort		Total
		Observed	Expected	Observed	Expected	
Step 1	1	38	28.737	81	90.263	119
	2	18	19.053	101	99.947	119
	3	17	16.056	102	102.944	119
	4	18	14.054	102	105.946	120
	5	4	12.270	116	107.730	120
	6	5	10.853	114	108.147	119
	7	5	9.389	114	109.611	119
	8	2	8.022	117	110.978	119
	9	9	6.416	110	112.584	119
	10	13	4.151	103	111.849	116

Classification Table^a

			Predicted		
			Binary cold comfort		
	Observed		Cold discomfort	Comfort	Percentage Correct
Step 1	Binary cold comfort	Cold discomfort	0	129	.0
		Comfort	1	1059	99.9
	Overall Percentage				89.1

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I. for EXP(B)	
								Lower	Upper
Step 1 ^a	Temp.oC	.203	.037	29.783	1	.000	1.225	1.139	1.318
	Wind speed m/s	.529	.394	1.804	1	.179	1.698	.784	3.676

Temp.oC by Wind speed m/s	-.025	.013	3.824	1	.051	.976	.952	1.000
Constant	-3.317	1.012	10.743	1	.001	.036		

a. Variable(s) entered on step 1: Temp.oC, Wind speed m/s, Temp.oC * Wind speed m/s .

Appendix 7.20 – Pearson's Correlations of Indoor Temperature & Wind Speed in conditioned environments for cases of perceived thermal comfort

Correlations

		Temp.oC	Wind speed m/s
Temp.oC	Pearson Correlation	1	.208**
	Sig. (2-tailed)		.000
	N	1062	1060
Wind speed m/s	Pearson Correlation	.208**	1
	Sig. (2-tailed)	.000	
	N	1060	1060

**, Correlation is significant at the 0.01 level (2-tailed).

Appendix 7.21 – Pearson's Correlation of Indoor Temperature & Wind Speed in conditioned environments for cases of perceived thermal discomfort due to cold.

Correlations

		Temp.oC	Wind speed m/s
Temp.oC	Pearson Correlation	1	.418**
	Sig. (2-tailed)		.000
	N	129	129
Wind speed m/s	Pearson Correlation	.418**	1
	Sig. (2-tailed)	.000	
	N	129	129

**, Correlation is significant at the 0.01 level (2-tailed).

Appendix 8.22 – Independent sample T-test comparing the mean of the temperature at which the low SEP and high SEP populations experience comfort in unconditioned environments

Group Statistics

	SES highlow excl.mid.	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	239	32.30	2.276	.147
	high	358	31.66	2.281	.121

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.110	.741	3.350	595	.001	.638	.190	.264	1.012
	Equal variances not assumed			3.352	511.018	.001	.638	.190	.264	1.012

Appendix 8.23 – Independent sample T-test comparing the mean temperature at which low SEP and high SEP populations experience hot discomfort and cold discomfort cases in unconditioned environments

Hot discomfort

Group Statistics

	SES highlow excl.mid.	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	18	33.98	2.407	.567
	high	39	32.91	2.707	.433

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.058	.810	1.438	55	.156	1.073	.746	-.422	2.568
	Equal variances not assumed			1.503	37.003	.141	1.073	.714	-.374	2.520

Cold discomfort

Group Statistics

	SES highlow excl.mid.	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	4	29.32	4.747	2.374
	high	3	30.03	.208	.120

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
--	--	---	--	------------------------------	--	--	--

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temp.oC	Equal variances assumed	3.374	.126	-.252	5	.811	-.708	2.810	-7.932	6.516
	Equal variances not assumed			-.298	3.015	.785	-.708	2.377	-8.250	6.833

Appendix 8.24 - Independent sample T-test comparing the mean of the temperature at which the low SEP and high SEP populations experience comfort in conditioned environments

Group Statistics

	SES 2 highlow excl. mid	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	94	28.24	2.995	.309
	high	420	28.21	3.074	.150

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.175	.676	.086	512	.932	.030	.349	-.656	.716
	Equal variances not assumed			.087	140.307	.931	.030	.343	-.649	.709

Appendix 8.25 – Independent sample T-test comparing the mean of the temperature at which low SEP and high SEP populations experience discomfort in conditioned environments

Hot discomfort

Group Statistics

	SES 2 highlow excl. mid	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	0 ^a	.	.	.
	high	3	27.27	2.136	1.233

a. t cannot be computed because at least one of the groups is empty.

Cold discomfort

Group Statistics

	SES 2 highlow excl. mid	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	low	4	25.95	1.145	.572
	high	64	27.77	3.887	.486

Independent Samples Test

Levene's Test for Equality of Variances		t-test for Equality of Means						
F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper

Temp.oC	Equal variances assumed	4.584	.036	-.927	66	.357	-1.819	1.961	-5.735	2.097
	Equal variances not assumed			-2.423	8.669	.039	-1.819	.751	-3.527	-.111

Appendix 8.26 – Independent sample T-test comparing means of temperature at which persons of varying income levels perceive comfort in unconditioned environments

Income group: 2 & 3 3001-7,000 vs 7001-15,000

Group Statistics

	income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	7001 - 15,000	65	32.60	2.095	.260

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.021	.885	2.621	65	.011	3.955	1.509	.941	6.968
	Equal variances not assumed			2.235	1.045	.259	3.955	1.769	-16.380	24.289

Income group: 2 & 4 3001-7,000 vs 15,001-30,000

Group Statistics

	income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	15,001 - 30,000	151	31.90	2.195	.179

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.009	.923	2.972	151	.003	4.647	1.563	1.558	7.736
	Equal variances not assumed			2.642	1.021	.226	4.647	1.759	-16.650	25.943

Income group: 2 & 5 3001-7,000 vs 30,001-50,000

Group Statistics

	income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	30001 - 50000	216	31.70	2.368	.161

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.012	.913	2.881	216	.004	4.848	1.682	1.532	8.164
Equal variances not assumed			2.758	1.017	.218	4.848	1.757	-16.618	26.313

Income group: 2 & 6
3001-7,000 vs 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	50,001 - 100,000	282	31.38	2.357	.140

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means			95% Confidence Interval of the Difference	
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Temp.oC	Equal variances assumed		.003	.954	3.088	282	.002	5.166	1.673
	Equal variances not assumed				2.943	1.013	.206	5.166	1.756
								Lower	Upper
								1.873	8.459
								-16.481	26.813

Income group: 2 & 7
3001-7,000 vs 100,001-300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	100,001 - 300,000	438	31.72	1.912	.091

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means			95% Confidence Interval of the Difference	
			F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Temp.oC	Equal variances assumed		.134	.715	3.563	438	.000	4.832	1.356
	Equal variances not assumed				2.757	1.005	.220	4.832	1.752
								Lower	Upper
								2.167	7.497
								-17.151	26.815

Income group: 2 & 8
3001-7,000 vs > 300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	3001 - 7000	2	36.55	2.475	1.750
	> 300,001	34	32.93	2.345	.402

Independent Samples Test

Levene's Test for Equality of Variances		t-test for Equality of Means	
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.018	.894	2.116	34	.042	3.618	1.709	.144	7.091
Equal variances not assumed			2.015	1.108	.274	3.618	1.796	-14.547	21.782

Income group: 3 & 4 7001-15,000 vs 15,001-30,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	65	32.60	2.095	.260
	15,001 - 30,000	151	31.90	2.195	.179

Independent Samples Test

Levene's Test for Equality of Variances			t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
Temp.oC Equal variances assumed	.031	.860	2.154	214	.032	.692	.321	.059	1.325
Equal variances not assumed			2.195	126.668	.030	.692	.315	.068	1.316

Income group: 3 & 5 7001-15,000 vs 30,001-50,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	65	32.60	2.095	.260
	30001 - 50000	216	31.70	2.368	.161

Independent Samples Test

Levene's Test for Equality of Variances			t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
Temp.oC Equal variances assumed	1.518	.219	2.735	279	.007	.893	.327	.250	1.536
Equal variances not assumed			2.921	117.477	.004	.893	.306	.288	1.499

Income group: 3 & 6 7001-15,000 vs 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	65	32.60	2.095	.260
	50,001 - 100,000	282	31.38	2.357	.140

Independent Samples Test

Levene's Test for Equality of Variances t-test for Equality of Means

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temp.oC	Equal variances assumed	.097	.756	3.810	345	.000	1.211	.318	.586	1.837
	Equal variances not assumed			4.101	104.744	.000	1.211	.295	.626	1.797

Income group: 3 & 7
7001-15,000 vs 100,001-300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	65	32.60	2.095	.260
	100,001 - 300,000	438	31.72	1.912	.091

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.308	.253	3.409	501	.001	.877	.257	.372	1.383
	Equal variances not assumed			3.185	80.613	.002	.877	.275	.329	1.425

Income group: 4 & 6
15,001-30,000 vs 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	151	31.90	2.195	.179
	50,001 - 100,000	282	31.38	2.357	.140

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.039	.844	2.237	431	.026	.519	.232	.063	.975
	Equal variances not assumed			2.286	326.086	.023	.519	.227	.072	.966

Income group: 4 & 8
15,001-30,000 vs <300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	151	31.90	2.195	.179
	> 300,001	34	32.93	2.345	.402

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.726	.395	-2.439	183	.016	-1.029	.422	-1.861	-.197
Equal variances not assumed			-2.338	46.894	.024	-1.029	.440	-1.914	-.144

**Income group: 5 & 8
30,001-50,000 vs <300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	30001 - 50000	216	31.70	2.368	.161
	> 300,001	34	32.93	2.345	.402

Independent Samples Test

Levene's Test for Equality of Variances			t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
Temp.oC Equal variances assumed	.005	.944	-2.819	248	.005	-1.230	.436	-2.089	-.371
Equal variances not assumed			-2.839	44.264	.007	-1.230	.433	-2.103	-.357

**Income group: 5 & 7
50,001-100,000 vs 100,001-300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	50,001 - 100,000	282	31.38	2.357	.140
	100,001 - 300,000	438	31.72	1.912	.091

Independent Samples Test

Levene's Test for Equality of Variances			t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
Temp.oC Equal variances assumed	5.779	.016	-2.086	718	.037	-.334	.160	-.648	-.020
Equal variances not assumed			-1.994	510.613	.047	-.334	.167	-.663	-.005

**Income group: 6 & 8
50,001-100,000 vs <300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	50,001 - 100,000	282	31.38	2.357	.140
	> 300,001	34	32.93	2.345	.402

Independent Samples Test

Levene's Test for Equality of Variances			t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temp.oC	Equal variances assumed	.459	.498	-3.621	314	.000	-1.548	.428	-2.390	-.707
	Equal variances not assumed			-3.635	41.453	.001	-1.548	.426	-2.408	-.688

**Income group: 7 & 8
100,001-300,000 vs <300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	100,001 - 300,000	438	31.72	1.912	.091
	> 300,001	34	32.93	2.345	.402

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	4.086	.044	-3.506	470	.000	-1.214	.346	-1.895	-.534
	Equal variances not assumed			-2.944	36.485	.006	-1.214	.412	-2.050	-.378

Appendix 8.27 – Independent sample T-tests comparing means of temperature at which persons of varying income levels perceive comfort in unconditioned environments where indoor temperature is limited to the range 30°C-to-35 °C.

**Income group: 3 & 5
7001-15,000 vs 30,001-50,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	51	32.18	1.239	.174
	30001 - 50000	153	31.74	1.260	.102

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.166	.684	2.184	202	.030	.443	.203	.043	.843
	Equal variances not assumed			2.202	87.003	.030	.443	.201	.043	.843

**Income group: 3 & 6
7001-15,000 vs 50,001-100,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	51	32.18	1.239	.174
	50,001 - 100,000	219	31.66	1.173	.079

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.520	.471	2.832	268	.005	.522	.184	.159	.885
	Equal variances not assumed			2.737	72.324	.008	.522	.191	.142	.903

Income group: 3 & 7 7001-15,000 vs 100,001-300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	51	32.18	1.239	.174
	100,001 - 300,000	368	31.71	1.165	.061

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.737	.391	2.678	417	.008	.470	.175	.125	.815
	Equal variances not assumed			2.556	62.871	.013	.470	.184	.102	.837

Income group: 4 & 5 15001-30,000 vs 30,001-50,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	119	32.08	1.173	.108
	30001 - 50000	153	31.74	1.260	.102

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	2.138	.145	2.238	270	.026	.334	.149	.040	.629
	Equal variances not assumed			2.258	261.437	.025	.334	.148	.043	.626

Income group: 4 & 6 15,001-30,000 vs 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	119	32.08	1.173	.108
	50,001 - 100,000	219	31.66	1.173	.079

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	.000	.990	3.095	336	.002	.414	.134	.151	.676
Equal variances not assumed			3.096	242.447	.002	.414	.134	.150	.677

**Income group: 4 & 7
15001-30,000 vs 100,001-300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	119	32.08	1.173	.108
	100,001 - 300,000	368	31.71	1.165	.061

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	.029	.864	2.935	485	.003	.361	.123	.119	.603
Equal variances not assumed			2.925	198.858	.004	.361	.123	.118	.605

Appendix 8.28 - Independent sample T-test comparing means of temperature at which persons of varying income levels perceive cold discomfort in conditioned environments

**Income group: 3 & 8
7001-15,000 vs > 300,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	7001 - 15,000	1	31.10	.	.
	> 300,001	4	25.33	1.473	.736

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	.	.	3.507	3	.039	5.775	1.647	.535	11.015
Equal variances not assumed			.	.	.	5.775	.	.	.

**Income group: 4 & 6
15,001-30,000 vs 50,001-100,000**

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	3	29.27	1.457	.841
	50,001 - 100,000	31	24.61	3.317	.596

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	1.393	.247	2.384	32	.023	4.660	1.955	.679	8.642
Equal variances not assumed			4.520	4.435	.008	4.660	1.031	1.905	7.415

Income group: 4 & 8
15,001-30,000 vs > 300,001

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	15,001 - 30,000	3	29.27	1.457	.841
	> 300,001	4	25.33	1.473	.736

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	.005	.945	3.519	5	.017	3.942	1.120	1.062	6.821
Equal variances not assumed			3.525	4.484	.020	3.942	1.118	.965	6.918

Income group: 5 & 6
30,001-50,000 vs > 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	30001 - 50000	24	26.83	2.622	.535
	50,001 - 100,000	31	24.61	3.317	.596

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	1.161	.286	2.688	53	.010	2.219	.825	.563	3.874
Equal variances not assumed			2.770	52.966	.008	2.219	.801	.612	3.825

Income group: 5 & 6
30,001-50,000 vs > 50,001-100,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	30001 - 50000	24	26.83	2.622	.535
	50,001 - 100,000	31	24.61	3.317	.596

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	1.161	.286	2.688	53	.010	2.219	.825	.563	3.874
Equal variances not assumed			2.770	52.966	.008	2.219	.801	.612	3.825

Income group: 5 & 7 30,001-50,000 vs > 100,001-300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	30001 - 50000	24	26.83	2.622	.535
	100,001 - 300,000	65	28.27	3.974	.493

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	8.846	.004	-1.651	87	.102	-1.446	.875	-3.186	.294
Equal variances not assumed			-1.987	62.420	.051	-1.446	.728	-2.900	.008

Income group: 6 & 7 50,001-100,000 vs > 100,001-300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	50,001 - 100,000	31	24.61	3.317	.596
	100,001 - 300,000	65	28.27	3.974	.493

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	3.414	.068	-4.445	94	.000	-3.664	.824	-5.301	-2.028
Equal variances not assumed			-4.739	69.788	.000	-3.664	.773	-5.207	-2.122

Income group: 7 & 8 100,001-300,000 vs > 300,000

Group Statistics

	Income group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	100,001 - 300,000	65	28.27	3.974	.493
	> 300,001	4	25.33	1.473	.736

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	4.654	.035	1.468	67	.147	2.946	2.007	-1.061	6.952
Equal variances not assumed			3.324	6.231	.015	2.946	.886	.797	5.095

Appendix 8.29 – Independent sample T-test comparing means of temperature at which persons of varying occupations perceive comfort in unconditioned environments

Occupation Groups: 2 & 3 Petty Trader – Skilled Worker

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Petty Trader	38	31.63	.937	.152
	Skilled worker	74	32.51	2.161	.251

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	16.812	.000	-2.416	110	.017	-.889	.368	-1.617	-.160
Equal variances not assumed			-3.026	107.756	.003	-.889	.294	-1.471	-.306

Occupation Groups: 3 & 4 Skilled Worker – Non-executive staff

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	74	32.51	2.161	.251
	Non-executive stff	382	31.83	2.018	.103

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	1.120	.291	2.645	454	.008	.686	.259	.176	1.196
Equal variances not assumed			2.526	99.212	.013	.686	.272	.147	1.225

Occupation Groups: 3 & 5 Skilled Worker – Supervisory level

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	74	32.51	2.161	.251
	Supervisory level	184	31.58	2.413	.178

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.907	.342	2.888	256	.004	.932	.323	.296	1.567
	Equal variances not assumed			3.027	149.539	.003	.932	.308	.324	1.540

Occupation Groups: 3 &6

Skilled Worker – Small shopkeeper/businessman

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	74	32.51	2.161	.251
	Small shopkeeper/businessman	91	31.58	1.778	.186

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	2.387	.124	3.044	163	.003	.934	.307	.328	1.539
	Equal variances not assumed			2.984	140.882	.003	.934	.313	.315	1.552

Occupation Groups: 3 &7

Skilled Worker – Lower/Middle executive officer

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	74	32.51	2.161	.251
	Lower/Middle executive officer	147	31.28	2.355	.194

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.187	.666	3.769	219	.000	1.231	.327	.587	1.875
	Equal variances not assumed			3.877	158.116	.000	1.231	.318	.604	1.858

Occupation Groups: 3 &10

Skilled Worker – Senior executive officer

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	74	32.51	2.161	.251

Senior executive/Officer	16	31.42	.963	.241
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Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	6.248	.014	1.980	88	.051	1.096	.554	-.004	2.196
	Equal variances not assumed			3.150	52.591	.003	1.096	.348	.398	1.794

Occupation Groups: 4 & 7 Non-executive staff – Lower/Middle executive officer

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Non-executive stff	382	31.83	2.018	.103
	Lower/Middle executive officer	147	31.28	2.355	.194

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	3.991	.046	2.653	527	.008	.545	.205	.141	.949
	Equal variances not assumed			2.478	233.063	.014	.545	.220	.112	.979

Occupation Groups: 7 & 8 Lower/Middle executive officer – Self-employed/ employed professional

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Lower/Middle executive officer	147	31.28	2.355	.194
	Self-emploed/employed professional	168	31.91	2.331	.180

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.014	.906	-2.353	313	.019	-.622	.264	-1.143	-.102
	Equal variances not assumed			-2.351	306.606	.019	-.622	.265	-1.143	-.101

Appendix 8.30 - Independent sample T-test comparing means of temperature at which persons of varying occupations perceive comfort in unconditioned environments restricted to indoor temperature between 30°C-to-35°C

Occupation Groups: 1 & 3 Unskilled worker – Skilled worker

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Unskilled worker	54	31.66	1.425	.194
	Skilled worker	57	32.17	1.171	.155

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	3.973	.049	-2.053	109	.042	-.507	.247	-.997	-.018
	Equal variances not assumed			-2.042	102.737	.044	-.507	.248	-1.000	-.015

Occupation Groups: 2 & 3 Petty trader – Skilled worker

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Petty Trader	38	31.63	.937	.152
	Skilled worker	57	32.17	1.171	.155

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	4.478	.037	-2.403	93	.018	-.546	.227	-.997	-.095
	Equal variances not assumed			-2.512	89.814	.014	-.546	.217	-.977	-.114

Occupation Groups: 3 & 5 Skilled worker – Supervisory level

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	57	32.17	1.171	.155
	Supervisory level	128	31.54	1.198	.106

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.441	.508	3.337	183	.001	.632	.189	.258	1.006
	Equal variances not assumed			3.366	109.805	.001	.632	.188	.260	1.004

Occupation Groups: 3 & 6 Skilled worker – Small shopkeeper/businessman

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	57	32.17	1.171	.155
	Small shopkeeper/businessman	77	31.66	1.146	.131

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.000	.991	2.534	132	.012	.512	.202	.112	.912
	Equal variances not assumed			2.526	119.350	.013	.512	.203	.111	.914

Occupation Groups: 3 & 7 Skilled worker – Lower/Middle executive officer

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Skilled worker	57	32.17	1.171	.155
	Lower/Middle executive officer	113	31.73	1.302	.122

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.148	.285	2.150	168	.033	.440	.205	.036	.844
	Equal variances not assumed			2.227	123.537	.028	.440	.198	.049	.831

Occupation Groups: 4 & 5 Unskilled worker – Skilled worker

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Non-executive stff	314	31.92	1.144	.065
	Supervisory level	128	31.54	1.198	.106

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	2.273	.132	3.134	440	.002	.381	.122	.142	.620
	Equal variances not assumed			3.074	226.327	.002	.381	.124	.137	.626

Appendix 8.31 - Independent sample T-test comparing means of temperature at which persons of varying occupations perceive cold discomfort in conditioned environments

Occupation Groups: 1 & 8
Unskilled worker – Self-employed/employed professional

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Unskilled worker	2	26.05	.495	.350
	Self-employed/employed professional	42	28.63	4.173	.644

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	4.618	.037	-.863	42	.393	-2.576	2.985	-8.599	3.447
	Equal variances not assumed			-3.515	15.027	.003	-2.576	.733	-4.138	-1.014

Occupation Groups: 4 & 8
Non-executive staff – Self-employed/employed professional

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Non-executive staff	44	26.61	3.730	.562
	Self-employed/employed professional	42	28.63	4.173	.644

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.080	.302	-2.368	84	.020	-2.019	.853	-3.715	-.324
	Equal variances not assumed			-2.362	81.941	.021	-2.019	.855	-3.720	-.319

Occupation Groups: 5 & 8
Supervisory level – Self-employed/employed professional

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Supervisory level	15	25.58	3.653	.943
	Self-employed/employed professional	42	28.63	4.173	.644

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.560	.217	-2.502	55	.015	-3.046	1.217	-5.486	-.607

Equal variances not assumed			-2.668	28.016	.013	-3.046	1.142	-5.385	-.707
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Occupation Groups: 6 & 11

Small shopkeeper/businessman – Large businessman/Factory owner

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Small shopkeeper/businessman	1	23.40	.	.
	Large businessman/ Factory owner	2	26.55	.212	.150

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.	.	-12.124	1	.052	-3.150	.260	-6.451	.151
	Equal variances not assumed			.	.	.	-3.150	.	.	.

Occupation Groups: 7 & 8

Lower/Middle executive officer – Self-employed/employed professional

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Lower/Middle executive officer	17	26.25	2.907	.705
	Self-emploed/employed professional	42	28.63	4.173	.644

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	5.972	.018	-2.139	57	.037	-2.373	1.110	-4.595	-.151
	Equal variances not assumed			-2.486	42.334	.017	-2.373	.955	-4.300	-.447

Occupation Groups: 8 & 11

Self-employed/employed professional – Large businessman/ Factory owner

Group Statistics

	standardised occupation used	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Self-emploed/employed professional	42	28.63	4.173	.644
	Large businessman/ Factory owner	2	26.55	.212	.150

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	5.210	.028	.696	42	.490	2.076	2.984	-3.946	8.098

Equal variances not assumed			3.140	40.661	.003	2.076	.661	.741	3.412
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Appendix 8.32 - Independent sample T-test comparing means of temperature at which persons of varying education levels perceive comfort in unconditioned environments

Education levels: 1 & 4 No formal schooling – Matric

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	No formal schooling	3	34.53	1.320	.762
	Matric	154	31.98	2.003	.161

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	
Temp.oC	Equal variances assumed	.446	.505	2.197	155	.029	2.557	1.164	.258
	Equal variances not assumed			3.281	2.183	.073	2.557	.779	-.540
									4.855
									5.654

Education levels: 1 & 5 No formal schooling – Intermediate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	No formal schooling	3	34.53	1.320	.762
	Intermediate	349	31.80	2.081	.111

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	
Temp.oC	Equal variances assumed	.528	.468	2.266	350	.024	2.730	1.205	.361
	Equal variances not assumed			3.544	2.086	.067	2.730	.770	-.457
									5.100
									5.917

Education levels: 1 & 6 No formal schooling – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	No formal schooling	3	34.53	1.320	.762
	Graduate	339	31.40	2.314	.126

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.714	.399	2.338	340	.020	3.131	1.339	.497	5.765
Equal variances not assumed			4.053	2.110	.051	3.131	.773	-.032	6.294

Education levels: 1 & 7 No formal schooling – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	No formal schooling	3	34.53	1.320	.762
	Post-graduate	277	31.70	2.058	.124

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	F	Sig.	t	df				Lower	Upper
Temp.oC Equal variances assumed	.553	.458	2.376	278	.018	2.832	1.192	.486	5.179
Equal variances not assumed			3.667	2.107	.062	2.832	.772	-.334	5.999

Education levels: 2 & 4 School class 1-5 – Matric

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	10	33.40	2.425	.767
	Matric	154	31.98	2.003	.161

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	F	Sig.	t	df				Lower	Upper
Temp.oC Equal variances assumed	.101	.751	2.149	162	.033	1.423	.662	.116	2.731
Equal variances not assumed			1.816	9.814	.100	1.423	.784	-.327	3.174

Education levels: 2 & 5 School class 1-5 – Intermediate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	10	33.40	2.425	.767
	Intermediate	349	31.80	2.081	.111

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.030	.863	2.381	357	.018	1.597	.671	.278	2.916
Equal variances not assumed			2.060	9.384	.068	1.597	.775	-.145	3.339

Education levels: 2 & 6
School class 1-5 – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	10	33.40	2.425	.767
	Graduate	339	31.40	2.314	.126

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	F	Sig.	t	df				Lower	Upper
Temp.oC Equal variances assumed	.035	.851	2.687	347	.008	1.998	.743	.536	3.460
Equal variances not assumed			2.570	9.490	.029	1.998	.777	.253	3.742

Education levels: 2 & 7
School class 1-5 – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	10	33.40	2.425	.767
	Post-graduate	277	31.70	2.058	.124

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means		Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	F	Sig.	t	df				Lower	Upper
Temp.oC Equal variances assumed	.032	.859	2.549	285	.011	1.699	.666	.387	3.011
Equal variances not assumed			2.187	9.474	.055	1.699	.777	-.045	3.443

Education levels: 3 & 5
School class 5-9 – Intermediate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	59	32.70	2.722	.354
	Intermediate	349	31.80	2.081	.111

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Temp.oC	Equal variances assumed	6.674	.010	2.922	406	.004	.899	.307	.294	1.503
	Equal variances not assumed			2.419	69.916	.018	.899	.372	.158	1.639

Education levels: 3 & 6 School class 5-9 – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	59	32.70	2.722	.354
	Graduate	339	31.40	2.314	.126

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference		Lower	Upper
Temp.oC	Equal variances assumed	2.542	.112	3.874	396	.000	1.299	.335		.640	1.959
	Equal variances not assumed			3.455	73.302	.001	1.299	.376		.550	2.049

Education levels: 3 & 7 School class 5-9 – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	59	32.70	2.722	.354
	Post-graduate	277	31.70	2.058	.124

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference		Lower	Upper
Temp.oC	Equal variances assumed	6.596	.011	3.190	334	.002	1.001	.314		.384	1.618
	Equal variances not assumed			2.666	72.754	.009	1.001	.375		.252	1.749

Education levels: 4 & 6 Matric – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Matric	154	31.98	2.003	.161
	Graduate	339	31.40	2.314	.126

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	2.661	.103	2.660	491	.008	.574	.216	.150	.998
Equal variances not assumed			2.807	338.331	.005	.574	.205	.172	.977

Education levels: 5 & 7 Intermediate – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Intermediate	349	31.80	2.081	.111
	Graduate	339	31.40	2.314	.126

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	2.337	.127	2.390	686	.017	.401	.168	.072	.730
Equal variances not assumed			2.387	673.831	.017	.401	.168	.071	.731

Appendix 8.33 - Independent sample T-test comparing means of temperature at which persons of varying education levels perceive comfort in unconditioned environments where comfort temperatures are restricted to between 30°C-to-35°C.

Education levels: 2 & 3 School class 1-5 – School class 5-9

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	7	33.34	1.078	.408
	School class 5-9	39	32.28	1.068	.171

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	.186	.668	2.416	44	.020	1.061	.439	.176	1.946
Equal variances not assumed			2.400	8.259	.042	1.061	.442	.047	2.075

Education levels: 2 & 4 School class 1-5 – Matric

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	7	33.34	1.078	.408
	Matric	127	31.71	1.135	.101

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	.296	.588	3.720	132	.000	1.636	.440	.766 2.506
	Equal variances not assumed			3.896	6.754	.006	1.636	.420	.636 2.636

Education levels: 2 & 5 School class 1-5 – Intermediate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	7	33.34	1.078	.408
	Intermediate	272	31.89	1.133	.069

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	.356	.551	3.344	277	.001	1.449	.433	.596 2.302
	Equal variances not assumed			3.505	6.346	.012	1.449	.413	.451 2.447

Education levels: 2 & 6 School class 1-5 – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	7	33.34	1.078	.408
	Graduate	265	31.67	1.268	.078

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	1.507	.221	3.453	270	.001	1.672	.484	.718 2.625
	Equal variances not assumed			4.028	6.446	.006	1.672	.415	.673 2.670

Education levels: 2 & 7 School class 1-5 – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 1-5	7	33.34	1.078	.408
	Post-graduate	225	31.71	1.197	.080

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.736	.392	3.565	230	.000	1.634	.458	.731 2.537
	Equal variances not assumed			3.934	6.469	.007	1.634	.415	.635 2.633

Education levels: 3 & 4 School class 5-9 – Matric

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	39	32.28	1.068	.171
	Matric	127	31.71	1.135	.101

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.088	.767	2.804	164	.006	.575	.205	.170 .980
	Equal variances not assumed			2.897	66.512	.005	.575	.198	.179 .971

Education levels: 3 & 5 School class 5-9 – Intermediate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	39	32.28	1.068	.171
	Intermediate	272	31.89	1.133	.069

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.156	.693	2.014	309	.045	.388	.193	.009 .767
	Equal variances not assumed			2.105	51.058	.040	.388	.184	.018 .758

Education levels: 3 & 6 School class 5-9 – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	39	32.28	1.068	.171

Graduate	265	31.67	1.268	.078
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Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	3.360	.068	2.861	302	.005	.611	.213	.191 1.031
	Equal variances not assumed			3.249	55.061	.002	.611	.188	.234 .987

Education levels: 3 & 7 School class 5-9 – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	School class 5-9	39	32.28	1.068	.171
	Post-graduate	225	31.71	1.197	.080

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	1.006	.317	2.802	262	.005	.573	.205	.170 .976
	Equal variances not assumed			3.037	55.902	.004	.573	.189	.195 .951

Education levels: 5 &6 Intermediate – Graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Intermediate	272	31.89	1.133	.069
	Graduate	265	31.67	1.268	.078

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower Upper
Temp.oC	Equal variances assumed	8.048	.005	2.148	535	.032	.223	.104	.019 .427
	Equal variances not assumed			2.145	524.947	.032	.223	.104	.019 .427

Appendix 8.34 - Independent sample T-test comparing means of temperature at which persons of varying occupations perceive cold discomfort in conditioned environments

Education levels: 4 & 7 Matric – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Matric	3	26.43	.751	.433
	Post-graduate	52	28.10	3.976	.551

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	5.498	.023	-.718	53	.476	-1.665	2.318	-6.313	2.984
	Equal variances not assumed			-2.374	12.440	.034	-1.665	.701	-3.187	-.143

Education levels: 6 & 7 Graduate – Post-graduate

Group Statistics

	education level	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Graduate	35	26.07	3.443	.582
	Post-graduate	52	28.10	3.976	.551

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	2.129	.148	-2.454	85	.016	-2.024	.825	-3.663	-.384
	Equal variances not assumed			-2.525	79.654	.014	-2.024	.802	-3.619	-.428

Appendix 8.35 – Independent sample T-test comparing the means of comfort temperature for the lowest SEP population in unconditioned environments based on prior exposure to conditioned work environments

Group Statistics

	climate office hours	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Fan	45	32.48	2.394	.357
	A/C	94	31.51	2.332	.240

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.134	.715	2.279	137	.024	.972	.426	.129	1.815
	Equal variances not assumed			2.258	84.765	.027	.972	.430	.116	1.827

Appendix 8.36 - Independent sample T-test comparing the means of comfort temperature for the lowest SEP population in unconditioned environments based on prior exposure to conditioned work environments where comfort temperatures are limited to 30°C-35°C.

Group Statistics

	climate office hours	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Fan	35	32.39	1.252	.212
	A/C	72	31.39	1.089	.128

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.291	.258	4.233	105	.000	.998	.236	.531	1.466
	Equal variances not assumed			4.032	59.720	.000	.998	.248	.503	1.494

Appendix 8.37 - – Independent sample T-test comparing the means of cold discomfort temperature for the low (and lower) SEP population in conditioned environments based on prior exposure to conditioned work environments

Group Statistics

	climate day	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Fan	20	26.52	2.551	.570
	A/C	23	24.04	3.002	.626

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	.595	.445	2.902	41	.006	2.486	.857	.756	4.216
	Equal variances not assumed			2.935	40.984	.005	2.486	.847	.775	4.196

Appendix 8.38 - Independent sample T-test comparing the means of cold discomfort temperature for the low (and lower) SEP population in conditioned environments based on prior exposure to conditioned work environments where cold discomfort temperatures are limited to 21°C-26°C

Group Statistics

	climate day	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	Fan	12	24.75	.984	.284
	A/C	14	23.20	1.808	.483

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	5.405	.029	2.648	24	.014	1.550	.585	.342	2.758

Equal variances not assumed			2.765	20.625	.012	1.550	.561	.383	2.717
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Appendix 8.39 - Independent sample T-test comparing the means of comfort temperature for the various population groups based on age in unconditioned environments.

Age group: 1&6

18-24 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	18-24	423	31.80	2.137	.104
	65+	7	29.34	1.223	.462

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.089	.297	3.038	428	.003	2.462	.810	.869	4.055
	Equal variances not assumed			5.195	6.621	.001	2.462	.474	1.328	3.595

Age group: 2&6

25-34 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	25-34	422	31.72	2.225	.108
	65+	7	29.34	1.223	.462

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				95% Confidence Interval of the Difference		
		F	Sig.	t	df	Sig. (2- tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC	Equal variances assumed	1.637	.201	2.819	427	.005	2.379	.844	.720	4.037
	Equal variances not assumed			5.010	6.676	.002	2.379	.475	1.245	3.513

Age group: 3&4

35-44 –to- 45-54

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	35-44	189	32.06	2.182	.159
	45-54	113	31.48	2.088	.196

Independent Samples Test

Levene's Test for Equality of Variances	t-test for Equality of Means
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	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.498	.481	2.292	300	.023	.585	.255	.083	1.088
Equal variances not assumed			2.317	244.041	.021	.585	.253	.088	1.083

Age group: 3&5 35-44 –to- 55-64

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	35-44	189	32.06	2.182	.159
	55-64	37	31.21	2.670	.439

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	.281	.597	2.099	224	.037	.856	.408	.053	1.659
Equal variances not assumed			1.833	45.879	.073	.856	.467	-.084	1.796

Age group: 3&6 35-44 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	35-44	189	32.06	2.182	.159
	65+	7	29.34	1.223	.462

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	1.566	.212	3.275	194	.001	2.721	.831	1.082	4.360
Equal variances not assumed			5.567	7.495	.001	2.721	.489	1.581	3.862

Age group: 4&6 45-54 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	45-54	113	31.48	2.088	.196
	65+	7	29.34	1.223	.462

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper

	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	1.072	.303	2.671	118	.009	2.136	.800	.552	3.719
Equal variances not assumed			4.252	8.347	.003	2.136	.502	.986	3.286

Age group: 5&6 55-64 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	55-64	37	31.21	2.670	.439
	65+	7	29.34	1.223	.462

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	1.192	.281	1.799	42	.079	1.865	1.037	-.227	3.957
Equal variances not assumed			2.926	19.109	.009	1.865	.638	.531	3.199

Appendix 8.40 - Independent sample T-test comparing the means of comfort temperature for the various population groups based on age in unconditioned environments where comfort temperature range is restricted to 30°C-to-35°C

Age group: 3&6 35-44 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	35-44	156	31.95	1.345	.108
	65+	2	31.05	.071	.050

Independent Samples Test

			Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Temp.oC Equal variances assumed	4.304	.040	.942	156	.347	.899	.954	-.985	2.783
Equal variances not assumed			7.572	27.891	.000	.899	.119	.656	1.142

Age group: 4&6 45-54 –to- 65+

Group Statistics

	age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	45-54	90	31.87	1.239	.131

65+	2	31.05	.071	.050
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Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	4.333	.040	.935	90	.352	.823	.881	-.926	2.573
Equal variances not assumed			5.888	40.165	.000	.823	.140	.541	1.106

Age group: 5&6 55-64 –to- 65+

Group Statistics

	Age group	N	Mean	Std. Deviation	Std. Error Mean
Temp.oC	55-64	31	31.82	1.327	.238
	65+	2	31.05	.071	.050

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Temp.oC Equal variances assumed	5.510	.025	.811	31	.423	.773	.952	-1.169	2.714
Equal variances not assumed			3.173	30.903	.003	.773	.243	.276	1.269

Appendix 8.41 – Predicted Values of Indoor thermal comfort temperatures for unconditioned environments from linear and quadratic equations for the lowest and highest socio-economic groups

To	Tc low SEP-linear equation	Tc high SEP linear equation	Tc low SEP quadratic equation	Tc high SEP quadratic equation
	$27.59+0.15T_o$	$30.8+0.05 T_o$	$23.08+0.44 T_o+4.67E^{-3} T_o^2$	$31.14+0.02 T_o+3.26E^{-4} T_o^2$
25	31.34	31.33	31.22	31.84
26	31.49	31.38	31.43	31.88
27	31.64	31.43	31.63	31.92
28	31.79	31.48	31.82	31.96
29	31.94	31.53	32.00	31.99
30	32.09	31.58	32.17	32.03
31	32.24	31.63	32.33	32.07
32	32.39	31.68	32.48	32.11
33	32.54	31.73	32.62	32.16
34	32.69	31.78	32.76	32.20
35	32.84	31.83	32.88	32.24
36	32.99	31.88	33.00	32.28
37	33.14	31.93	33.10	32.33
38	33.29	31.98	33.20	32.37

39	33.44	32.03	33.29	32.42
40	33.59	32.08	33.37	32.46
41	33.74	32.13	33.44	32.51
42	33.89	32.18	33.50	32.56
43	34.04	32.23	33.55	32.60
44	34.19	32.28	33.59	32.65
45	34.34	32.33	33.63	32.70

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