Studying the Adaptive Comfort Model
A Case Study in Arid Climate: Cairo, Egypt.

Amgad Aly Fahmy Farghal

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Amgad Aly Fahmy Farghal, M.Sc.

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Hauptreferent: Prof. Andreas Wagner
Karlsruhe Institute für Technologie (KIT), Deutschland.

Korreferent: Prof. Richard de Dear
The University of Sydney, Australia

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Abstract

Thermal Comfort is an important parameter in determining user satisfaction; the definition of the boundaries affecting comfort conditions allows energy conservation and helps in setting the standards. This study focused on investigating the thermal environment and its effect on the comfort mechanism in the hot arid climate of Cairo, Egypt.

The effects of individual factors on the perception and preference of occupants in three educational buildings in the Greater Cairo Region were studied. The buildings were allocated in Cairo University and Ain Shams University and The Arab Academy for Science and Technology (AAST), the first two buildings are naturally ventilated and the third building is a mixed mode one. The buildings were analyzed in order to form a class three thermal comfort field study. The development of the questionnaire used in the study is discussed showing the common questions adopted from other similar research work and the modifications made to suit the study in a different culture.

The architecture department in all the former places was the focus of the study. In Cairo University there are four floors each 2225m^2 serving the department's needs, the study examined the main halls of 1250 m^2 where sections are held, and also the lecturing space of 225 m^2 were examined together with employees' rooms ranging from 50 m^2 to 100 m^2. In Ain Shams University two floors each 1850 m^2 is serving the department of architecture, the examined spaces include drawing halls and studios of 975 m^2, and lecturing halls of 145 m^2, employees' rooms range from 50 m^2 to 100 m^2. In AAST building the spaces used to serve the department's needs are allocated within the four floors of the building, the department is using drawing halls and studios of about 275 m^2 and the lecturing halls are about 75 m^2, employees' rooms are about 100 m^2.

The study shows the difference between comfort perceptions according to the different size of examined spaces. The field studies were carried out during the autumn 2007, spring 2008, autumn 2008 and spring 2009. A transverse sampling was used in the field studies, the days selected in the four field studies considered the main schedule

of the working days excluding days after holidays in order to avoid any bias in the data obtained. Three intervals of time were considered, from 10 to 12 in the morning, from 12 to 2 at noon and from 2 to 4 resembling the end of day.

Data gathered represent physical measurements of air temperature and relative humidity in the examined spaces, together with the data from a paper based survey filled by the subjects at the end of their classes. Air temperature and relative humidity were measured using data loggers (Hobo of the company Onset), and a Nomad portable weather station (Casella) were used in some days of the survey to verify the data from the data loggers.

The survey results were processed, correlations between thermal sensations and physical parameters were found and the neutral temperatures were calculated for each season. The buildings' thermal environments were checked for conformity to the acceptable environments according to the adaptive comfort model implemented in the international ASHRAE Standard 55-2004. The data points representing the indoor temperatures for votes rating (slightly cool, just right and slightly warm) on the ASHRAE scale were correlated with their corresponding mean outdoor temperatures, and then plotted against the adaptive comfort model. The results showed that the population of the study could bear higher indoor temperatures than that incorporated in the current model. The Adaptive Comfort Model and the detailed slopes of different climatic zones for different buildings were analysed. An ANOVA test for different buildings' neutralities across different climatic zones resulted in a significant difference between these thermal neutralities which can be explained by the different climates, this led to the suggestion of a variable comfort model depending on different climate zones.

Eine Untersuchung des Adaptiven Komfortmodells
Eine Felduntersuchung in einem trockenen Klima: Kairo, Ägypten

Kurzfassung

Der thermische Komfort ist ein wichtiger Parameter bei der Ermittlung der Nutzerzufriedenheit. Die Bestimmung von Komfortgrenzwerten ermöglicht Energieeinsparungen und hilft beim Festlegen von Normen. Diese Studie untersucht die thermischen Bedingungen im trockenheißen Klima Kairos und ihren Einfluss auf den Komfortmechanismus.

Der Einfluss individueller Faktoren auf das Empfinden und die Präferenz von Nutzern in drei Hochschulgebäuden im Großraum Kairo wurde untersucht. Die Gebäude gehören zur Universität Kairo, zur Ain Shams University und zur Arabischen Akademie für Wissenschaft und Technik (AAST). Die ersten beiden Gebäude sind natürlich belüftet, das dritte Gebäude ist klimatisiert. Die Studie ist als Felduntersuchung des thermischen Komforts angelegt, die den Anforderungen der Klasse 3 nach ASHRAE RP-884 entspricht. Die Entwicklung des Fragebogens, der in dieser Untersuchung verwendet wurde, wird erläutert. Dabei wird gezeigt, welche Fragen aus anderen, ähnlichen Forschungsarbeiten übernommen wurden und welche Anpassungen an den kulturellen Hintergrund vorgenommen wurden.

Schwerpunkt der Untersuchung waren die Architekturfakultäten der oben genannten Einrichtungen. Die Architekturfakultät der Universität Kairo verfügt über vier Geschosse mit jeweils 2.225 m² Fläche. Die Studie untersuchte die 1.250 m² großen Säle, in denen Übungen stattfinden, Hörsäle von jeweils 225 m² und Räume der Angestellten, die 50 bis 100 m² groß sind. Die Architekturfakultät der Ain Shams University verfügt über zwei 1.850 m² große Geschosse. Die untersuchten Bereiche umfassen Zeichensäle und Studios von 975 m², Hörsäle von 145 m² und Räume der Angestellten, die 50 bis 100 m² groß sind. In der AAST sind die Räume der Architekturfakultät im viergeschossigen AAST-Gebäude untergebracht. Die Fakultät

nutzt Zeichensäle und Studios von ca. 275 m² und Hörsäle von ca. 75 m², die Räume der Angestellten sind ca. 100 m² groß.

Die Studie zeigt die Abhängigkeit des Komfortempfindens von der Größe des untersuchten Raumes. Die Felduntersuchungen wurden im Herbst 2007, Frühling 2008, Herbst 2008 und Frühling 2009 durchgeführt und sind als Querschnittstudie angelegt. Bei der Auswahl der Tage für die vier Felduntersuchungen wurde der Stundenplan berücksichtigt. Arbeitstage nach Feiertagen wurden ausgeschlossen, um Verzerrungen in den gewonnenen Daten zu vermeiden. Drei Zeitabschnitte wurden betrachtet, 10:00 bis 12:00 Uhr am Vormittag, 12:00 bis 14:00 Uhr am Mittag und 14:00 bis 16:00 Uhr als Ende des Arbeitstages.

Die gesammelten Daten umfassen physikalische Messungen der Lufttemperatur und der relativen Feuchte in den untersuchten Räumen sowie die Daten aus den Papierfragebögen, die von den Probanden am Ende ihres Unterrichts ausgefüllt wurden. Lufttemperatur und relative Feuchte wurden mit Hilfe von Hobo-Datenloggern gemessen (Firma Onset), eine tragbare Nomad-Wetterstation (Firma Casella) wurde an einigen Tagen verwendet, um die Messwerte der Datenlogger zu überprüfen.

Bei der Analyse der Daten zeigten sich Korrelationen zwischen thermischem Empfinden und physikalischen Parametern, die neutrale Temperatur wurde für jede Jahreszeit berechnet. Die Konformität der Raumklimabedingungen der Gebäude mit den Komfortgrenzen des adaptiven Komfortmodells nach dem internationalen ASHRAE Standard 55-2004 wurde überprüft. Die Innentemperaturen, die bei einer Bewertung auf der ASHRAE-Skala von „eher kühl", „genau richtig" oder „eher warm" gemessen wurden, wurden mit der entsprechenden mittleren Außentemperatur korreliert und dann mit dem adaptiven Komfortmodell verglichen. Die Ergebnisse zeigen, dass die Grundgesamtheit dieser Studie höhere Innentemperaturen akzeptiert als das aktuelle Modell ausweist. Das adaptive Komfortmodell und die Wertekurven verschiedener Klimazonen mit mehreren Gebäuden wurden analysiert. Eine Varianzanalyse des neutralen Wertes verschiedener Gebäude in unterschiedlichen Klimazonen zeigte einen signifikanten Unterschied zwischen diesen neutralen Werten, der mit den verschiedenen Klimaten erklärt werden kann. Daraus wurde der Vorschlag eines variablen Komfortmodells abgeleitet, das die Klimazone berücksichtigt.

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CHAPTER ONE RESEARCH OVERVIEW

1.1 INTRODUCTION

Thermal comfort standards are required to help building designers and managers to provide a satisfying indoor climate that building occupants will find thermally comfortable. The definition of a good indoor climate is important to the success of a building; it secures comfortable indoor thermal conditions and at the same time regulates the energy consumption in the building. As humans can and do live in a range of climates from the tropics to high latitudes, the internationally accepted definition of thermal comfort as used by ASHRAE is **“that condition of mind which expresses satisfaction with the thermal environment”.** Perceptions of this environment are mainly affected by six parameters, four that are measured represented in air temperature, radiant temperature, relative humidity and air velocity. The other two parameters are estimated represented in the activity and clothing of subjects (Nicol and Humphreys 2002).

In order to define a thermal comfort range two approaches have been developed, in both approaches tests with people giving subjective votes and correlating them with measured climate parameters were performed. The first approach depends on tests in laboratory using climate chambers, while the second approach depends on field experiments in real buildings testing people in their real environment. The first approach determined a range of comfort temperatures which occupants of buildings will find comfortable. This range is mainly determined in the ASHRAE standard 55-2004 by a PMV “predicted mean vote” derived from studies of individuals in tightly controlled conditions. According to further studies, the feasibility to meet such range is found in buildings including air conditions and may as well include heating systems; these buildings provide better temperature control than could be obtained from opening windows.

The second approach which is the adaptive approach is based on field surveys of thermal comfort, and demonstrates that people are more tolerant to temperature changes than climate chamber studies. Occupants consciously and unconsciously act to affect the heat balance of the body. These actions may change metabolic heat production by changing activity or affecting the rate of heat loss from the body by changing clothing and posture, or change their thermal environment by controlling windows, doors, blinds, fans, etc. Adaptive variables are extremely important in “free running buildings” those buildings without active heating or cooling systems (Gossauer and Wagner 2007).

1.2 PROBLEM DEFINITION

The adaptive comfort model implemented in the ASHRAE standard 55-2004 is a relation between mean outdoor air temperature and the corresponding acceptable indoor air temperatures. The standard is based mainly on 36 naturally ventilated buildings, where most of these buildings represent the moderate climates and only two buildings representing the desert climate. The effect of this is that the standard is limited to the mean outdoor temperatures ranging from 10 °C to 33 °C, while the mean outdoor temperatures in hot arid climates in the summer reach a higher limit. The study of the relation between mean outdoor temperatures and accepted indoor temperatures in hot arid climates may give a wider range than that incorporated in the existing standard.

Another issue is that the adaptive comfort standard is generalised over different climatic zones. The classification of the standard into different climate zones, and setting a standard to each climate may expand the range of acceptable temperatures and give the opportunity for more energy conservation.

1.3 RESEARCH SCOPE

The research is mainly based on educational buildings in the Greater Cairo Region, in Egypt, a hot arid climate. The buildings are studied in the autumn and spring seasons where most of the academic calendar lies. The outcomes represented two types of buildings, the naturally ventilated educational buildings and the mixed mode educational buildings. The results could not be generalized over the whole country unless other studies are carried out in other different building types and different climatic zones within the country.

1.4 RESEARCH GOAL

The intention of the fieldwork was to observe and specify the different thermal environments within each building, determine the comfortable temperatures and the acceptable environments as indicated by the occupants, also to investigate the effect of different indoor thermal environments within and between spaces on the occupants' comfort and satisfaction, characterize the main physical and psychological factors influencing thermal comfort and satisfaction perception, and to compare the results obtained with the current adaptive comfort standard.

1.5 RESEARCH METHODOLOGY

The research is divided into three parts. The first is a review concerning the thermal comfort research, in an attempt to formulate a detailed background about the subject and to accomplish the understanding of the basic ideas behind thermal comfort. In this section a review of the literature that deals with thermal comfort is carried out, where the main principles of comfort are set to formulate the second part.

The research follows in its second part by an analytical approach explaining the research methodology and the data analysis. This part introduces the methodology followed in the field studies carried out and explains the methods used to gather different types of data and the reasoning behind each. It also discusses the methods used in the analysis of the data. The part of data analysis extracts the outcome from the field studies and correlates the comfort votes to the thermal environments' variables.

Finally, concluding the experience gained in the previous part, the third part shows the conclusion from the data analysis and applies the conclusions to a wider scope. Figure 1 shows the map of the research methodology.

The Research Methodology			
Part one	Theoretical	**Chapter One** Introduction To The Study	Introduce the research aims, scope and methodology
		Chapter Two Literature Review	Introduce the historic review about thermal comfort and the precedent actions and prospective aims.
Part Two	Analytical	**Chapter Three** Objectives and Methodology	Showing the objectives of the research and the methods followed in obtaining data.
		Chapter Four Data Analysis	Introduce the outcome from the data gathered and its analysis.
		Chapter Five Discussion	Discuss the data analyzed from the previous chapter and compare them to other research outcomes
Part Three	Evaluation	**Chapter Six** Conclusion	Conclusion and set of parameters to act as guiding for the future

Figure 1: The research methodology

CHAPTER TWO LITERATURE REVIEW

2.1 INTRODUCTION

Building occupants are affected by the design of buildings and their input after occupancy, where they can evaluate real life conditions, is a valuable source of data. The data gathered can be used to judge the indoor thermal quality, and its effect on comfort. Achieving thermal comfort is the main target behind designing mechanically conditioned office buildings (Schiller 1990). It was found that temperature is one of the most important aspects that affect the occupants' satisfaction and at the same time it is one of the factors that users frequently complain from (Brill, et al. 1984).

As climate control devices are among the largest sources of energy use in buildings, it is important to balance energy savings against occupant needs. This could be used to determine the range of thermal comfort conditions that could be used in the design of new buildings. A lot of studies were carried out in recent decades aiming at determining the comfortable thermal conditions within different types of buildings regarding the methods of heating and cooling used in each. In these studies, two main methodical approaches were used. The first was laboratory experiments using a climate chamber as an environment for the study. The second method was running field studies in real life context using real buildings as an environment of the study. Advantages and disadvantages of both types are pointed out in this chapter and the outcome of both approaches is described. Moreover, the second method of field studies is fully discussed as it is the base of this research.

2.2 HISTORIC REVIEW

Thermal comfort is an important issue, hence a wide variety of scientific disciplines are interested in studying it, ranging from environmental psychologists, concerned with perceived comfort and productivity in buildings, to engineers (Gossauer and Wagner 2007). Comfort conditions from the physiological point of view can be obtained when a person maintains a normal balance between production and loss of heat at normal body temperature and without sweating (Yaglou 1949).

Other concepts, which are of interest to many of the comfort community, are based on three main assumptions as pointed out by (Auliciems 1981). The first assumption describes the relation between thermoregulatory activity and subjective acceptability, indicating that minimal thermoregulatory activity is equated to maximum subjective acceptability. The second assumption sets the relation between thermal sensation and levels of discomfort implying that both are synonymous. The third assumption determines that perception of warmth is exclusively the function of thermal stimuli. None of the previous assumptions consider that thermal sensation depends on parameters of past cultural and climatic experience and personal expectations.

It was until the late seventies when comfort community depended on the previous concepts in deriving their comfort models. These concepts are translated into equivalent relations between different variables that are related to comfort as shown in Table 1. As indicated by (Auliciems 1981), the need to consider environmental perceptions beyond the level of physiological reception, response and simple evaluation is implied in the above description of comfort relations.

In the 1980s there was a great progress in the air conditioning industry, and buildings were strongly influenced by social, technical and material changes. The former progresses lead to the extension of the definition of thermal comfort to include the environmental and expectations from memory. It was argued that thermal comfort is a multivariate phenomenon that is influenced by behaviour (clothing and activity) and expectations as well as by environment and memory (Brager and de Dear 2003).

Today, the general and common definition of thermal comfort is given in ASHRAE 55, in 1992, as "**that condition of mind that expresses satisfaction with the thermal environment".** The term "expresses satisfaction" must involve, in addition to the affective component, that of cognition which is necessary to the processes of environmental perception. With the growing complexity of indoor environment, it became almost impossible to "measure" comfort directly (Brager and de Dear 2003).

The following parts of this chapter will describe the different methodical approaches of measuring thermal comfort as well as the outcome and drawbacks of each.

Table 1: The schedule shows the Relations between different variables, as assumed by traditional comfort research. (Auliciems 1981)

Environmental Warmth	Thermoregulatory response	Thermal sensation	Assumed comfort level
Hotter than neutral	Sweating	Warm - Hot	Unacceptable
Nearly neutral	Vasodilatation	Slightly warm	Acceptable
Neutral	Minimal	None	Maximum
Nearly neutral	Vasoconstriction	Slightly cool	Acceptable
Colder than neutral	Thermo genesis	Cool - Cold	Unacceptable

2.3 COMFORT MODELS

In order to discover formulas that describe the thermal comfort state, subjective sensations resulting from external thermal stimuli are adopted as a valid measure of the thermal quality of the surrounding thermal environment. The estimation of the thermal comfort level is largely based upon the responses on verbal scales of sensation. Subjects are asked to vote, expressing their sensation on a verbal scale. Measurements of the physical environmental factors are also determined. Both are, then, combined in order to indicate the conditions of the thermal comfort state.

The study, here, will focus on the thermal comfort models implemented in the ASHRAE standard 55 (2004). Two types of thermal comfort models form the base of the standard in order to define temperature ranges that should result in thermal satisfaction for at least 80% of occupants in a space. The standard is based on two types of thermal comfort models. The first is developed by Fanger and colleagues on the basis of laboratory studies (Fanger 1970). This is known as the Fanger's Predicted Mean Vote (PMV) model which is adopted by many international standards and guidelines, providing an index of thermal comfort. The second type of thermal comfort models is based on field studies in the real environments resulting in a new adaptive model developed in the 1990s by Brager and de Dear that is incorporated alongside the PMV model as an optional method to be used in the case of free running buildings. Both types of models will be discussed here.

2.3.1 Types of Thermal Comfort Models

Models can be classified into heat balance models and adaptive models. The heat balance models are mainly due to experiments in climate chambers, while the adaptive models are developed based on field studies. It became obvious that different results are obtained when testing people in their real life conditions, especially in the case when these conditions are not an air-conditioned space. In the 1970s the use of air conditioning and the development of new materials grew which brought up the necessity of quantifying thermal comfort (Gossauer and Wagner 2007). Today, the need to conserve energy in a manner that promotes the usage of naturally ventilated buildings but does not sacrifice the occupants' satisfaction implies the usage of adaptive thermal comfort models (de Dear and Brager 2002)

2.3.1.1 Heat balance models

Thermal comfort may be approached from the standpoint of thermal physiology. This approach seeks the body-states people find comfortable at various levels of activity, establishes the heat and moisture transfer properties of clothing, and evaluates the effects of the physical environment (air temperature, radiation exchange, air movement and humidity). The research is commonly conducted in climate controlled rooms with subjects in standard clothing and performing standard tasks. The resulting models of human response are used to assess the effect of any proposed environment and clothing ensemble. The best known model is the PMV-PPD model (Fanger 1972) which is incorporated into the ASHRAE standard 55; the model implies a steady state human heat balance, which is independent of external climate factors. It predicts the mean thermal sensation of a group of people on a scale from cold (-3) through neutral

(0) to hot (3), together with the predicted percentage of people dissatisfied (PPD) with the environment (Humphreys and Nicol 2007)

PMV is based on Fanger's comfort equation (see Equation 1). The satisfaction of the comfort equation is a condition for optimal thermal comfort of a large group of people, or, when most of this group experiences thermal neutrality, and no local discomfort exists (Fanger 1967). Fanger used data from another study (McNall, et al. 1967) to derive a linear relationship between activity levels and sweat rate. In this study, college-age participants, who were exposed to different thermal conditions while wearing standardised clothing, voted on their thermal sensation using the ASHRAE scale. The linear relationship was formed from those participants (n=183) who stated that they felt thermally neutral (i.e. voted '0') for a given activity level. Then another study was conducted, on 20 college-age participants, to derive a linear relationship between activity level and mean skin temperature (Fanger 1967). In this experiment, participants wore standardised clothing and took part in climate chamber tests at four different activity levels (sedentary, low, medium and high). It is important to note that participants were not asked to vote on their thermal sensation in this study. Instead, the experimental conditions used temperatures that had been found to achieve thermal neutrality in another study (McNall, et al. 1967). Although Fanger assumed that the participants were at, or near, thermal neutrality, this assumption was not directly tested (Charles 2003).

After that the results were transformed into two linear relationships of heat balance equations, to create a 'comfort equation'. The comfort equation describes all combinations of the six PMV input variables that result in a neutral thermal sensation. These variables are divided into four physical variables, air temperature, radiant temperature, air velocity and relative humidity, and two personal variables, the metabolic rate and clothing insulation. Activity level is measured in terms of metabolic rate, or met units, and clothing insulation in clo units, these values are estimated using tables (see Appendix A for estimation of metabolic rates and Appendix B for estimation of clothing insulation). The comfort equation was, then, validated against other studies (Nevins, et al. 1966) and (McNall, et al. 1967), in which college-age participants rated their thermal sensation in response to specified thermal environments. The predictions made by the comfort equation were in agreement with the results from these studies.

$$\mathbf{f\,(M,\,I_{cl},\,v,t_r,t_a,p_w) = 0}$$

Equation 1: Fanger's comfort Equation. Where M = metabolic rate in met units, Icl = cloth index in clo units. v = air velocity in m/s, tr = mean radiant temperature in ^{o}C, ta = ambient air temperature in ^{o}C, Pw = vapour pressure of water in ambient air in Pa units.

The comfort equation predicts conditions where occupants will feel thermally neutral. However, for practical applications, it is also important to consider situations where subjects do not feel neutral. By combining data from the previous studies with his own studies, Fanger used data from 1396 participants to expand the comfort equation. Fanger derived his comfort equation (Fanger 1967) based on college-age students exposed to steady-state conditions in a climate chamber for a 3-hour period in winter at sea level (1,013 hPa) while wearing standardized clothing and performing standardized activities while exposed to different thermal environments. The resulting equation described thermal comfort as the imbalance between the actual heat flow from the body in a given thermal environment and the heat flow required for neutral conditions for a given activity. This expanded equation related thermal conditions to a seven-point thermal sensation scale, and became known as the PMV index (Fanger 1970). The final equation for optimal thermal comfort is fairly complex and need not concern us here. The PMV model is based on the fact that the human body produces heat, exchanges heat with the environment, and loses heat by diffusion and evaporation of body liquids. During normal activities these processes result in an average core body temperature of approximately 37°C. The body's temperature control system tries to maintain these temperatures even when thermal disturbances occur. The human body should meet a number of conditions in order to perceive thermal comfort. According to (Fanger 1970) the requirements for steady-state thermal comfort are: (i) the body is in heat balance, (ii) mean skin temperature and sweat rate, influencing this heat balance, are within narrow limits, and (iii) no local discomfort exists. Local discomfort to be avoided includes draughts, radiant asymmetry, or temperature gradients. The PMV model applies to healthy adult people and cannot, without corrections, be applied to children, older adults and the disabled (Hoof 2008). The model has been globally applied for almost 40 years throughout all building types, although Fanger was quite clear that his PMV model was intended for application by the heating, ventilation and air-conditioning (HVAC) industry in the creation of artificial climates in controlled spaces (de Dear and Brager 2002).

Based on PMV, the predicted percentage of people dissatisfied (PPD) can be determined. The PPD index is related to the PMV as shown in Figure 2. It is based on the assumption that people voting +2, +3, –2, or –3 on the thermal sensation scale are dissatisfied, and the simplification that PPD is symmetric around a neutral PMV. The Predicted Percentage Dissatisfied (PPD is calculated from PMV, and predicts the percentage of people who are likely to be dissatisfied within a given thermal environment. The PMV and PPD form a U-shaped relationship, where percentage dissatisfied increases for PMV values above and below zero.

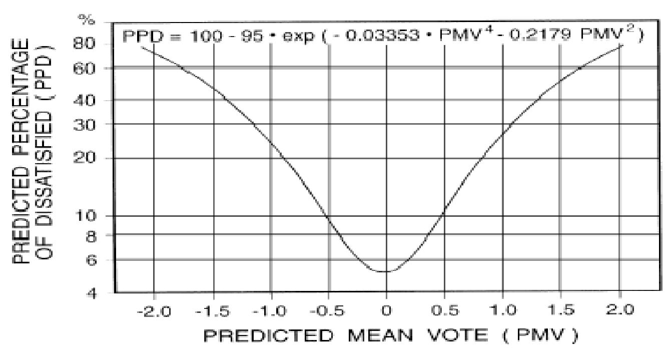

Figure 2: Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (ASHRAE standard-55, 2004)

The PMV thermal sensation index predicts the mean thermal sensation vote for a large group of persons and indicates the deviation from presumed optimal thermal comfort (thermal neutrality). The index provides a score that corresponds to the ASHRAE thermal sensation scale. It is generally accepted that a person with a thermal sensation in one of the three middle categories considers his environment acceptable, and that someone voting in one of the four outer categories is dissatisfied with his thermal environment (D. McIntyre 1980) (ASHRAE 2004).

To ensure a comfortable indoor environment, PMV should be kept 0 with a tolerance of ±0.5 scale units. Fanger stated that the PMV model was derived in laboratory settings and should, therefore, be used with care for PMV values below -2 and above +2 (Hoof 2008). The PMV model is designed to predict the average thermal sensation for a large group of people. Within such a group, optimal thermal conditions are likely to vary between individuals by up to 1.15ºC (Fanger and Langklide 1975), or up to 1 scale unit of the ASHRAE thermal sensation scale (Humphreys and Nicol 2002). Therefore, even if the thermal environment in a space is maintained in accordance with the PMV model, there will be some occupants who are thermally uncomfortable. These differences between people are acknowledged by (Fanger 1970), and are also reflected in the PPD index. At the neutral temperature, as defined by the PMV index, PPD indicates that 5% of occupants will still be dissatisfied with the thermal environment. Therefore, while the PMV model can be used to determine appropriate temperatures that will satisfy the majority of occupants, it is unrealistic to expect all occupants to be thermally satisfied.

2.3.1.2 Adaptive models

Thermal comfort may also be approached from the standpoint of human adaptation; this adaptive approach investigates the dynamic relation between people and their everyday environment, paying attention to the "adaptations" people make to their clothing and to their thermal environment to secure comfort. It sees thermal comfort as part of a self-regulating system because it concerns the whole range of actions people take to ensure their comfort. In the adaptive approach of modelling thermal comfort, it is not only the physics that affect the perception of the environment; other factors such as climatic settings, social conditioning, economic considerations and other contextual factors play a role in thermal preferences (Brager and de Dear 1998).

The adaptive hypothesis states that one's satisfaction with the indoor climate is achieved by matching the actual thermal environmental conditions prevailing at that point in time and space, with one's thermal expectations. This is achieved either through the way people interact with the environment and modify their own behaviour; or the way they may change their expectations and thermal preferences because of contextual factors and past thermal history. The adaptive theory explains thermal comfort, not as an exclusive product of heat balance formulae, but as a more holistic concept, involving other variables, in which human adaptation plays a fundamental role. The adaptive model reflects a 'give and take' relationship between the environment and the user, the person is no longer considered as a passive recipient but instead is an active agent interacting with and adjusting to the person-environment system via multiple feedback loops. There are mainly three feedback loops, behavioural feedback-adjustment, physiological feedback-acclimatization and psychological feedback – habituation and expectation; each is discussed here in details (de Dear, Brager and Cooper 1997).

1) **Behavioral feedback – adjustment:**

Also referred to as physical adaptation, which mainly includes all modifications a person can consciously or unconsciously make in order to change the heat and mass fluxes governing the body's thermal balance. The sense of discomfort is considered an initiator of the adaptive response; physical adaptation is considered as being the most effective form of adaptation, offering the greatest opportunity for people to play an active role in maintaining their own comfort. Figure 3 summarizes the behavioural feedback loop.

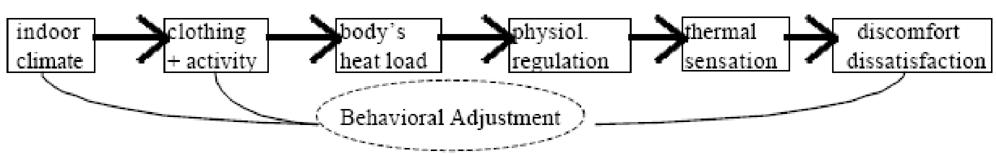

Figure 3: Behavioral feedback loop. (de Dear, Brager and Cooper 1997)

Physical adjustment can be categorized into three main categories as follows (Brager and de Dear 1998):

a. Personal adjustment: which includes personal variables, where persons adjust themselves to the surroundings by adjusting clothing, activity, posture, eating or drinking hot and cold things, and even moving to a different location seeking more comfortable environments … etc.

b. Technological or environmental adjustment: this represents the interaction of the person with the surroundings that offer an opportunity to change the microclimate, for example, opening or closing windows, turning on fans or heating devices, adjusting blinds, and adjusting the HVAC controls … etc.

c. Cultural adjustments as scheduling activities, siestas or adjusting the dress codes … etc.

Contextual factors play a main role in determining the opportunity offered to the occupants to interact with their environments. Context can be described in terms of adaptive opportunity compared to the constraints or restrictions on the thermoregulatory degrees of freedom (Nicol and Humphreys 1973). A building can provide its owners an adaptive opportunity through its attributes (windows, floor plan … etc.), characteristics of the methods of cooling or heating (e.g. centralized HVAC or decentralized task conditioning controls at each workstation), the organizational and social conditions governing the space (e.g. type of dress code, place of working). The adaptive opportunity may be limited to a set of constraints that are classified into five main types: constraints due to climate, buildings in harsh or extreme climates might afford their occupants fewer adaptive opportunities. Economic constraints are considered in the cost of thermal environmental control. Constraints due to social custom or regulation, affecting the pattern of clothing and regulating the freedom to behavioral thermoregulation. Constraints due to task or occupation affect comfort, and finally constraints due to design.

The second type of adaptation is the:

2) Physiological feedback-acclimatization

Physiological adaptation involves changes in the human body's physiological responses, as a reaction to exposure to thermal environmental factors, in the form of repeated and prolonged exposure to stimuli, leading to a gradual diminution in the strain induced by such exposure (de Dear, Brager and Cooper 1997). There are two main forms of physiological adaptation:

a. Genetic adaptation: This becomes part of the genetic heritage of an individual or group of people. This type of adaptation develops at a time scale beyond the lifetime of an individual, and involves the time between generations.

b. Acclimatization: This can be carried out within a person's lifetime. Acclimatization occurs after several days of exposure to a certain thermal stimuli, e.g. hotter or cooler environments, but in general it is a prolonged seasonal process where its full attainment results from everyday experiences. Physiological acclimatization is mediated by the automatic nervous system and directly affects the physiological thermoregulation set points.

Acclimatization is an unconscious feedback loop mediated by the autonomic nervous system, which directly affects our physiological thermoregulation set points. Like the behavioural adjustment depicted earlier, the physiological feedback process of acclimatization can also be depicted schematically in Figure 4.

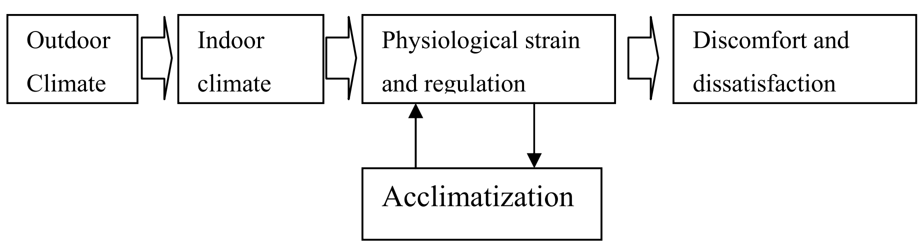

Figure 4: Physiological feedback loop. ((de Dear, Brager and Cooper 1997)

3) Psychological feedback – habituation and expectation

Psychological adaptation includes the effects of cognitive and cultural variables and describes the extent to which habituation and expectation alter one's perception of and reaction to sensory information. As described by researchers in psychophysics, it is the repeated exposure to an environmental stressor that leads to a diminution of the evoked sensation's intensity. Psychological adaptation, which is not considered in heat balance equations, can have a great influence on thermal comfort. Although being one of the most important adaptive processes, it is the least studied, mostly due to its complex nature. The adaptive model recognizes the potential for a feedback loop where one's past and current thermal experiences, with both indoor and outdoor climate, can directly affect one's thermal response and cognitive assessment of acceptability as described in Figure 5 (de Dear and Brager 1998).

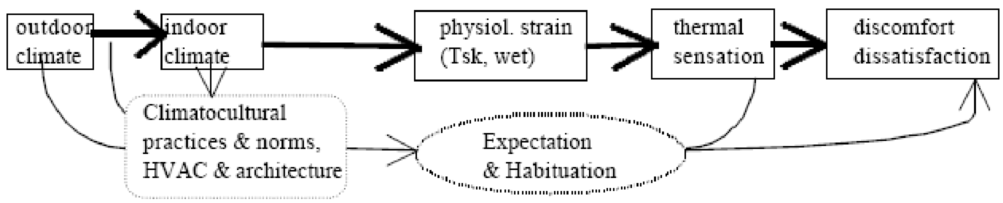

Figure 5: Psychological feedback loop. (de Dear, Brager and Cooper 1997)

The principle research method of getting an adaptive model is the field studies as fully described later in this chapter (Humphreys and Nicol 2007). The following is a review of some of the earliest studies of adaptation that resulted in adaptive comfort models; this will give a glimpse of the attempts done before the implementation of any of the adaptive models in the international standards. Then a peer review will explain the mechanism of the existing adaptive model that is part of the international standard ASHRAE – 55 (2004).

The early attempts at deducing an adaptive model was that of (M. A. Humphreys 1976), using the early field studies preceding the model by forty years, with a total number of observations exceeding 200,000, from a wide variety of climates and countries, ranging from winter in Sweden to summer in Iraq. The equation derived predicted the temperature of thermal neutrality, T_n, from the mean temperature, T_m, experienced by the respondents during the survey is Equation 2.

$$T_n = 2.56 + 0.831\ T_m\ (°C)........................(r = +\ 0.96)$$

Equation 2: The Adaptive Comfort Model of Humphrey's (1975). T_m is considered as the mean air temperature or the globe temperature recorded within the building, T_n is the neutral temperature

Figure 6 is a scatter diagram showing the mean temperature and the neutral temperature. Over 92% of the variation of the neutral temperature is associated with the variation of the mean temperature.

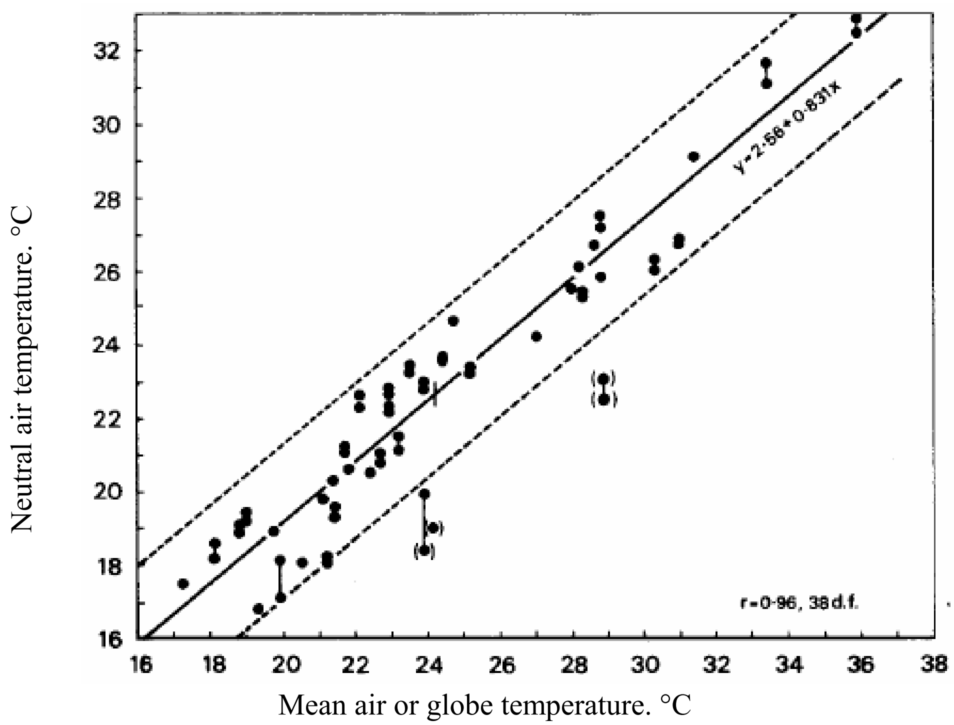

Figure 6: Scatter diagram of mean temperature and neutral temperature, for Humphrey's 1975 comfort model. After (M. A. Humphreys 1976)

After that, (Auliciems 1969) suggested that there might be a statistical relationship between indoor thermal neutralities and outdoor climate. (M. Humphreys 1978) investigated this relationship further and found convincing evidence for adaptation to outdoor climate as shown in Figure 7. The outdoor climate affected indoor neutrality especially in the case of free running buildings, which depended on natural ventilation. In such buildings, the adaptive model of dependence of indoor comfort temperatures upon the mean monthly outdoor temperature is depicted in Equation 3, where 94% of the variation of the neutral temperature in free running buildings is associated with the variation of the mean monthly outdoor temperature.

$$T_n = 11.9 + 0.534\ T_m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(r = 0.97)$$

Equation 3: The Adaptive comfort model of Humphreys (1978). Where T_n is the predicted neutral temperature and T_m is the mean outdoor temperature for the months in question.

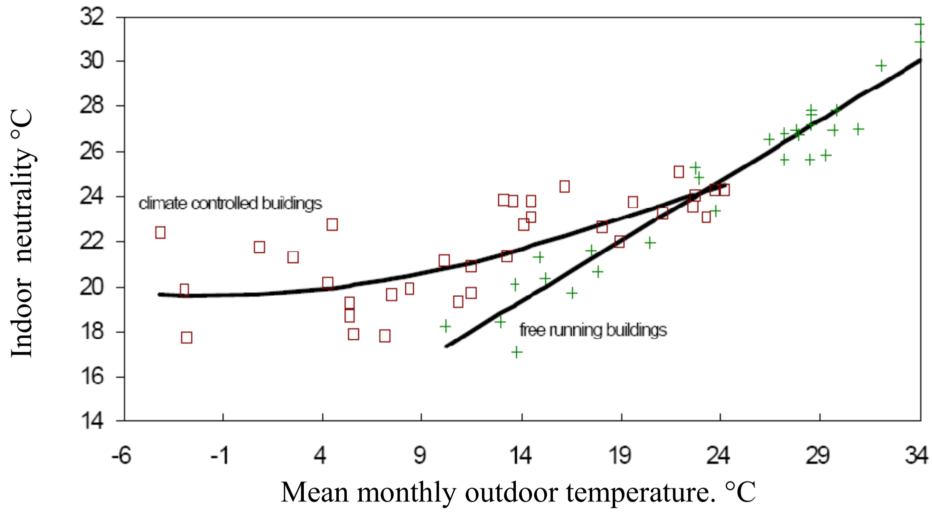

Figure 7: The statistical dependence of indoor thermal neutralities on climate. (After (M. A. Humphreys 1976)).

In 1981, Auliciems reviewed the data used by Humphreys, and supplemented it by others. These revisions increased the database to 53 separate field studies in various climatic zones covering more countries and more climates, resulting in an enlarged database. Using both types of buildings, the free running buildings and the conditioned ones, he derived the adaptive model in Equation 4, and this was valid for T_n between 18°C and 28°C.

$$T_n = 17.6 + 0.31\ T_m \ldots\ldots\ldots\ldots\ldots\ldots(r = 0.88)$$

Equation 4: The Adaptive comfort model of Auliciems (1981). Where T_n is the predicted neutral temperature and T_m is the mean outdoor temperature for the months in question.

Since then many other researchers found similar correlations, but none of these attempts were included in the international standards of thermal comfort. It was not until 1998 when a research (de Dear, Brager and Cooper 1997) based on the analysis of 21,000 sets of raw data compiled from field studies in 160 buildings, both air conditioned and naturally ventilated, located on four continents in different climatic zones, suggested the different ways the adaptive comfort model could be used for the design, operation, or evaluation of buildings, and for research applications. The resulting model was the base of the new ASHRAE standard -55 (2004) where it implemented an adaptive comfort model to be used as an optional method in free running buildings. The following is an explanation of this model which is the reference point in this study.

The purpose of ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy), is “to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space”. While “acceptability” is never precisely defined by the standard, it is commonly accepted within the thermal comfort research community that “acceptable” is synonymous with “satisfaction”, and that “satisfaction” is indirectly associated with thermal sensations of “slightly warm”, “neutral”, and “slightly cool”, and that “thermal sensation” is the question most commonly asked in both laboratory and field studies of thermal comfort.

The Adaptive Comfort Standard (ACS) is mainly an outcome of analyzing a global database of 21000 measurements accompanied with their subjective votes, where office buildings were the most common type of buildings surveyed. According to the method of heating and cooling used, the buildings could be classified into three main prototypes: air conditioned, naturally ventilated and mixed mode. Locations include Bangkok, Indonesia, Singapore, Athens, Michigan, several locations each in California, England, and Wales, six cities across Australia, and five cities in Pakistan.

The focus, here, will be on naturally ventilated buildings, where the natural ventilation occurred through operable windows that were directly controlled by the occupants. The standard includes an adaptive comfort model which is a relation between mean outdoor air temperature and the corresponding acceptable indoor air temperatures. The data concerning the naturally ventilated buildings in the global database were extracted separately, forming a subgroup depending only on naturally ventilated buildings. The statistical analysis underlying the model considered each building as the unit of analysis, and a weighted analysis followed, where the number of votes in each building represented the weight.

A comparison of the observed and predicted lines within each building illustrates the role of adaptation in free running building type as shown in Figure 8 . The difference between these two lines in the naturally ventilated buildings shows that such behavioural adjustments accounted for only half of the climatic dependence of comfort temperatures. The rest must come from influences not accounted for by the PMV model, and the analysis done by the researchers (de Dear, Brager and Cooper 1997) suggested that psychological adaptation is the most likely explanation.

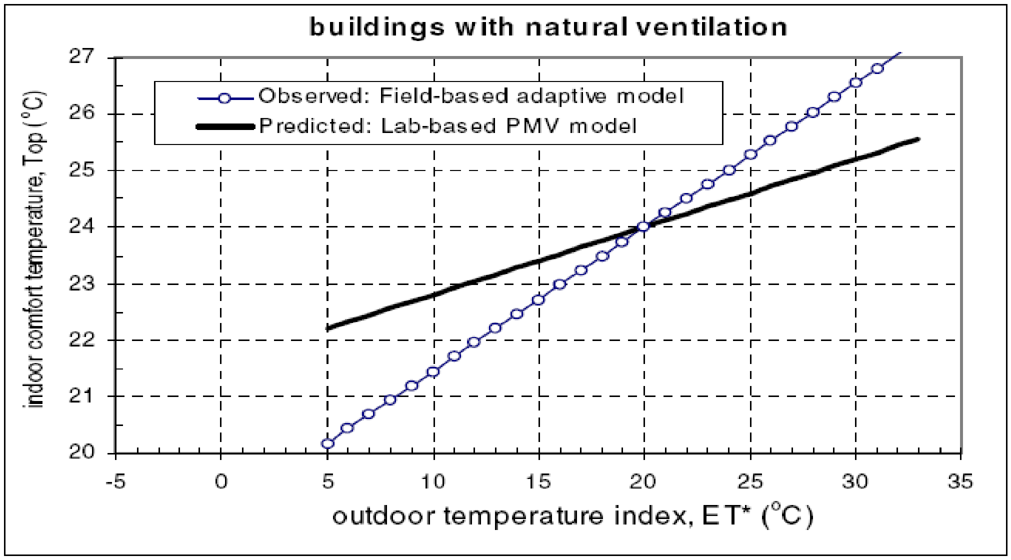

Figure 8: Observed and predicted indoor comfort temperatures from RP-884 database, for naturally ventilated buildings. (Brager and de Dear 2001)

The outdoor climatic environment for each building was characterized in terms of mean outdoor dry bulb temperature $T_{a,out}$, instead of ET*. Optimum comfort temperature, T_{comf}, was then re-calculated based on mean $T_{a,out}$ as in Equation 5.

$$T_{comf} = 0.31 \times T_{a,out} + 17.8 \text{ (deg C)}$$

Equation 5: The Adaptive Comfort Model of ASHRAE Standard 55 (2004). Where T_{comf} is the predicted comfortable temperature and $T_{a,out}$ is the mean outdoor temperature for the months in question (Brager and de Dear 2001)

Only statistically significant (at $p < 0.05$) buildings (data points) were considered, forming the data on which the (ACS) model is based upon. This criterion in the selection of the database forming the model resulted in 36 out of 44 significant buildings, with almost 8900 subjective votes. The buildings selected covered seven climatic zones, the type of each climatic zone and the number of buildings covering each zone is listed in Table 2.

The next step was to define a range of temperatures corresponding with 90% and 80% acceptability. Only a small subset of the studies in the RP-884 database included direct assessments of thermal acceptability, and the analysis of these data was not statistically significant. “Acceptability” was inferred from the thermal sensation votes, and started with the widely used relationship between group mean thermal sensation vote and thermal dissatisfaction (i.e., the classic PMV-PPD curve see Figure 2). The PMV-PPD relationship indicates that a large group of subjects expressing mean thermal sensation vote of +0.5 (or +0.85) could expect to have 10% (or 20%) of its members voting outside the central three categories of the thermal sensation scale. Applying the + 0.5 and + 0.85 criteria to each building’s regression model of thermal sensation ,as a function of indoor temperature, produced a 90% and 80% acceptable comfort zone, respectively, for each building. Arithmetically averaging those comfort zone widths for all the NV buildings produced a mean comfort zone band of 5°C for 90% acceptability, and 7°C for 80% acceptability, both centered on the optimum comfort temperature shown in Equation 5. These mean values were applied as a constant temperature range around the empirically-derived optimum temperature in Equation 5. The resulting 90% and 80% acceptability limits are shown in Figure 9.

As indicated by the standard, in order for this optional method to apply, the space in question must be equipped with operable windows that open to the outdoors and that can be readily opened and adjusted by the occupants of the space. There must be no mechanical cooling system for the space (e.g., refrigerated air conditioning, radiant cooling, or desiccant cooling). Mechanical ventilation with unconditioned air may be utilized, but opening and closing of windows must be the primary means of regulating the thermal conditions in the space. The space may be provided with a heating system, but this optional method does not apply when the heating system is in operation. It applies only to spaces where the occupants are engaged in near sedentary physical activities, with metabolic rates ranging from 1.0 met to 1.3 met. This optional method applies only to spaces where the occupants may freely adapt their clothing to the indoor and/or outdoor thermal conditions.

Table 2: Climatic zones covered by the Adaptive Comfort Standard are shown, and the number of buildings in each zone is indicated.

Climate	Number of Buildings
Desert	2
Semi Desert	6
West coast marine	8
Mediterranean	10
Humid subtropical	5
Tropical savannah	4
Wet equatorial	1
Total	36

A very similar adaptive comfort model is now implemented in the European standard EN 15251 (Indoor environmental input parameters for design and assessment of energy performance of buildings). The intended standard for thermal comfort for buildings in the free running mode is based on the data collected from the European project Smart Controls and Thermal Comfort (SCATs), where physical measurements were made and subjective responses were recorded in 26 European offices in France, Greece, Portugal, Sweden and the United Kingdom at monthly intervals over approximately one year.

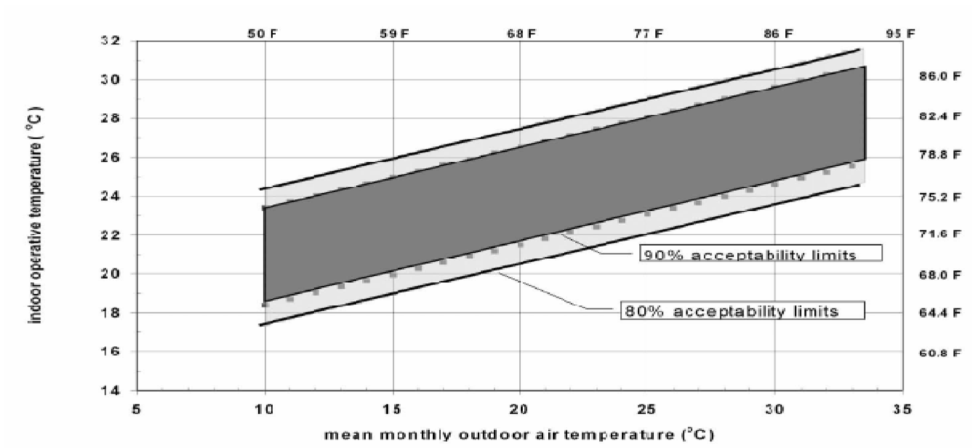

Figure 9: The adaptive comfort standard, showing the acceptable operative temperature ranges for naturally conditioned spaces. (ASHRAE Standard-55 2004)

Many of these data were gathered from naturally ventilated office buildings which were in free running mode outside the heating season. To be noticed that a free running building is one which no energy is being used either for heating or for cooling at the time of the survey. The use of fans to increase air movement doesn't exclude the building from the free running mode. These criteria resulted in 1449 buildings to represent the free running buildings and to be used for analysis to set out the standard.

To calculate the neutral temperature from fairly a small sample of comfort votes on a particular day in a particular building, the Griffiths method is used, where the neutral temperature can be calculated from the comfort vote using Equation 6, by assuming that a comfort vote of zero (neutral) will represent comfort. The Griffiths' constant describes the relation between subjective warmth and temperature assuming no adaptation takes place, the Grifiths constant is taken to be 0.5 in the calculation of the standard.

$$T_{comf} = Tg - C/G$$

Equation 6: The estimation of neutral temperature T_{comf} (°C) using Griffiths' method, where T_g is the globe temperature (°C), C is the comfort vote and G (K^{-1}) is the Griffiths constant. (Nicol and Humphreys 2010)

The adaptive approach to predicting neutral temperature in free running buildings has to relate the neutral temperature to a measure of outdoor temperature. An improvement on the monthly means in this standard is to use an exponentially weighted running mean of the daily mean air temperature. The exponentially weighted running mean temperature T_{rm} for any day is expressed in the series

$$T_{rm} = (1- \alpha) \{T_{od-1} + \alpha\, T_{od-2} + \alpha_2\, T_{od-3} \ldots\ldots\}$$

Equation 7: Where α is a constant (<1), T_{rm} is the exponentially weighted running mean temperature ,T_{od-1} etc are the 24 – daily mean temperature for yesterday, the day before and so on. (Nicol and Humphreys 2010)

For a series of days the value of T_{rm} for any day can be simply calculated from the value of the running mean and of the mean outdoor temperature for the previous day (T_{rm-1} and T_{od-1}) as in Equation 8.

$$T_{rm} = (1- \alpha)\, T_{od-1} + \alpha\, T_{rm-1}$$

Equation 8: The values of the exponentially weighted running mean temperature T_{rm} for any day. (Nicol and Humphreys 2010)

The resulted preferred relationship between neutral temperature and outdoor temperature using Griffiths' constant of value 0.5 and α of value 0.8 is:

$$T_{comf} = 0.33\, T_{rm} + 18.8$$

Equation 9: The adaptive comfort equation implemented in the European standard EN 15251. (Nicol and Humphreys 2010)

The limits of Equation 9 are shown in Figure 10, coming from Annex A2 in the standard. The categories shown in the diagram refer to the descriptors shown in Table 3 , and are placed in order of building type. Categories are defined by the type of building and are not intended to imply the superiority of a particular category. To achieve inclusion in any particular category the indoor operative temperature should not fall outside the given temperature range for more than 3-5 % of occupied hours at any particular running mean value of the outdoor temperature.

Category	Explanation	Limit (T_{diff}, K)
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2
II	Normal expectation for new buildings and renovations	±3
III	A moderate expectation (used for existing buildings)	±4
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	±>4

Table 3: Applicability of the categories and their associated acceptable temperature ranges in free-running mode. (Nicol and Humphreys 2010)

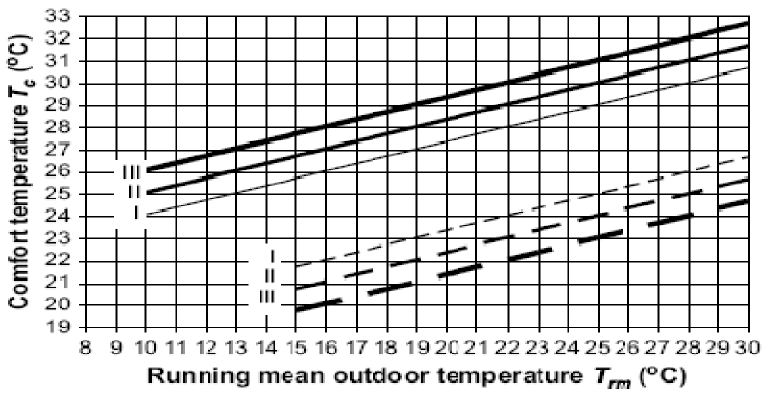

Figure 10: Design values for the upper (continuous lines) and lower (dashed lines) limits for operative temperature in buildings without mechanical cooling systems (free running) for the different categories of buildings as a function of the exponentially weighted running mean of the external temperature. (Nicol and Humphreys 2010)

Although the adaptive comfort charts of both standards, the ASHRAE standard and the European standard, are conceptually similar but there are many differences between both standards, these differences are as follows,

First of all the databases are different ASHRAE 55-2004 uses the data from the ASHRAE world database of field experiments collected by de Dear, while EN15251 uses the data from the more recent European SCATs project. Secondly the building classification is different The ASHRAE chart applies only to naturally ventilated buildings, while the EN15251 chart applies to any building in the free running mode. Another difference is the derivation of the neutral temperature. For EN15251 a standard relation between thermal sensation and operative temperature was derived, and then applied to every observation in the data. For the ASHRAE standard the data were divided into batches, each batch being the data from a particular survey in a particular building. Separate regression coefficients had been derived from each contributing batch of data, and batches whose regression coefficient failed to reach statistical significance were excluded. The different methods will not yield identical neutral temperature. Also the outdoor temperature is defined differently. The ASHRAE chart is expressed in terms of the monthly mean outdoor air temperature. For EN15251 contemporaneous weather data were used for all the contributing surveys. This enabled the construction and testing of an exponentially weighted running mean of the outdoor air temperature. (Nicol and Humphreys 2010)

2.3.2 Limitations of each type

Laboratory and field evidence, as well as everyday observations, establish that expression of human thermal states cannot be encompassed adequately by physiological parameters alone. At present, it is proved that thermal experiences and expectations are functions of both the natural climatic and techno-cultural environments, thus satisfaction is also related to both these environments. It is noted by a large number of researchers that people in different parts of the world may become accustomed to and express satisfaction with temperatures other than those found “comfortable” in other regions. These differences, therefore, may be – in part – a result of cultural factors, including levels of microclimatic control (Auliciems 1981). The limitation of both types of thermal comfort models is discussed below.

2.3.2.1 PMV-PPD

The strength of the PMV model is the possibility of comprehensive measurement in controlled conditions, and the use of sound experimental design (Humphreys and Nicol 2007). The PMV model is based on climate chamber experiments, during which the four physical variables (air temperature, mean radiant temperature, relative humidity, and air velocity) can be closely controlled and monitored. The use of standardised clothing and activities does not ensure that clothing insulation and activity level can be accurately quantified. In field study settings, discrepancies between actual and predicted thermal sensations reflect, in part, the difficulties inherent in obtaining accurate measures of clothing insulation and activity level. In most practical settings, poor estimations of these two variables are likely to reduce the accuracy of PMV predictions. In field settings, it is more difficult to control or to accurately measure these six variables. Measurement error resulting from these difficulties has been argued to contribute to the discrepancies found between PMV and actual thermal sensation (Benton, Bauman and Fountain 1990), (de Dear and Brager 1998), (N. Oseland 1994).

Establishing the insulating properties of clothing is a time-consuming and detailed process that is usually conducted in laboratory experiments, where clothing insulation tables are constructed, and usually using thermal manikins in conditions of still air. Clothing insulation studies show good agreement between thermal manikins and humans during sedentary activities, but that their correspondence decreases for other activity levels (Oseland and Humphreys 1994). Clothing insulation is not measured in thermal comfort studies, instead an estimate is considered to represent that value using tables that have been developed from clothing insulation studies (see Appendix B). Some researchers assume an average clo value for all occupants based on the season and climate of the study location. More detailed studies ask occupants to complete a garment checklist, which can, then, be used to select a more appropriate clo value for the group, or separate clo values for each participant. Using detailed garment checklists, up-to-date clothing insulation tables, and accounting for chair insulation can, therefore, improve thermal comfort researchers' estimations of clo values. The difference between measured clo value and the estimated values in comfort studies repulse the correspondence between PMV and actual thermal sensation votes. In addition, clo estimates do not accurately reflect differences between people, changes in clothing during the day, or social and contextual constraints on clothing choices (de Dear and Brager 2002) (Oseland and Humphreys 1994). Therefore, clo values present a source of concern for PMV calculations, and are likely to contribute to discrepancies between predicted and actual thermal sensation.

Activity level is measured in terms of metabolic rate, or 'met' (Gagge, Burton and Bazett 1941). Analyses using the ASHRAE RP-844 database showed that the PMV's accuracy varied according to met rate. The PMV model best predicted actual thermal sensation for activity levels below 1.4 met. Above 1.8 met, PMV overestimated actual thermal sensation by up to one scale unit (Humphreys and Nicol 2002). The most accurate method for determining met is through laboratory studies, where heat or oxygen productions are measured for participants conducting specific activities (Havenith, Holmer and Parsons 2002). Alternatively, the participant's heart rate can be measured and compared to previously developed tables of heart rate for specific activities. It is also very important to consider the activity prior to the comfort experiment as it might influence the current met rate. All of these methods, however, are time-consuming and invasive, and are generally not practical for use by thermal comfort researchers. Instead, these researchers relied on estimates, based on tables of met rates for specific activities and occupations. In most studies, an average met rate is assumed for the group. More recent studies ask occupants to record their activities over the last hour, and this information is used to develop a more accurate average for the group, or individualised met estimates for each participant. Activity level is probably one of the least well-described parameters of all the parameters that affect thermal sensation, comfort and temperature preferences indoors. Current met tables provide information for the 'average' person, and as such do not accurately reflect differences between people or contexts (Charles 2003).

Fanger conducted a series of climate chamber experiments to investigate the existence of physiological acclimatisation (Fanger 1970), (Fanger, Hojbjere and Thomsen 1977), (Olesen and Fanger 1971). It was found that there is not a significant change in the neutral temperature when exposing a person for a period of 10 days to 35°C in a climate chamber. In further studies, native participants from Denmark and the United States were compared to native participants from the Tropics, as well as participants regularly exposed to cold environments (meat-packing workers and cold-water swimmers). Participants' physiological processes (sweat rate, heart rate … etc.) were found to differ only slightly between the groups. The only significant finding from these comparisons was that the meat-packers' neutral temperature was 1ºC lower than that of non-cold exposed participants. The researchers considered this difference of minor importance in practice and concluded that people are not physiologically adept at changing their neutral temperatures (Olesen and Fanger 1971).

The PMV model was developed from laboratory studies, but the effects of the building type were not investigated during its development. Studies that compared PMV applications in naturally ventilated and air conditioned buildings suggest that there are differences based on the building type. A number of studies showed that the observed neutral temperature in air-conditioned buildings differs from that in naturally ventilated buildings. Human response to conditions in real buildings may be influenced by a range of complex factors that are not accounted for in the heat balance models. These can include demographics (gender, age, culture and economic status), context (building design, building function, season, climate and semantics), environmental interactions (lighting, acoustics, and indoor air quality) and cognition (attitude, preference and expectations). Researchers and practitioners believe that non-thermal factors cannot be dismissed so easily (Brager and de Dear 1998). Studies in Australia found differences in the neutral temperature of different building types ranging from 1.3 to 1.7°C, and found that PMV predictions for air-conditioned buildings were between 0.8ºC higher and 0.6ºC lower than reported neutral temperatures (de Dear and Auliciems 1985). Another study found that the neutral temperatures in naturally ventilated buildings in Bangkok were 2.7°C higher than those of air conditioned spaces (Busch 1992). Predictions in naturally ventilated buildings were, by comparison, between 0.6ºC lower and 2.1ºC higher than observed neutral temperatures. A similar trend with PMV over-predicting neutral temperatures in naturally ventilated buildings by 3.4ºC, but over-predicting air-conditioned buildings by only 0.8ºC (Bush 1990). Finally, (de Dear, Leow and Foo 1991) found that PMV under-predicted neutral temperatures in air-conditioned buildings by 0.2ºC, but over-predicted them in naturally ventilated buildings by 2.8ºC. From this, it can be concluded that researchers found that PMV predictions agree with actual thermal sensation better in air-conditioned buildings, when compared to naturally ventilated buildings.

The PMV model does not directly address the influence of outdoor climate. However, it was noted above that studies conducted in different parts of the world reported different neutral temperatures, suggesting that outdoor climate could have an influence on thermal sensation. A number of recent field studies also suggested that neutral temperatures differ by climate or season (Cena and de Dear 2001) and (de Dear, Fountain, et al. 1993). In general, occupants in warmer climates or seasons tend to report warmer neutral temperatures (de Dear and Brager 1998).

In addition to differences between actual and predicted neutral temperatures, several field studies suggested that occupants' sensitivity to changes in temperature differ from those predicted from PMV. For example, (de Dear, Fountain, et al. 1993) found that, although observed neutral temperatures were largely consistent with those predicted by PMV, predicted and actual thermal sensation differed for non-neutral conditions, and increased the further away from neutrality occupants were. These findings suggested that occupants were more sensitive to changes in temperature than the PMV model predicted. A number of other studies also supported this conclusion (Busch 1992) (N. Oseland 1995) (Schiller 1990) (Charles 2003).

In an attempt to study these discrepancies more systematically, ASHRAE commissioned the formation of a large database of thermal comfort studies (de Dear and Brager 1998). The database, part of ASHRAE research project RP-884, is the result of a series of high-quality thermal comfort field studies conducted in different climates around the world. To be included studies had to carefully measure the six PMV input variables and the thermal sensation of actual occupants using a standardised procedure. The database contains raw data from these studies which means that the whole database can be subjected to the same analyses. This reduces the variability of findings that might be influenced by different statistical approaches between studies. Data on 22,346 participants from 160 buildings were collected, and included data from four continents. This database was subjected to analysis by a number of researchers. Overall, thermal comfort studies suggested that the PMV model does not always accurately predict the actual thermal sensation of occupants, particularly in field settings. Two main factors are commonly cited as contributing to the discrepancies described above: measurement error, and contextual assumptions.

In laboratory experiments, personal factors that are likely to influence thermal sensations are reduced to a minimum, especially the influence of variable clothing. Parameters of ambient warmth are controlled at specified levels. In climate chambers, physiological reactions of the human subjects to the climate parameters, such as air temperature, radiant temperature, humidity and air velocity, can be investigated under controlled conditions.

2.3.2.2 Adaptive model

The problem with a field study is that the measurements of the physical parameters are not precise and obtaining accuracy is always difficult. Secondly, it is difficult to generalize from the statistical analysis, because the results from the analysis of one survey often do not apply to the data from another even in similar circumstances. An additional problem mentioned is that errors in the input data can give rise to errors in the relationships predicted by the statistical analysis; this is due to the inaccuracy of the measurements resulting from a transient environment (Nicol and Humphreys 2002)

The strength of the adaptive approach is that it touches on many topics including climatology, the design and construction of buildings, the provision and use of thermal controls, the history and sociology of clothing and the influences of culture together with human thermal physiology. It, therefore, encompasses all aspects of thermal comfort studied in the laboratory (Humphreys and Nicol 2007)

Several researchers have developed relationships between thermal sensation and outdoor temperature as mentioned before. Researchers examined the results of a large number of field studies from around the world, and developed an equation that related thermal sensation to mean monthly outdoor temperature, as (M. Humphreys 1978), (Auliciems 1981) and more recently by (Brager and de Dear 2001), using the ASHRAE RP-884 database. In all of these cases, mean monthly outdoor temperature was found to be a significant predictor of occupants' thermal sensation. In order for the field studies to have a general applicability, the individual results should be combined to produce general rules (F. Nicol 1993).

Behavioural adaptation refers to the actions that occupants might take to achieve comfortable thermal conditions. These behaviours include opening windows, adjusting blinds or shading devices, operating fans, adjusting thermostats or blocking ventilation outlets, changing clothing, moving to a different room, modifying activity levels, and even consuming hot or cold food and drinks. (Baker and Standeven 1996) observed office occupants in Greece in order to investigate their behavioural adaptations. During

863 observed hours, they recorded 273 adjustments to the environmental aspects of the room, and 62 clothing adjustments. Occupants also reported that the outdoor temperature influenced their choice of clothing for the day. In addition to behavioural adjustments, occupants might also modify their expectations and attitudes towards the thermal environment. This psychological adaptation is argued to be influenced by culture, social norms, and previous experience, and is likely to be context dependent (Baker and Standeven 1996) (N. Oseland 1995).

2.3.3 Importance of comfort models

User satisfaction is a main issue that should be considered while designing buildings, and of the main effective parameters on the user satisfaction is the thermal conditions. (Griffiths 1990) found that the 'right temperature' is one of the things people considered most important in buildings.

The issue is to identify desirable indoor air temperature and, thus, determine building design temperature which, in turn, implies rates of energy consumption (Auliciems 1981). A decrease in the outdoor-indoor temperature difference will decrease the usage of heating or cooling machines, thus leading to energy consumption.

Comfort models are also used in the development or planning of air conditioning systems, and the development of standards and design guidelines that could be used to promote the usage of new energy efficient building concepts and technologies, especially those featuring natural ventilation and passive cooling techniques (Gossauer and Wagner 2007). The implication of a single temperature for energy consumption is that a building may need both heating and cooling at different times of the year. A variable temperature standard, as implemented in the new ASHRAE standard-55 (2004) for free running buildings, helps in energy conservation.

2.4 COMFORT STUDIES

The physical conditions for voting vary from carefully controlled experiments in laboratory studies to the naturally encountered conditions in field studies. In both cases, the verbal scales are presented to subjects who have to cast votes to describe their particular state of the thermal environment. The purpose of these studies is to define the range of conditions that are acceptable by the subjects involved.

Field studies are the principle research method of obtaining adaptive models. This methodology is fully described here, where people are asked for their response to their thermal environment. The response is recorded while the thermal environment is measured simultaneously. Notes on clothing and activity may be taken from which the thermal insulation of the ensembles and the metabolic rates of people can be estimated. The opening or closing of windows, the raising or lowering of blinds, and the switching on or off of fans may be noted, together with any other actions that people take to ensure their comfort. Usually no attempt is made by the researcher to control the environment, while in some cases the interventions are made to investigate the subjects' reactions. The researcher in such surveys has often been a local person, or someone with an interest in that particular climate. From such field studies an understanding has developed of how people achieve thermal comfort in daily life, and what environments people typically create or accept in different cultures and climates (Humphreys and Nicol 2007). The interest is, generally, in finding a range of temperatures and other environmental variables that represent the comfort conditions for the people of the studied locality. Because the aim is to obtain a typical reaction to conditions, there is no attempt to interfere with the normal conditions or modes of dress, in order to study people in their normal life conditions to assess the full complexity of the situation (F. Nicol 1993). The setting of the field study is discussed here in details.

2.4.1 The Respondents

People who accept the involvement in a field study of thermal comfort are the occupants of the space within their normal surroundings; this is only intruded upon when measurements are taken or when questionnaires are filled in. The method of taking measurements and the time of distributing and filling out the questionnaire determine the intensity of interference in the normal life of the occupants. Most studies involved occupants who led a lightly active everyday life (M. A. Humphreys 1976). The subjects need to be briefed on the aims and methods of the survey, and they need to be clear about what is expected of them.

In choosing a sample, it is important to choose people familiar with their surroundings and the climate they are living in. The sample should represent the diversity in the population in such things as sex, age and bodily dimensions. There are two basic forms of survey sampling: the transverse and the longitudinal sampling. The transverse sampling allows the whole population to give a single or small number of comfort assessments. In the longitudinal sampling, the subject gives more than one assessment over a long time period providing a large amount of data (F. Nicol 1993).

2.4.2 Time Sampling

Time plays an important part in the adaptive process. Choosing the time of day and time of year at which a survey is carried out is an important issue. The human response to the conditions at a specific moment depends on one's experience of conditions over the previous period, in other words on one's thermal history. People can adapt to the change of conditions in about a week, therefore, the survey should not take too long to complete. The recommendation is to keep the time sampling as short as it could be, no longer than two weeks. Also, it is recommended to keep surveys throughout the day and evening so that time series effects in the responses can be investigated.

Avoiding any interference in the normal conditions of the space makes the field study lose some of the advantages of the planned experiments. Although this is the trend in most field studies, some of them, when studying people in air conditioned spaces, controlled the temperature in order to cause some variations in the thermal conditions. By altering the temperature around the operating level, they were able to obtain a variation of response sufficient for analysis (M. A. Humphreys 1976).

2.4.3 The Measurement of Physical Parameters

In most cases of field studies and often for simplicity, only the air temperature is measured. If the measuring device is not protected from the effect of radiation, so the readings are to some extent affected by the mean radiant temperature of the surrounding surfaces. While in some other studies, the air temperature, the mean radiant temperature, the relative humidity and the air velocity are measured, allowing the calculation of any composite thermal index depending on these variables. The accuracy of the physical measurement should be ±0.5 K for air temperatures. If the globe temperature is to be measured and used to evaluate the mean radiant temperature, then the accuracy of the globe and air temperature measurements needs to be ±0.2 K (F. Nicol 1993).

2.4.4 The measurement of personal parameters

The subjective sensation of warmth, or thermal comfort, of the subjects is traditionally measured using the seven point scale as described in 2.4.5. Using a descriptive scale as the ASHRAE scale or Bedford scale may cause the danger of overlapping with the cultural use of words. This can be overcome by using a scale of preference. The most commonly used is the three point preference scale, where respondents are asked about what they prefer, and the answer is sorted in three categories (F. Nicol 1993).

Two other personal parameters affect the thermal sensation of the subjects involved in a field study, their clothing and their metabolic rate. As for the clothing, it is not controlled in the field studies, and it can be recorded in two different manners. The first is by describing the overall suits worn by the respondent, and the second is by recording each item. This may help in determining the clo value, which gives an indication of the way people have adjusted to the prevailing temperature, and could also be used in determining the respondent’s thermal state using the PMV model.

The metabolic rate varies according to the physical activity of the respondent, but, as mentioned before, most of the field studies involved occupants who led a lightly active everyday life, where the metabolic rate was given as a general description of the activity of the respondents. The complete record of activity requires both the continuous supervision of the respondent and the recording of oxygen consumption which is normally not applicable (M. A. Humphreys 1976).

2.4.5 Scaling

The estimation of comfort levels has been largely based upon the responses on verbal scales of sensation, where the verbal scales contain discrete thermal sensations to describe the environment and which have been assigned sequential numerical values. The verbal scales are assumed to be ratio scales (Auliciems 1981).

As noted by (M. A. Humphreys 1976), the number of steps per scale ranged from three to twenty five, but the most common used verbal scales are the ASHRAE scale (1968) and the Bedford scale (1936). Both are symmetrical scales with seven categories as shown in Table 4. The Bedford scale tends to confuse sensation and comfort as it is a combined estimate of warmth and comfort compared to the ASHRAE scale; this appears to be considered negligible by researchers as stated by (Auliciems 1981) depending on the relations in Table 1, while (M. A. Humphreys 1976) criticized this combination based on the fact that the relation between warmth and comfort is not necessarily constant.

The scales are introduced to the subjects of a thermal field study in the form of a question asking about either their thermal state as “How do you feel at the moment?” or asking about the state of the space as “How do you find the space temperature”. The question is normally one of a structured series of questions covering various aspects of the environment.

2.4.6 Survey design

Two basic types of sampling techniques are used, the “transverse” and the “longitudinal” types. The first type allows a larger number of subjects to contribute to the study at the same time, as each respondent gives one assessment of the thermal environment. This type indicates the extent of variation among individuals’ responses, which gives a good estimation of the population. The inclusion of a large number of subjects (representing the whole or most of the population) results in avoiding any bias in the results. This also means that the intrusion of the privacy of the respondents will be kept to a minimum. The problem with such a method appears when conducting the survey for a short time (e.g. one day), then the variety of the environmental variables and conditions surrounding the subjects is limited, and may not represent the normal life conditions faced by the population. To overcome this defect it is better to conduct the survey over a number of days or even weeks (F. Nicol 1993).

The longitudinal sampling ends in a small number of observations, due to the number of instruments afforded or the number of volunteers mustered. One problem is that subjects are required to exert a certain amount of dedication, particularly if the survey is extended beyond the subjects' working hours. The small number of sampling may lead to a sampling bias in the results or the sample may not be typical of the whole. However, such a way of sampling allows insight into the effect of time series on comfort (F. Nicol 1993).

Table 4: The "ASHRAE" scale and the "Bedford" scale of warmth, with their categories being numbered as used in many field studies

ASHRAE scale	Bedford Scale	Common numerical coding
Hot	Much too warm	+3
Warm	Too warm	+2
Slightly warm	Comfortably warm	+1
Neutral	Comfortable	0
Slightly cool	Comfortably cool	-1
Cool	Too cool	-2
Cold	Much too cool	-3

2.4.7 Data analysis

The method of evaluating the thermal conditions of the space is done by correlating the subjective vote of the occupants to the measured climate parameters. In the standards, the base of the commonly used models is the regression analysis, while in practice and research the Probit analysis is another method that is used for analysis (M. A. Humphreys 1976)

Regression analysis is one of the methods used to analyze the data gathered from a thermal field study; the method is valid based on two main assumptions as indicated by (Auliciems 1981). The first assumption is that there is an equal increase in the thermal sensation corresponding to an equal increase in the thermal stimuli; the second is that transformation of subjective votes of thermal sensation into real numbers is valid. This leads to treating the verbal scales, used in the field study, as ratio scales, which means that the thermal sensation is treated as a continuous variable.

This method allows the prediction of the thermal sensation, as it is considered a dependant variable based upon the independent variable "the indoor temperature" in thermal field studies, which allows the calculation of the neutral temperature. This is done by using the equation of the correlation between the thermal sensations and the indoor temperature (M. A. Humphreys 1976). The magnitude of correlation coefficients varies considerably between studies depending upon several factors which include the number of sensation steps used, the precision of the physical measurements, the variability between the subjects and the sample size. The slope of the regression line depends on the size of the correlation coefficient. The procedures employed in laboratory work are likely to eliminate a variety of noise factors, producing higher values of correlation coefficients, which means steeper slopes. It is noted that in laboratory experiments the multiple correlation coefficient may approach values between $r = 0.70$ and $r = 0.85$, while in the field these values usually decrease to reach a value between $r = 0.30$ and $r = 0.55$. Thus typical regression coefficients using a 7 point verbal scale for laboratory work are between $b = 0.30$ and $b = 0.35$, and for field studies between $b = 0.15$ and $b = 0.25$, depending mainly on the population and circumstances of the survey (McIntyre 1978).

The second method of analysis is the transition boundaries known as Probit analysis, which was first applied to thermal sensation by Chrenko (1955). This method finds the proportions of comfort assessments which are on the several response categories over the range of environments encountered in the study. From these proportions the neutral temperature can be calculated and used to estimate the variation in the responses among the population in the case of a transverse study, or of individual consistency in the case of a longitudinal survey.

2.4.8 Classification of field studies

(Brager and de Dear 1998) classified thermal comfort field studies into three main groups based on the standard of the instrumentation used for recording the different indoor physical parameters (air temperature, radiant temperature, air velocity and relative humidity), as well as on the procedures used. The classification is as follows:

Class (i) represents the study in which all the sensors and procedures are in 100 percent compliance with the specifications in ASHRAE 55 (ASHRAE 2004) . In this type of field study, the measurements should be taken at three heights above the floor level with laboratory grade instrumentation. This procedure allows a careful examination of the effects of non-uniformities in the environment as well as a comparison between buildings.

Class (ii) indicates studies where all the physical environmental variables necessary for calculating the PMV and the PPD indices are measured and collected at the same time and place when and where the thermal questionnaire are administered, most likely at one height. This allows an assessment of the impact of behavioural adjustment and control on subjective responses.

Class (iii) is based on simple measurements of indoor temperature and possibly relative humidity at one height above the floor. The physical measurements can possibly be asynchronous with subjective measurements usually represented by a questionnaire with rating scales. This class offers the widest range of published data.

Another classification by (F. Nicol 1993), is also divided into three types as follows:

Level (i): it is formed of simple measurements of temperature in the occupied space, and no subjective response is needed in this case.

Level (ii): where measurements of the thermal environment is accompanied by the subjective response to it.

Level (iii): in which all factors needed to calculate the heat exchange are measured together with the subjective response.

2.4.9 Strengths and weaknesses of field studies

The freedom of the respondents and their uncontrolled environments are at once the strengths and weaknesses of the field study. The strength of such conditions is that the assessments represent the feelings of daily life, and not a conditional status for a period of time as in the climate chamber studies. Also the process of adaptation to the everyday variations could be observed which is not obtainable in case of climate chambers.

The weakness is that this condition of freedom of the respondents and the environmental conditions can not allow the precise measurement of the factors affecting the heat exchange between the respondents and their environment. This makes it difficult to compare the results from one study to the predictions based on the heat transfer theory. But this could be overcome by comparing the results of many field studies when combining their results together.

Also if insufficient attention has been paid to the presentation of specific questions asked for the respondents, for example it is not clear if significant differences are obtained when the subjects are asked to interpret their own thermal states, or alternatively to comment on the state of the environment by response on the same subjective scale. Perhaps the least satisfactory of all is the insufficient detail given to sampling procedures, in view of the repeatedly demonstrated large variability between and within people, little reliance can be placed upon the recommendations of specific thermal level, or comparisons between groups of people and regions of the world if small samples have been employed.

2.5 CONCLUSION

Field studies showed the diversity of the environments that populations find comfortable to be greater than can readily be explained by current heat balance models. With the strong likelihood of global warming, and in an era of increasingly expensive fuel, there is a powerful incentive to reduce energy-use in buildings. If field studies guided the formulation of standards of thermal comfort in buildings, consumption of energy for heating and cooling could be reduced without sacrificing comfort or well being.

Fanger's PMV model combined four physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and two personal variables (clothing insulation and activity level) into an index that can be used to predict the average thermal sensation of a large group of people in a space. The PMV model is not always a good predictor of actual thermal sensation, particularly in field study settings. Discrepancies between actual and predicted neutral temperatures reflect the difficulties inherent in obtaining accurate measures of clothing insulation and metabolic rate. In most practical settings, poor estimations of these two variables are likely to reduce the accuracy of PMV predictions. Bias in PMV predictions varies by context, and is more accurate in air-conditioned buildings than in naturally ventilated ones, in part because of the influence of outdoor temperature and opportunities for adaptation. The most appropriate method allowing the deduction of adaptive comfort models is field studies. The use of several field studies allowed the production of the adaptive comfort model, implemented in the ASHRAE 55 (2004) standard, which can be used as an alternative method in the design and evaluation of free running buildings.

CHAPTER ONE	RESEARCH OVERVIEW
CHAPTER TWO	**LITERATURE REVIEW**
CHAPTER THREE	OBJECTIVES AND METHODOLOGY
CHAPTER FOUR	DATA ANALYSIS
CHAPTER FIVE	DISCUSSION
CHAPTER SIX	CONCLUSION

CHAPTER THREE OBJECTIVES AND METHODOLOGY

In response to the newly implemented "adaptive comfort model" in the ASHRAE standard 55-2004, a field survey was carried out in Cairo, Egypt, a hot dry climate, during the seasons of autumn 2007, spring 2008, autumn 2008 and spring 2009.Three university buildings were chosen to represent the main types of universities in Cairo. In terms of thermal environment, two of them were naturally ventilated and the third was a mixed mode building.

This chapter describes the design of the field study, and clarifies the objectives and methodology of the study. The buildings surveyed are presented in this chapter.

3.1 OBJECTIVES

The intention of the proposed fieldwork was

3.1.1 Observation and specification of the different thermal environments within each building in order to investigate the thermal characteristics of the indoor environment within each of the selected buildings:

This part targets the investigation of the effect of design requirements on the thermal environment variability in each of the selected buildings. In order to satisfy the different functional requirements within the same building, spaces may differ in their area or use, thereby affecting the indoor thermal environment.

The indoor thermal environment treatment might depend on passive strategies as natural ventilation or active strategies involving different types of air conditioning. The study investigated the different types of treatment applied in each building and categorized the spaces according to the governing control strategy in each, comparing naturally ventilated spaces to mixed mode spaces.

3.1.2 Determination of the comfortable temperatures and the acceptable environments as indicated by the occupants, and investigation of the effect of different indoor thermal environments within and between spaces on the occupants' comfort and satisfaction:

The scope, here , was to assess the indoor thermal environment based on the feedback from the occupants through their subjective votes of thermal sensation, preference and acceptability, together with their votes of satisfaction regarding the indoor thermal environment in variable zones in the same space and even in different spaces within the same building. The effect of different thermal control strategies that might be applied in different spaces within the same building on the comfort perception was also assessed.

The purpose was to assess whether there was a difference in the occupants' experience and expectations regarding different thermal conditions and different technologies within and between different spaces within the same building. This allowed the comparison of the outcome due to different buildings, where they incorporated different circumstantial restraints.

The aim was to determine the temperature range that satisfied the majority of the occupants, as well as their degree of acceptance of different thermal indoor conditions; and to determine the influence of different control strategies on the occupants' response, indicating the influence on the adaptive opportunities and the impact on defining comfort and satisfaction.

3.1.3 Characterization of the main physical and psychological factors influencing thermal comfort and satisfaction, quantification of the effect of the indoor/outdoor environments on the characteristics of these factors:

The indoor thermal environment affects occupant's reactions; therefore, the purpose of this part was to determine the impact of the indoor thermal environment on the adaptive behaviour, together with the effect of these behaviours on the voting process. The aim was to observe and record to what extent people interact and in what ways they perceive and adapt to their surroundings.

Behavioural adjustment is classified into three main sub-categories (refer to 2.3.1.2). The first is related to the personal adjustment to the surroundings, the second defines the technological and environmental adjustments that are available, for example opening and closing of windows or changing the set points of air conditioning if possible. The third concerns cultural and social adjustments as adjusting clothing or arranging activities according to climatic conditions. Questions assessing the three categories were implemented in the questionnaire used in the study.

Psychological adaptation is explored through determining the effect of the current and past thermal experiences on the thermal sensation and through indicating the thermal perception based on the effect of both the perceived degree of freedom over the surroundings and the available personal control of the existing conditions.

3.1.4 Comparison of the results obtained with the current models resulting from comfort theories:

The aim of this part was to compare the outcome of the data gathered to the existing standards that identify thermal comfort conditions according to the new adaptive comfort model.

3.2 METHODOLOGY

An early preparation for the field study was required - i.e. The pre-stage of the field study-to discuss the actions taken to facilitate the organization of the actual field experiment. The field study itself explained the techniques for gathering and analyzing data concerning the physical measurements and subjective responses.

3.2.1 Pre-Stage of the field study:

The purpose of the field study was the data collection by distributing questionnaires while simultaneously monitoring the indoor thermal environment of the examined spaces. Preparations to facilitate the success of the field study were done, including obtaining data concerning the design of the selected buildings and their thermal profiles, questionnaire design and testing. These steps were done according to the following criteria.

3.2.1.1 Ascertaining participation of the selected buildings and obtaining related data:

Communicating with the managers of the selected buildings, introducing the research team and explaining the aim and methodology of the study was essential in order to finalize the selections of buildings and to discover their responses and willingness to participate in the study. This resulted in the participation of three buildings out of five buildings.

After finalizing the selection of buildings, during this stage, the architectural drawings for the selected buildings were obtained. The buildings were carefully studied in their existing conditions and within their actual contextual environments.

Interviews with the buildings' designer were arranged to obtain data concerning the general architectural concept of the buildings together with the architecture drawings of the buildings. The designers' opinions concerning the use of air conditioning or passive techniques were debated and their impact on the design features was pointed out. The designers' comments on the design of the spaces and his opinion about their thermal environments were considered through the process of sampling.

When the designer was not available, such as in the case with old buildings, the interview was conducted with the building's managers and those responsible for the building services.

3.2.1.2 Site visits, data acquisition and validation:

Site visits to the different buildings were done after obtaining the architectural drawings (mainly the plans of different building floors) to ensure the accuracy of the data obtained and at the same time to indicate the original setting on the drawings and to modify any changes within the buildings, just to form an as built set of drawings.

Different thermal concepts were indicated and oriented onto the drawings. The aim was to produce a set of drawings which included the architectural and mechanical features that might affect the indoor thermal environments of the spaces in order to aid in the process of selection.

Although the main aim was to investigate the real site, it was also important to familiarize with the different buildings and the spaces that will be examined.

3.2.1.3 Investigating the indoor thermal profile of the targeted spaces:

A preliminary study of the spaces that were selected in each building was done in order to specify the characteristics of the indoor thermal environment. That has a reflection when placing the measuring instruments in the real study and it showed the critical zones within spaces. For a minimum of three days, throughout the working hours of the building, the spaces were monitored using the same instruments that were used in the field study together with an internal weather station obtained from the Housing and Building Research Center (HBRC) of Egypt. Air temperature and relative humidity were measured using data loggers (HOBO of the company Onset) and, on some days of the survey, a Nomad portable weather station (Casella) was used to verify the data from the data loggers as a method of calibration. Moreover, the ten data loggers used were calibrated with each other to point out the differences between their records; the differences did not exceed 0.5 degree for temperature and 5% for relative humidity.

The data loggers measurement range for temperature as specified by the manufacturing company is -20° to 70°C, (accuracy: ±0.4°@ 25°C), and for relative humidity 25% to 95% RH, (accuracy: ±3.5% over the whole range). The response time of the data loggers in air flow of 1m/s is 6 minutes for 90% temperature and 1 minute for 90% relative humidity. The data logger is shown in Figure 11.

Figure 11: The data loggers of the company Onset used in the field studies

Using the Nomad portable weather station with accuracy: ±0.3° C@ 0°C and ±55° C@ 50°C measurement for temperature and accuracy: ±3 % for relative humidity revealed that the difference between the air temperature and the radiant air temperature did not exceed one degree Celsius. This justified considering the air temperature measured by the data loggers as the operative temperature, as operative temperature is approximated by the simple average of the air temperature and mean radiant temperature. In addition, the measurements showed that the air velocity didn't exceed 0.06 m/sec in all the spaces even when using ceiling fans and that was why the air velocity was not measured in the main field study. The data loggers were distributed over the whole space and were placed on the working plane with a stand to adjust their heights to the same level as the students' heads.

3.2.1.4 Questionnaire design and its examination:

Questionnaires used previously in other field studies (Wagner, et al. 2006) influenced the design of the questionnaire adopted in this study. The questionnaire design followed several steps starting with the compilation of a six-page first draft. The target of the questionnaire was to obtain information about the respondents' expectations and experiences before their entry to the building, their comfort votes for the time of the survey, their psychological perception of the degree of freedom available, and the physical actions done to accommodate themselves to the indoor climate. The method of obtaining such data is discussed below:

To understand the norms of thermal quality the respondents were accustomed to, they were asked to answer questions about experiences and expectations, questions assessing their psychological adaptation methods and inquiring about their daily routine that focused on the usage of air conditioning and heaters, in addition to the type of transportation used. The question asking about the usage of air conditions was deleted in later versions of the questionnaire as it is not applicable in the case of naturally ventilated buildings. In addition, the respondents were asked about their expectations of the outdoor climate in the day of the survey together with their expectations regarding the indoor climate of the space where the survey was taking place.

In comfort votes, semantic differential scales are the most popular scales and are recommend (F. Nicol 1993). This type of scaling allows for an easy conversion of the results into interval numerical scales. In the case of assessing thermal sensation the seven point scale, 3 = very warm, 2 = warm, 1= slightly warm, 0 = temperate, -1=slightly cool, -2 = cool and -3 very cool, was used. The semantics differed from that in the ASHRAE scale for ease of translation. The semantics of the ASHRAE original scale is not translated easily. “Neutral”, existing on the ASHRAE Scale, was replaced by temperate. In addition, the two extremes of the scale “hot” and “cold” were avoided, and semantics expressing the graduation of being cool or warm were used.The Arabic language does not contain two different words for cool versus cold or for warm versus hot, which made it more practical to use the semantics for slightly cool, cool and very cool as well as using slightly warm, warm and very warm.

The thermal sensation was assessed using a seven-point scale. (McIntyre 1978) pointed out that the seven point scale was in line with common practice of many psychological scales. Moreover, it was the most common in this field, which means that it would be easy to compare to the results of other field studies in this area of research.

The traditional language for comfort questionnaires is English, and translation to other languages is not easy as the terms used may have different meanings than the ones used in English language questionnaires. In order to overcome such issues and to examine the clarity of semantics, the questionnaire was tested in Karlsruhe on five people whose mother tongue was Arabic, the native language in Egypt.

The thermal preference was assessed using a five-point scale which is preferable to a three-point scale. This made occupants much more precise about their selections and it gave the occupants a wider scale for selection. A question assessing the acceptance of the thermal environment was also directly asked, with only two answers provided, “acceptable or not acceptable”. Similar questions were asked to assess the humidity.

The second part of the questionnaire assessed physical adaptation, through questions assessing the available options for the occupants to change their indoor climate, and their degree of satisfaction with the perceived degree of freedom in order to change their indoor environments.

A question assessing the degree of satisfaction was answered on a six-point scale that differentiated between being satisfied or not. There was no intermediate neutral point; the respondent was either "satisfied" or "unsatisfied" on three different levels. Other questions were related to environmental adaptation i.e. opening/closing windows and doors, etc. and personal adaptation i.e. changing clothes, drinking and eating.

Another question asking about the clothes worn by the subjects was included. Social customs and cultural needs, together with the seasonal pattern of outdoor weather conditions, are the main factors affecting the type of ensembles and garments worn by people throughout their lives. The database adopted in Appendix B, lacks values corresponding to items of clothing used in Egypt especially the exact values for the veil (Hijab) and Abaya. Even a study concerning the clothing area factors of typical Arabian Gulf ensembles did not provide these values. The veil is mainly made of a large variety of fabrics and colours used as an Islamic head cover to conceal female hair. The Abaya is a traditional silk or wool loose cloak, reflecting the female religious belief, covering the whole body except for the face, palms of hands and toes.

Egyptian female clothing consists basically of three types of attires: (1) Islamic attire (Abaya); (2) Conservative traditional attire (long dress with long sleeve); (3) Western style attire (jeans and blouse). Another piece of clothing that is not included in the standards is a body-hugging long-sleeved top very widely known in Egypt as a "body" usually worn by females under clothes to hide any visible body parts.

Another shortage in the available resources was the clo value of flip-flop slippers. Within both seasons of the study some of the males reported wearing flip-flops-a popular summer footwear- on hot days.

A cover page was designed in order to introduce the research team, the aim of the study and the instructions on how to complete the questionnaire. It described how "confidentiality" was reserved and provided contacts for further information to the respondents. The first version for the cover page is attached in Appendix C. The translated version is in Appendix D and the used questionnaire is attached in Appendix E and the translated version is in Appendix F.

After designing the questionnaire, an examination of the outcome was done, to ensure intelligibility of the semantics forming the questionnaire, as it is mainly adapted from other questionnaires that were originally formed in different languages.

The examination also helped to determine the average time it took to introduce it to the occupants and the time required by the occupants to fill it. These were essential issues that led to some modifications to the questionnaire before the real study.

It was very obvious that the questionnaire was too long as it required from ten to fifteen minutes to fill, while the students' breaks between lectures were around twenty minutes. These results led to the shortening of the questionnaire. The cover page was not distributed, but it was verbally stated that it was available for those respondents who were interested in more information. Moreover, some of the questions were excluded e.g. the questions inquiring about general use of heaters and air conditioning at home. Questions assessing the air quality, the description of the air quality within the space and air velocity were omitted as there was not a measured reference quantity for these parameters. The questions inquiring about physical adaptation and methods of controlling the space were replaced by the researcher's observations during his presence in the place where the subjects were attending their lectures. The list concerning the clo value was modified to include items such as the veil, Abaya and body, as well as flip-flops and other sports foot-wear common in the Egyptian culture.

3.3 FIELD STUDY SETTING

Several field studies to investigate thermal comfort have been carried out; the data acquired by researchers differed in their details according to two main disciplines, the information obtained and the measurements done. The descriptions of field studies according to these two variables were classified into different categories. According to (Brager and de Dear 1998) a class 3 field study is based on simple physical measurements of the indoor environment with possibly asynchronous subjective questionnaires. (F. Nicol 1993) defined a level 3 survey indicating that a number of subjects provided subjective responses while the surrounding environment was concurrently measured and which included data on clothing and activity. The following field study description and explanation followed the attributes of class 3 and level 3 field studies, refer to 2.4.8.

3.3.1 Sampling strategy

This section discusses the sampling strategies used to select the population, the type of buildings, spaces within each building, and the selection of subjects.

3.3.1.1 Selection of population and their environment

Egypt lies in a hot arid climate; it extends between the northern latitudes of 23º and 32º and eastern longitudes of 25º and 36º. According to the Köppen Climate Classification System, Egypt is located within the hot dry climate. Bioclimatic classifications that were carried out, based on temperatures, humidity and solar heat gains, for Egypt shows main six regional climates as shown in Figure 12 (Egyptian Climatic Authorities 1997). The study was carried on in region number six.

Region [1], Mediterranean Sea climates. 22-to-28^{O}C dbt & 50-to-80%RH
Region [2], Upper and Lower west desert. 30-to-38^{O}C dbt & 40-to-60%RH
Region [3], Upper Egypt valley at Sudan borders. 30-to-45^{O}C dbt & 15-to-40%RH
Region [4], Southern-Upper Egypt valley. 31-to-42^{O}C dbt & 20-to-55%RH
Region [5], Northern-Upper Egypt valley. 30-to-40^{O}C dbt & 30-to-55%RH
Region [6], Delta Region. 22-to-37^{O}C dbt & 45-to-65%RH
Region [7], Sinai, Red Sea Zone. 23-to-41^{O}C dbt & 17-to-50%RH

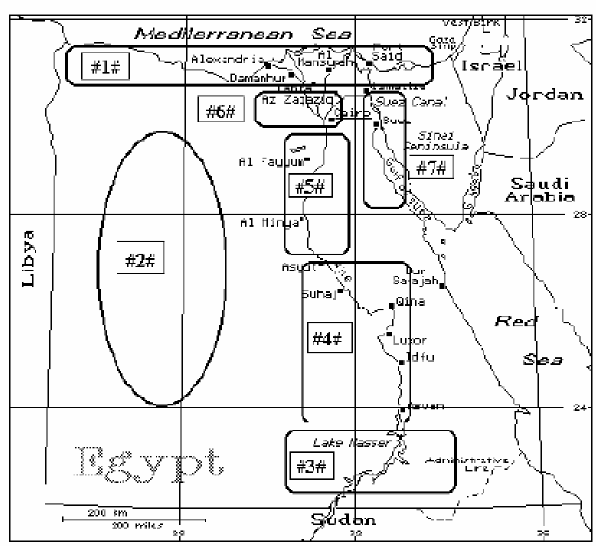

Figure 12: Climatic Classifications for Different Regions in Egypt & Average Summer Conditions (Egyptian Climatic Authorities 1997)

The selected region represents the Greater Cairo region. The educational buildings that were selected in this study were universities. The selection of university buildings is based on the hypothesis that the managers will allow and promote such a study in their buildings as they are mostly scientists.

Many researchers previously obtained data examining thermal adaptation to the indoor thermal environments from students (Corgnati, Filippi and Viazzo 2007). Three universities were surveyed. The main criteria used in the choice of the buildings were the willingness of the managers to allow the study to be carried out in their premises; variability of the building age, recently designed verses older buildings and the distribution of buildings over the Greater Cairo Region. In addition, the design concept played a role in the selection of the buildings, as passively designed buildings were selected as well as mixed mode buildings to investigate the different design features influencing thermal comfort perception. The sample from each university considered the type of acclimatization used, size and number of floors, population size and their distribution, and degree of personal control over the environment.

Two of the buildings examined are part of Cairo University and Ain Shams University campuses. The selected parts are naturally ventilated buildings using ceiling fans, and they represent the governmental educational buildings in Greater Cairo Region. The third building is part of the Arab Academy for Science, Technology and Maritime Transport (AAST) – the Cairo Campus. It represents a private organization within the same geographical zone which uses air conditioning. The Architectural Departments in all of the former buildings were the focus of the study, in addition to the spaces that were used by the employees.

In Cairo University, the Architectural Department building has four floors with an area of 2225 m^2 each. The study focused on the main halls with an area of 1085 m^2 each where studios and drawing sections are held, as well as the lecture halls with an area of 239 m^2 each. Figure 13 shows a typical floor plan of the Architecture Department in Cairo University. The employees occupied other scattered spaces in different buildings ranging from 30 m^2 with two to four persons and up to 100 m^2 with seven to fifteen persons.

In Ain Shams University, the Architectural Department has two floors with an area of 1850 m^2 each serving the department's needs. The examined spaces included drawing halls with an area between 610 m^2 and 915 m^2 as well as lecture halls of 135 m^2. Figure 14 shows a typical floor plan of the Architecture Department in Ain Shams University. The employees occupied spaces in other buildings ranging from 40 m^2 to 100 m^2.

In AAST, the College of Engineering has one main building where spaces are allocated according to departmental needs. Within the building, there are four floors with an area of 2500 m2 each. The examined spaces included drawing halls of about 252 m2 each and lecture rooms of about 65 m2 each. Figure 15 shows a typical floor plan of the Architecture Department in AAST.

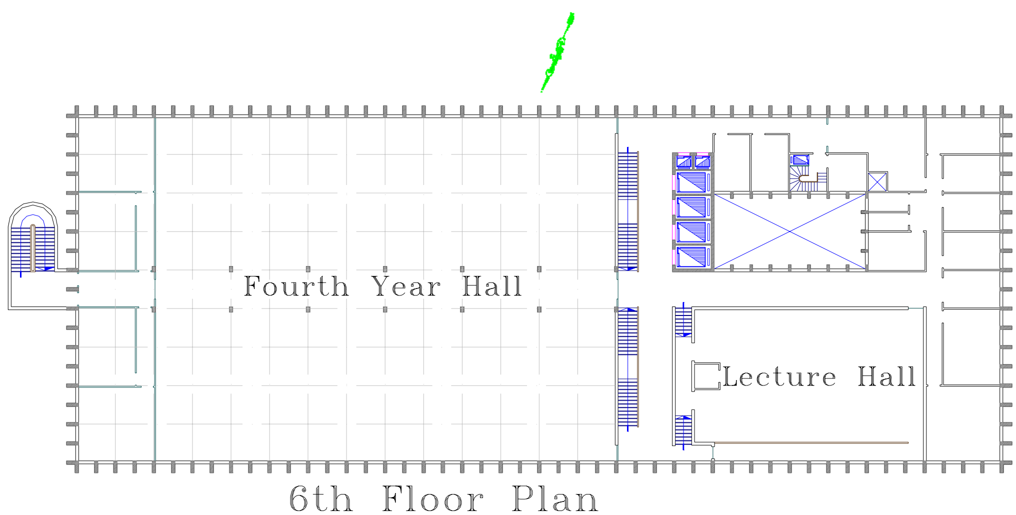

Figure 13: A typical floor plan of the Architecture Department in Cairo University.

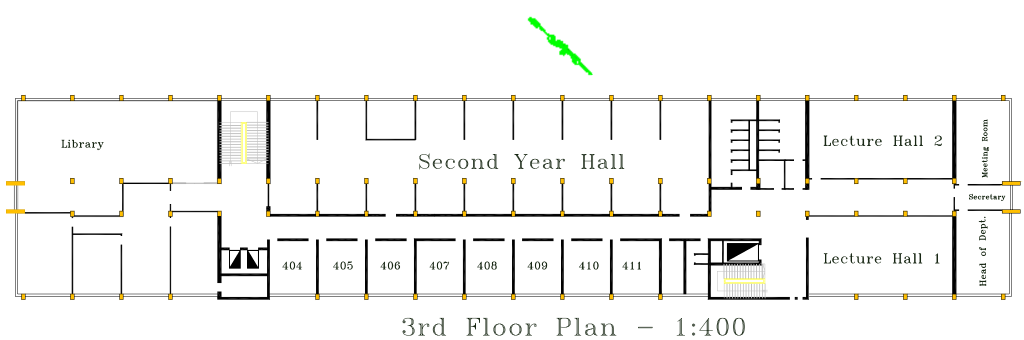

Figure 14: A typical floor plan of the Architecture Department in Ain Shams University.

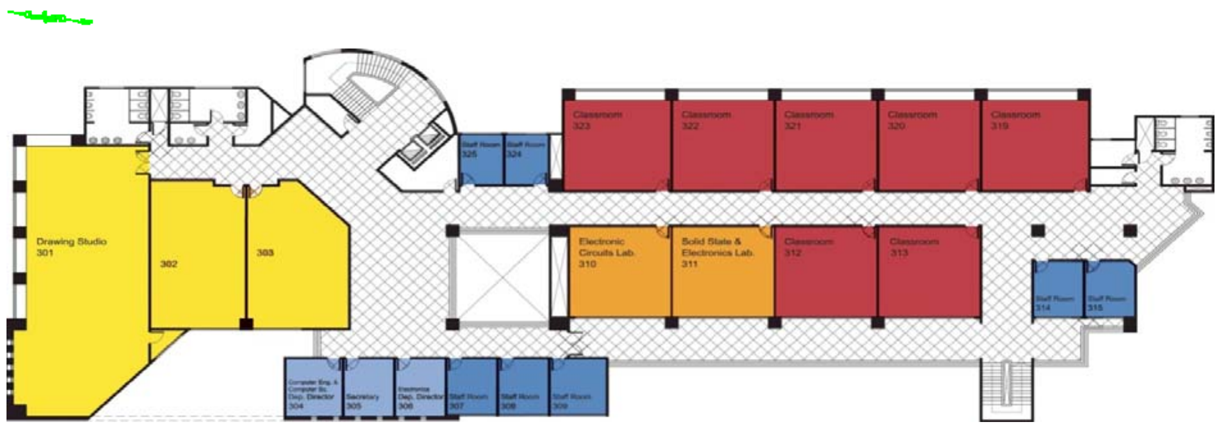

Figure 15: A typical floor plan of the Architecture Department in AAST

3.3.1.2 Selection of the subject sample

A transverse survey sampling was used in this field study to ensure the contribution of a majority of subjects representing the occupants of each building, and to avoid any risks with the individual sampling bias that could be found as a result of using a longitudinal survey. In addition, this allowed a large number of surveyed subjects to provide their votes which increased the accuracy of the outcome and minimized the disruption to the lives of the subjects.

In the ASHRAE RP-884 the longitudinal studies were treated as cross- sectional research designs for the purpose of statistical analysis. This means that a transverse selection is sufficient to compare results with the existing standards.

The study aimed at having a general overview of typical situations found within the selected buildings; this could be achieved by a transverse survey. Longitudinal sampling surveys are recommended for thermal comfort studies, especially if the research objective is an in-depth study of the mechanism of thermal comfort and adaptive behaviour over time (F. Nicol 1993). The time required and instrumentation needed for a longitudinal survey is outside the scope of this study.

Referring to Nicol's Handbook for Field Study, the recommended minimum number for a transverse survey is 100 subjects (F. Nicol 1993), as the number of subjects represents the same number of observations. This number of subjects was reached in each building. The number of subjects within each space varied according to the space size. Spaces with 25 to 50 persons were considered small or medium sized, and in this case, all the subjects within the space were invited to fill in the questionnaire at the same time. In large spaces, with more than 50 persons, the researcher also invited all the subjects to fill in the questionnaire while measuring their surrounding physical environment.

3.3.1.3 Time sampling

The role of time when conducting the survey was as important as the subject sampling. The selection of time reflects the experience of the subjects at the period of filling the questionnaire, as well as the dynamic relationship between the subjects and their thermal environments. Three strategies governed the time selection in the field study: concerning the seasons, the days of the week and the timing within the day of the survey.

The first strategy was the selection of the seasons. Spring and autumn were selected to represent the extreme conditions within the whole year, as they represent the coldest and hottest times of the academic year. November and December typified cold periods and February, March, April and May were the hot period. The study extended in July where employees were the subjects of the study.

The second strategy was the selection of the days of the week. Humans expressing their relationship to their thermal environment are affected by their experience of conditions over the previous period (F. Nicol 1993). This shows that the response of the subjects during the time of the survey is influenced by their thermal experience in the past. The study considered the main schedule of the working days while excluding those following holidays in order to avoid any bias in the data obtained.

The third strategy was the selection of the time during the survey day. The survey was carried out over the working hours of the day, three intervals of time were considered, from 10 to 12 in the morning, from 12 to 2 at noon and from 2 to 4 at the end of day.

The former strategies dealt with the selection of time to run the survey; the duration of the surveys is dealt with here. Within the same building the survey did not extend longer than one week. The time required by the subjects to fill in the questionnaire was minimized as much as possible, averaging from 10 minutes to a maximum of 15 minutes.

3.3.2 Thermal environment monitoring

The indoor thermal environment was simultaneously measured during the distribution of the questionnaire. The subjects were asked to start filling the questionnaire only if they passed a minimum of 30 minutes in the space. The measurements characterized the environment by measuring air temperature and relative humidity. These measurements are related to the comfort assessments in the chapter of data analysis.

In mixed mode spaces, air handling units were identified and the distribution of the measuring tools followed the critical zones of the surveyed room. The use of data loggers “Hobos” had the advantage of little intrusion and interference and allowed the measurements to take place every 5 minutes. The distribution of measuring tools took place before the beginning of lectures.

Proper placement of the tools was determined by a pre-test determining the qualitative patterns in each space. Selection regarding the proximity of windows, doors, solid corners, centre of the room, and level of the workplace was considered carefully to ensure the accurate measuring of the conditions in each space in general. Equipments were placed at a number of places on a horizontal plane at a vertical height of about 0.9 meter when the subjects were seated, and at a height of 1.1 meter when they are standing. One of these points was at the centre of the room and the others were indicated according to the previous features. Figure 16 shows the distribution of the measuring equipments in one of the studied spaces.

Figure 16: The data Loggers distributed over the whole space and their heights adjusted to the level of the students' heads.

Metrological data collected at the local weather station of Cairo were obtained. The external outdoor air temperature in each of the surveyed buildings was measured by placing one of the Hobos in the external environment; the aim was to regard any extreme differences due to the micro climatic conditions and urban heating. Air temperature and relative humidity were measured using data loggers (HOBO of the company onset), the measurement range of temperature is -20° to 70°c, and for relative humidity 5% to 95% RH.

3.3.3 Clothing and clo values

Social customs and cultural needs, together with seasonal pattern of outdoor weather conditions, are the main factors affecting the type of ensembles and garments worn by people throughout their lives. The clo values of the garments that are used in the calculation of the overall clo value are attached in Appendix G.

3.3.4 Questionnaire distribution

Group-administered questionnaires were distributed to students 20 minutes prior the end of classes in spaces allocated for lectures and studios, where the occupants were at least one hour within the space prior their voting. In other places, such as employees' rooms, the subjects were asked to vote after spending at least 30 minutes in the space.

The questionnaires were distributed to the respondents with verbal explanations and a written statement. After collecting the answered questionnaires, data were organized at the end of each day, and the data sets were managed on a daily basis for coordination with the data obtained from the data loggers.

3.3.5 Statistical analysis of the results

According to (F. Nicol 1993) the statistical analysis is the most common way of analyzing data obtained out of field studies, where the comfort votes are treated as the dependant variable and the environmental parameters as the independent variable. The data obtained were analyzed statistically using SPSS (Statistical packages for the Social Science).

Correlations are inferred; although that will not specify any causal effects, for considering the correlation statistically significant, significance value should be lower than 0.05. The Pearson correlation is used to measure the degree and direction of linear relationship between two variables. This is done in the chapter of the data analysis later in this work.

The analysis of variance (ANOVA) is a hypothesis testing procedure that is used to evaluate mean differences between two or more populations. The format for reporting the results states that the degrees of freedom for between and within treatments respectively. These values are placed in parentheses immediately following the symbol F. Next the calculated value for F is reported, followed by probability of committing a type I error (Gravetter and Wallnau 2004).

The development of formulas that predicted the relation between different variables was done using regression analysis. Regression analyses, as well as parametric correlations are suitable to scores measured on interval scales, normally distributed and have roughly the same variability. This assumption was fulfilled; it certainly breaks down in the end categories of the comfort scale, which had ranges that were semi infinite. In most cases, however, the majority of comfort votes were in the central categories with only a few votes at the extremities.

The chapter of data analysis is mainly based on the previous facts and it shows the outcome from the data collected.

CHAPTER FOUR DATA ANALYSIS

This chapter presents the results of the four field surveys' data analysis. The thermal environment's characteristics and their impact on comfort votes are studied. A comparison of the outcome from the actual field surveys to the adaptive comfort model is shown. The adaptive behaviour and its impact on comfort votes are discussed. The data analysis is mainly divided into two sections; the first section compares the outcome from the naturally ventilated buildings to the outcome from the mixed mode buildings; the second section focuses on the calculation of neutral temperature from naturally ventilated buildings and mixed mode buildings.

4.4 FREQUENCY OF VOTES AND THEIR DISTRIBUTION

The days included in the study and the frequency of votes on each day, for both building types and across the four seasons of the study, are shown in Figure 17. The study included a total number of 48 surveyed days, 27 of them had more than 50 votes and the rest, 21 days, had less than 50 votes each. The buildings, included in the study, were of two types regarding the control of the internal thermal conditions; Cairo and Ain Shams are naturally ventilated buildings, and AAST is a mixed mode building.

The months included in the study were February, March, April, May, July, November and December. The votes in July came from employees of the buildings; in the other months, both employees and students participated in the study. Figure 18 shows the distribution of votes according to different spaces for all days of the study across the four seasons included in the study.

The study conducted in autumn 2007 focused on students only; while in spring 2008, the study included both employees and students who participated on separate days. Studies conducted during the following two seasons allowed students and employees to participate on the same days, making it possible to compare different types of users experiencing the same indoor thermal conditions, but having different methods of adaptations.

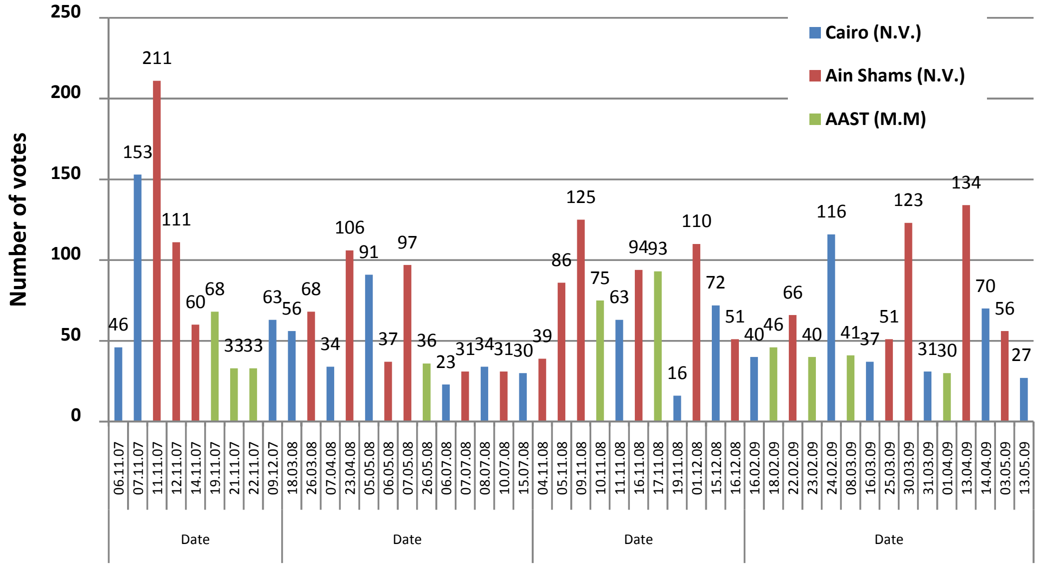

Figure 17: The days included in the study and frequency of votes on each day for both building types across the four seasons of the study, (N.V.) stands for naturally ventilated buildings and (M.M.) stands for mixed mode buildings

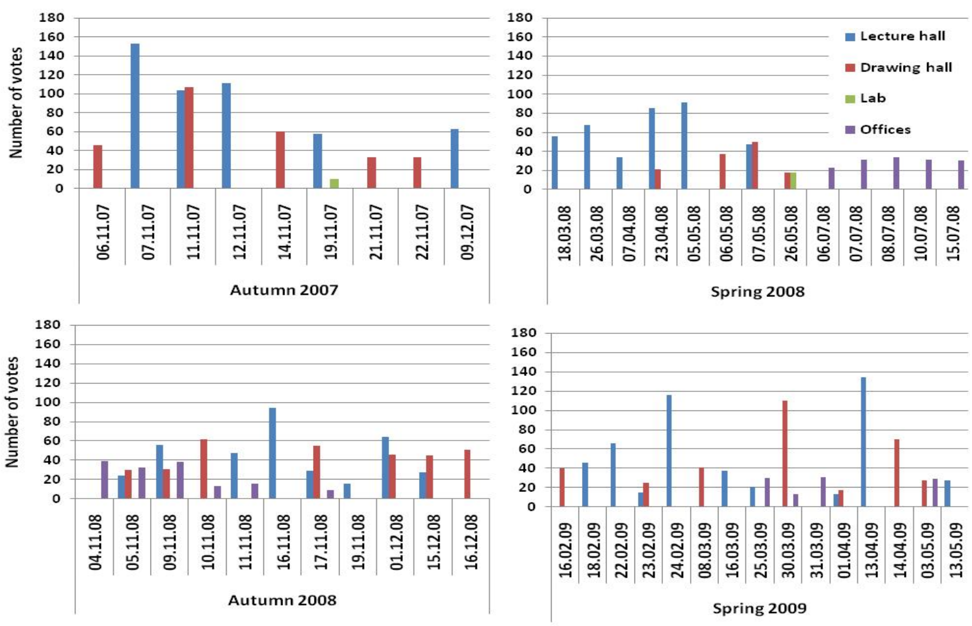

Figure 18: The distribution of votes according to different space types on all days of the study

Table 5: The distribution of votes on each day over the four seasons of the study

Season	Date	Space	Number of votes
Autumn 2007	06.11.07	Cairo	46
	07.11.07	Cairo	153
	11.11.07	Ain Shams	211
	12.11.07	Ain Shams	111
	14.11.07	Ain Shams	60
	19.11.07	AAST	68
	21.11.07	AAST	33
	22.11.07	AAST	33
	09.12.07	Cairo	63
Spring 2008	18.03.08	Cairo	56
	26.03.08	Ain Shams	68
	07.04.08	Cairo	34
	23.04.08	Ain Shams	106
	05.05.08	Cairo	91
	06.05.08	Ain Shams	37
	07.05.08	Ain Shams	97
	26.05.08	AAST	36
	06.07.08	Cairo	23
	07.07.08	Ain Shams	31
	08.07.08	Cairo	34
	10.07.08	Ain Shams	31
	15.07.08	Cairo	30
Autumn 2008	04.11.08	Ain Shams	39
	05.11.08	Ain Shams	86
	09.11.08	Ain Shams	125
	10.11.08	AAST	75
	11.11.08	Cairo	63
	16.11.08	Ain Shams	94
	17.11.08	AAST	93
	19.11.08	Cairo	16
	01.12.08	Ain Shams	110
	15.12.08	Cairo	72
	16.12.08	Ain Shams	51
Spring 2009	16.02.09	Cairo	40
	18.02.09	AAST	46
	22.02.09	Ain Shams	66
	23.02.09	AAST	40
	24.02.09	Cairo	116
	08.03.09	AAST	41
	16.03.09	Cairo	37
	25.03.09	Ain Shams	51
	30.03.09	Ain Shams	123
	31.03.09	Cairo	31
	01.04.09	AAST	30
	13.04.09	Ain Shams	134
	14.04.09	Cairo	70
	03.05.09	Ain Shams	56
	13.05.09	Cairo	27

The number of votes on each day of the field studies, over the four seasons is clarified in Table 5 . The study covered four seasons, autumn 2007, spring 2008, autumn 2008 and spring 2009. The number of votes in autumn 2007 was 778. The number of votes in spring 2008 was 674. The number of votes in autumn 2008 was 824 and the number of votes in spring 2009 was 908. The resulting number of votes was 3184, where 2689 votes represented the naturally ventilated spaces and 495 votes represented the mixed mode spaces.

4.5 DISTRIBUTION OF VOTES BY AGE AND GENDER

The distribution of votes by age and gender is shown in Figure 19 and Figure 20 for both building types. In naturally ventilated buildings, Figure 19, the percentage of female votes was 60.7 %, while the percentage of male votes was 36.2 %; 3.1 % did not answer the question determining the gender type. 82.7 % of the votes were younger than 25; this age category represented students, while the other age categories represented employees and lecturers. In mixed mode buildings, the percentage of male votes was 65.1 %, while the percentage of female votes was 33.9 %, only 1 % did not indicate their gender. Regarding the age, 89.5 % of the votes were less than 25, while 10.5 % represented the other age categories.

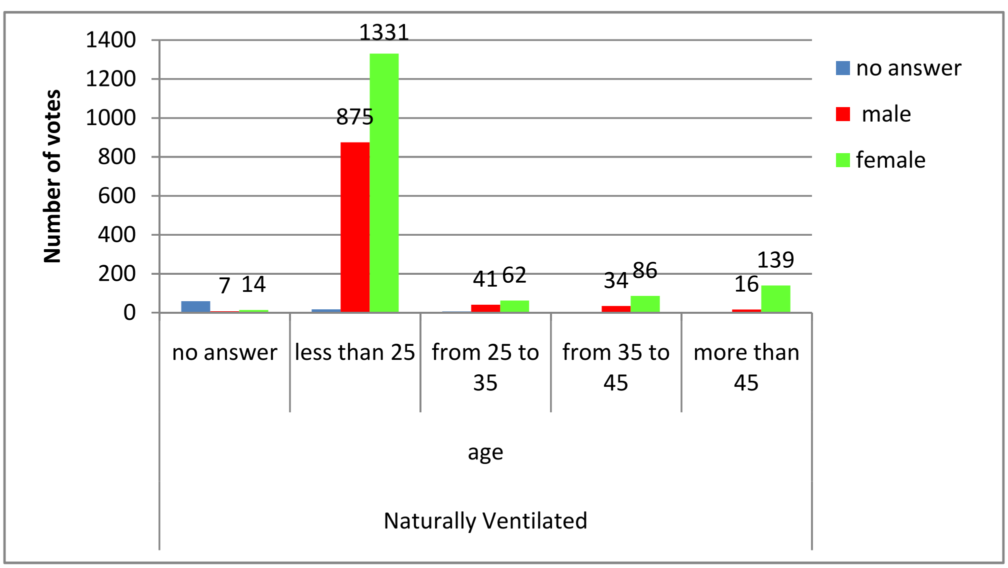

Figure 19: The distribution of votes in naturally ventilated buildings by age and gender

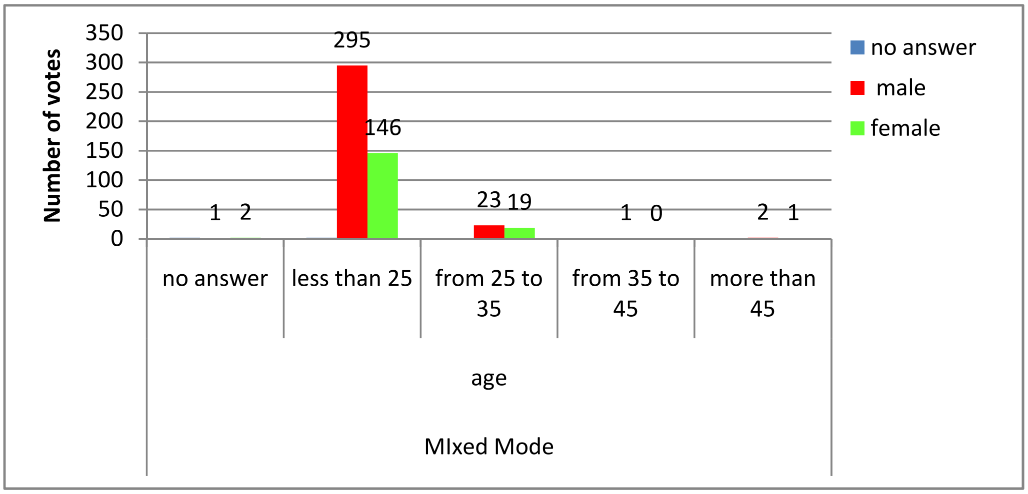

Figure 20: The distribution of votes in mixed mode buildings by age and gender

4.6 THERMAL ENVIRONMENT'S CHARACTERISTICS

This section deals with the thermal environment in the four different field studies. The parameters measured were the indoor air temperature and the relative humidity. The value of each represents the mean value calculated from the readings of all devices that were placed in each space. The values obtained for each space and the mean values of each building during the different four seasons of the field studies are discussed. The indoor air temperature was found to be almost the same as the operative temperature as discussed before in the methodology followed in measuring the indoor parameters. The outdoor air temperature was obtained from the Egyptian Meteorological Authority from the nearest metrological station, less than 50 km from any of the three buildings. The mean of the 6 a.m. and 3 p.m. readings represented the value of each point.

4.6.1 Air Temperature

The indoor air temperature was measured in one or more spaces on each day of the field studies. The mean indoor air temperature and the mean outdoor air temperature for naturally ventilated buildings in each day of the field studies over the four seasons are shown in Figure 21. It can be observed that the maximum mean indoor temperature recorded was 34.33°C, and the minimum mean indoor air temperature was 20.53°C, which means that the study covered a range of 14 K. The minimum mean outdoor air temperature was 16.1 and the maximum mean outdoor temperature was 34.95°C, covering a range of outdoor temperatures of 19 K.

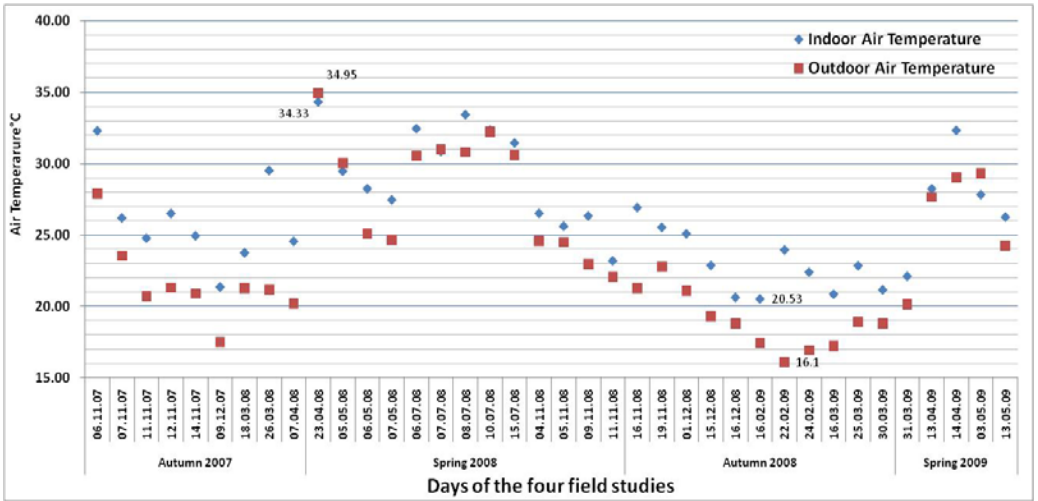

Figure 21: The mean indoor air temperature values (°C) recorded during the days of the study, and the mean outdoor air temperature values (°C) obtained from the Egyptian Meteorological Authority for naturally ventilated buildings

The mean indoor air temperature and the mean outdoor air temperature for mixed mode buildings in each day of the field studies over the four seasons are shown in Figure 22. It can be observed that the maximum mean indoor temperature recorded was 27.07°C, and the minimum mean indoor air temperature was 21.23°C, which means that the study covered a range of 6 K. The minimum mean outdoor air temperature was 17°C and the maximum mean outdoor temperature was 26.6°C, covering a range of outdoor temperatures of 9.5 K.

The general trend in the autumn seasons was that the recorded indoor temperature started from a high temperature and decreased as the study continued, while the reverse occurred in the spring seasons. The mean outdoor air temperature was always lower than the mean indoor air temperature as the survey was conducted between the 10 a.m. and 4 p.m., while the mean outdoor air temperature was calculated as the average of the 6 a.m. and the 3p.m. readings.

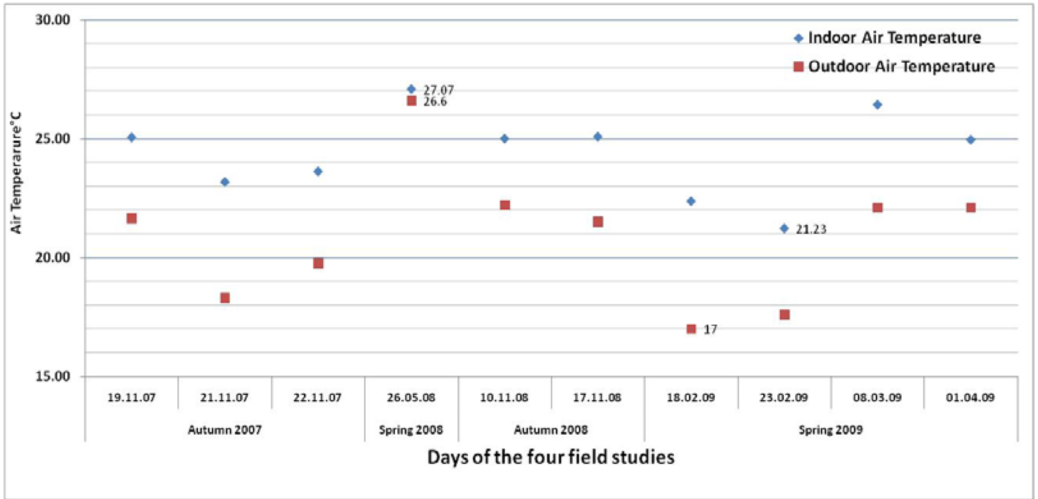

Figure 22: The mean indoor air temperature values (°C) recorded during the days of the study, and the mean outdoor air temperature values (°C) obtained from the Egyptian Meteorological Authority for mixed mode buildings

The mean indoor air temperature, with the 95% confidence interval, for different building types across each season is shown in Figure 23. The mean indoor air temperature in the case of mixed mode buildings was lower than the mean indoor air temperature in the case of naturally ventilated buildings; this was due to the usage of air conditioning in the case of mixed mode buildings.

Spring 2008 had the higher means for both building types, and it was higher than the average range covered by the other studies in the other three seasons. This led to the investigation of the thermal range covered in each building type across the four seasons. On reviewing Table 6, it is clear that the days covered in spring 2008 had indoor air temperatures more than 25° C, which led to a higher mean of the indoor air temperature than the other seasons investigated in the study. The range of indoor air temperatures between 21°C and 25°C was clearly represented in the season of spring 2009; this had an impact on the neutral temperature calculated for each season later on.

The analysis of variance of the indoor air temperature for different types of buildings is shown in Appendix I, where there was no difference in autumn 2008; this is also clear from Figure 23. But in autumn 2007, spring 2008 and spring 2009 there was a significant difference between the indoor air temperatures of both types of buildings within each of these seasons. For autumn 2007, $\alpha = 0.05$, $F(1,776) = 42.494$ and $P <$

0.001, for spring 2008, $\alpha = 0.05$, $F(1,672) = 23.37$ and $P < 0.001$, for autumn 2008, $\alpha = 0.05$, $F(1,822) = 0.090$ and $P = 0.765$, and for spring 2009, $\alpha = 0.05$, $F(1,906) = 11.915$ and $P < 0.001$.

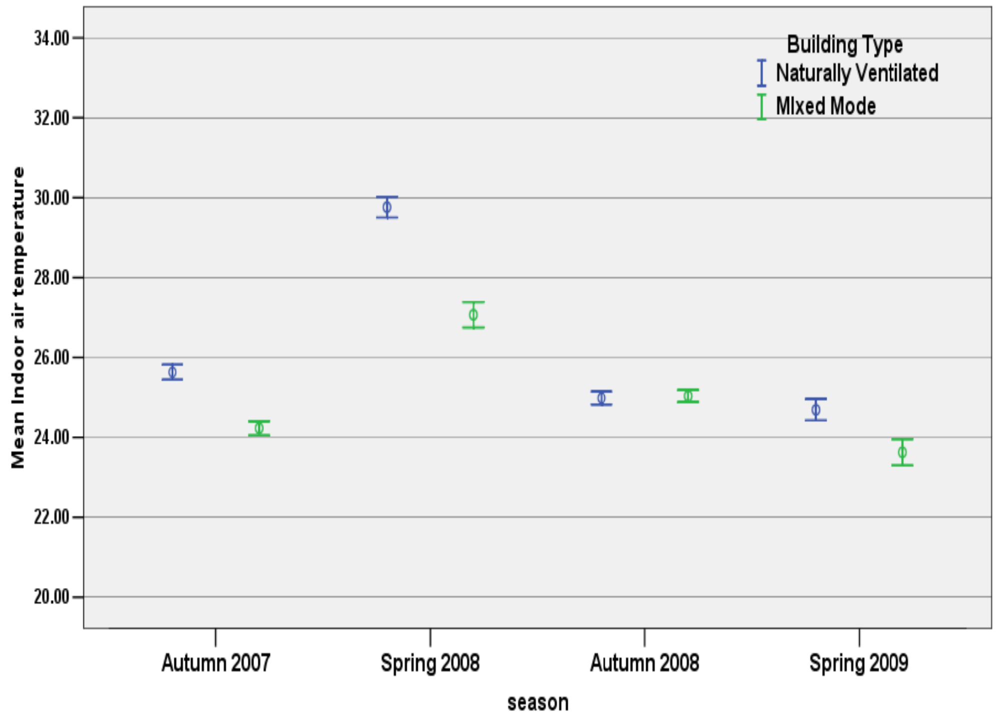

Figure 23: The mean indoor air temperature for the different building types across the four seasons of the study

Table 6: The cumulative percentage of the indoor air temperature for different building types across the four seasons of the study

Air Temperature

season	Building Type		Frequency	Percent	Valid Percent	Cumulative Percent
Autumn 2007	Naturally Ventilated	21.00	63	9.8	9.8	9.8
		24.00	113	17.5	17.5	27.3
		25.00	60	9.3	9.3	36.6
		26.00	251	39.0	39.0	75.6
		27.00	111	17.2	17.2	92.9
		32.00	46	7.1	7.1	100.0
		Total	644	100.0	100.0	
	MIxed Mode	23.00	43	32.1	32.1	32.1
		24.00	33	24.6	24.6	56.7
		25.00	21	15.7	15.7	72.4
		26.00	37	27.6	27.6	100.0
		Total	134	100.0	100.0	
Spring 2008	Naturally Ventilated	24.00	56	8.8	8.8	8.8
		25.00	34	5.3	5.3	14.1
		27.00	50	7.8	7.8	21.9
		28.00	84	13.2	13.2	35.1
		29.00	68	10.7	10.7	45.8
		30.00	91	14.3	14.3	60.0
		31.00	61	9.6	9.6	69.6
		32.00	96	15.0	15.0	84.6
		33.00	34	5.3	5.3	90.0
		35.00	21	3.3	3.3	93.3
		36.00	43	6.7	6.7	100.0
		Total	638	100.0	100.0	
	MIxed Mode	26.00	18	50.0	50.0	50.0
		28.00	18	50.0	50.0	100.0
		Total	36	100.0	100.0	
Autumn 2008	Naturally Ventilated	21.00	51	7.8	7.8	7.8
		22.00	74	11.3	11.3	19.1
		23.00	91	13.9	13.9	32.9
		24.00	7	1.1	1.1	34.0
		25.00	72	11.0	11.0	45.0
		26.00	108	16.5	16.5	61.4
		27.00	227	34.6	34.6	96.0
		28.00	26	4.0	4.0	100.0
		Total	656	100.0	100.0	
	MIxed Mode	23.00	15	8.9	8.9	8.9
		24.00	49	29.2	29.2	38.1
		25.00	35	20.8	20.8	58.9
		26.00	69	41.1	41.1	100.0
		Total	168	100.0	100.0	
Spring 2009	Naturally Ventilated	21.00	217	28.9	28.9	28.9
		22.00	138	18.4	18.4	47.3
		23.00	22	2.9	2.9	50.2
		24.00	66	8.8	8.8	59.0
		25.00	21	2.8	2.8	61.8
		26.00	27	3.6	3.6	65.4
		28.00	190	25.3	25.3	90.7
		32.00	70	9.3	9.3	100.0
		Total	751	100.0	100.0	
	MIxed Mode	21.00	25	15.9	15.9	15.9
		22.00	34	21.7	21.7	37.6
		23.00	27	17.2	17.2	54.8
		25.00	30	19.1	19.1	73.9
		26.00	41	26.1	26.1	100.0
		Total	157	100.0	100.0	

4.6.2 Relative Humidity

The mean indoor relative humidity of each day and corresponding mean outdoor relative humidity for naturally ventilated buildings are shown in Figure 24. The minimum indoor relative humidity was 20.60% and the maximum indoor relative humidity was 60.43%, covering a range of 40%. The minimum outdoor relative humidity was 22% and the maximum outdoor relative humidity was 65.50%, covering a range of 43.50%.

The mean indoor relative humidity of each day and corresponding mean outdoor relative humidity for mixed mode buildings are shown in Figure 25. The minimum indoor relative humidity was 25.27% and the maximum indoor relative humidity was 55.25%, covering a range of 30%. The minimum outdoor relative humidity was 35% and the maximum outdoor relative humidity was 67.50%, covering a range of 32.50%.

In most cases in both building types, the indoor relative humidity percentage is within acceptable ranges, the mean indoor relative humidity lay between the 40% and the 60% as recommended by (CIBSE 1997) for office work.

4.6.3 Summary

The fact that the buildings' mean indoor air temperature was always higher than the mean outdoor air temperature shows that there was a great potential for using passive cooling techniques to lower the internal air temperatures. This could be applied to both types of buildings, while in the case of mixed mode buildings this would result in reducing the need for air condition.

The hottest season examined was spring 2008, and the coldest season was spring 2009, the mean indoor air temperatures examined were on average 25 °C except in spring 2008.

The analysis of variance showed a significant difference between the mean air temperatures of both building types except for the season of autumn 2008.

The indoor relative humidity percentages were within the acceptable limits for office work in autumn seasons, in spring seasons it went below this range.

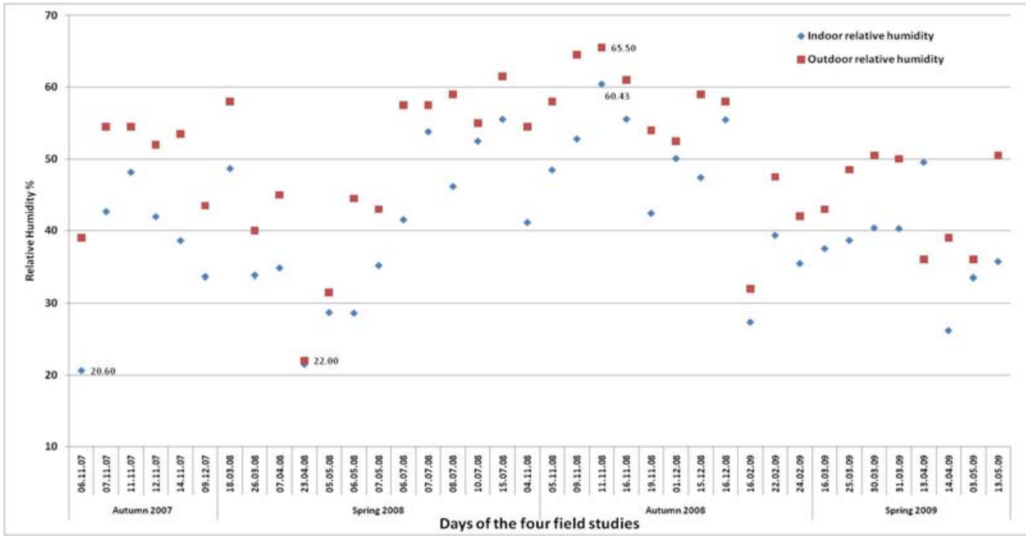

Figure 24: The mean indoor relative humidity (%) for the days of the study together with the corresponding outdoor relative humidity for naturally ventilated buildings

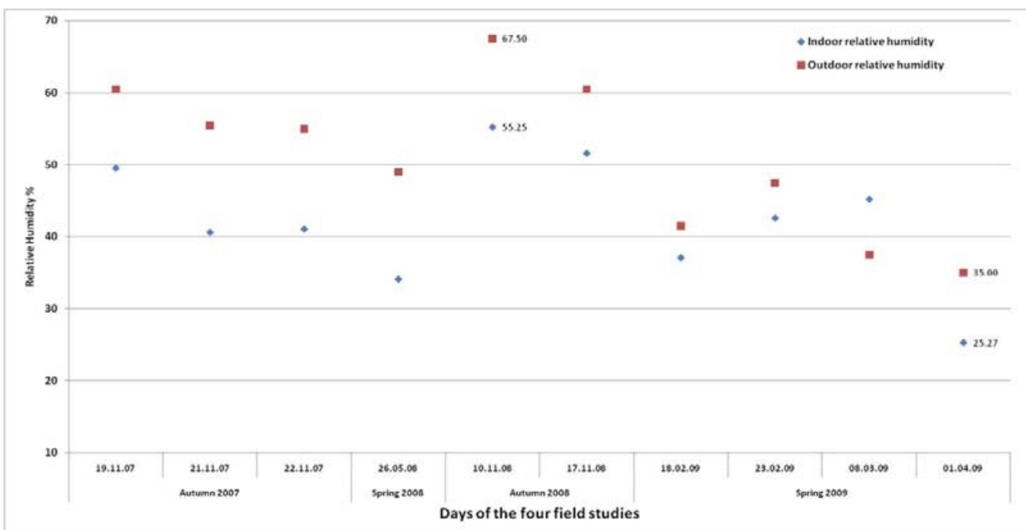

Figure 25: The mean indoor relative humidity (%) for the days of the study together with the corresponding outdoor relative humidity for mixed mode buildings

4.7 COMFORT VOTES

This section presents the results of the votes obtained in the four seasons' questionnaires on the various comfort parameters. It includes thermal comfort parameters such as thermal sensation, thermal preference and thermal acceptance; it also includes humidity comfort parameters such as humidity sensation, humidity preference and humidity acceptance. The last parameter discussed is the overall satisfaction with climatic conditions.

4.7.1 Thermal sensation votes

The distribution of thermal sensation votes across the different building types in the four seasons of the study is shown in Figure 26, Figure 27, Figure 28 and Figure 29. The percentages of the votes across the seven categories of the ASHRAE scale are shown in Table 7. In the autumn seasons, the percentage of votes for the central category of the scale (-1, 0, 1) is 88% for the mixed mode buildings, and the case of naturally ventilated buildings did not differ except in the autumn 2008, which was 84%. This meant that in the autumn seasons, the response to the thermal sensation did not differ among different building types. This was confirmed by the analysis of variance in the autumn seasons, where in autumn 2007 the ANOVA is $\alpha = 0.05$, $F(1,777) = 1.546$ and $P = 0.214$, and in autumn 2008 the ANOVA is $\alpha = 0.05$, $F(1,821) = 0.224$ and $P = 0.636$.

The case differed for the spring seasons. Spring 2008 (refer to 4.6.1) was considered the hottest conditions of the whole study. The percentage of votes for the central category of the ASHRAE scale (-1, 0, 1) was 67% for mixed mode buildings and 54% for naturally ventilated buildings. In spring 2009, the percentage of votes for the central category of the ASHRAE scale (-1, 0, 1) was 88% for the mixed mode buildings and 78% for the naturally ventilated buildings.

The ANOVA test showed that there was a difference between the votes of mixed mode buildings and naturally ventilated spaces, where ANOVA for spring 2008 was $\alpha = 0.05$, $F(1,672) = 5.096$ and $P = 0.024$, and for spring 2009 was $\alpha = 0.05$, $F(1,906) = 4.386$ and $P = 0.037$. This difference reflected the effect of using air conditioning in the spring season in the mixed mode buildings, which resulted in a higher percentage of comfortable votes in mixed mode buildings than in naturally ventilated buildings. The case was different in the autumn seasons as using the air conditioner is not common during this period of the year.

Table 7: Percentage of thermal sensation votes for each type of buildings over the four seasons of the study

		Mixed Mode % of votes	Naturally Ventilated % of votes
Autumn 2007	Cold	0	0
	Cool	5	2
	Slightly Cool	16	17
	Just Right	53	52
	Slightly Warm	19	19
	Warm	5	8
	Hot	1	2
Spring 2008	Cold	0	0
	Cool	0	0
	Slightly Cool	0	2
	Just Right	56	32
	Slightly Warm	11	20
	Warm	22	20
	Hot	11	26
Autumn 2008	Cold	0	1
	Cool	1	2
	Slightly Cool	9	14
	Just Right	55	47
	Slightly Warm	24	23
	Warm	8	10
	Hot	4	5
Spring 2009	Cold	0	0
	Cool	1	1
	Slightly Cool	6	8
	Just Right	52	47
	Slightly Warm	30.6	23
	Warm	8.3	14
	Hot	1.9	7

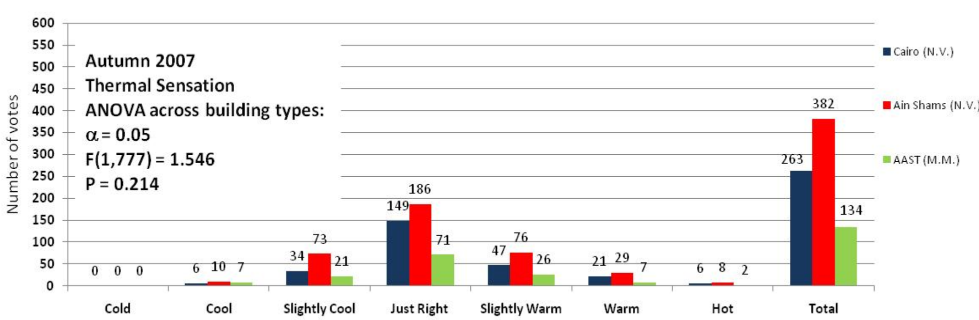

Figure 26: The distribution of thermal sensation votes of the different building types in autumn 2007, and the analysis of variance across different building types (α = 0.05, F (1,777) = 1.546 and P = 0.214)

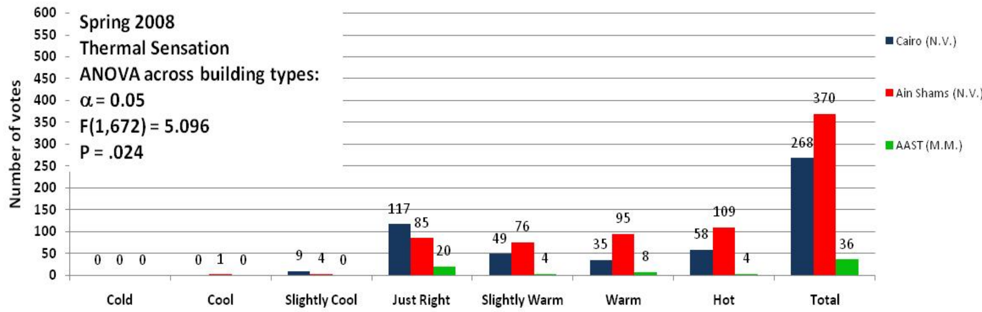

Figure 27: The distribution of thermal sensation votes of the different building types in spring 2008, and the analysis of variance across different building types (α = 0.05, F (1,672) = 5. 096 and P = 0.024)

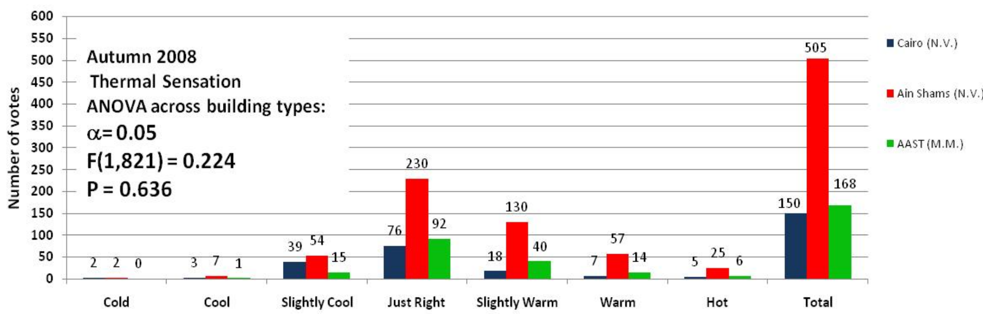

Figure 28: The distribution of thermal sensation votes of the different building types in autumn 2008, and the analysis of variance across different building types (α = 0.05, F (1,821) = 0.224 and P = 0.636)

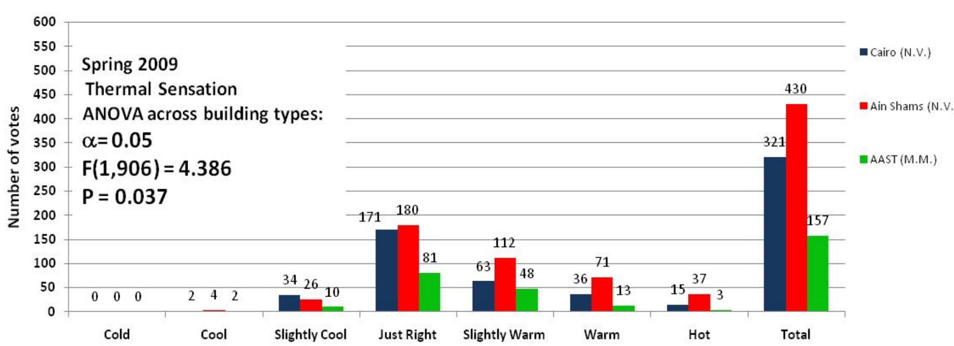

Figure 29: The distribution of thermal sensation votes of the different building types in spring 2009, and the analysis of variance across different building types (α = 0.05, F (1,906) = 4.386 and P = 0.037)

Figure 30 shows the mean of the thermal sensation vote for the different types of buildings for the four seasons of the study. It is obvious that the mean for mixed mode buildings was always below the naturally ventilated buildings except in autumn 2008 where they are almost coinciding. The higher means were in the hottest season spring 2008.

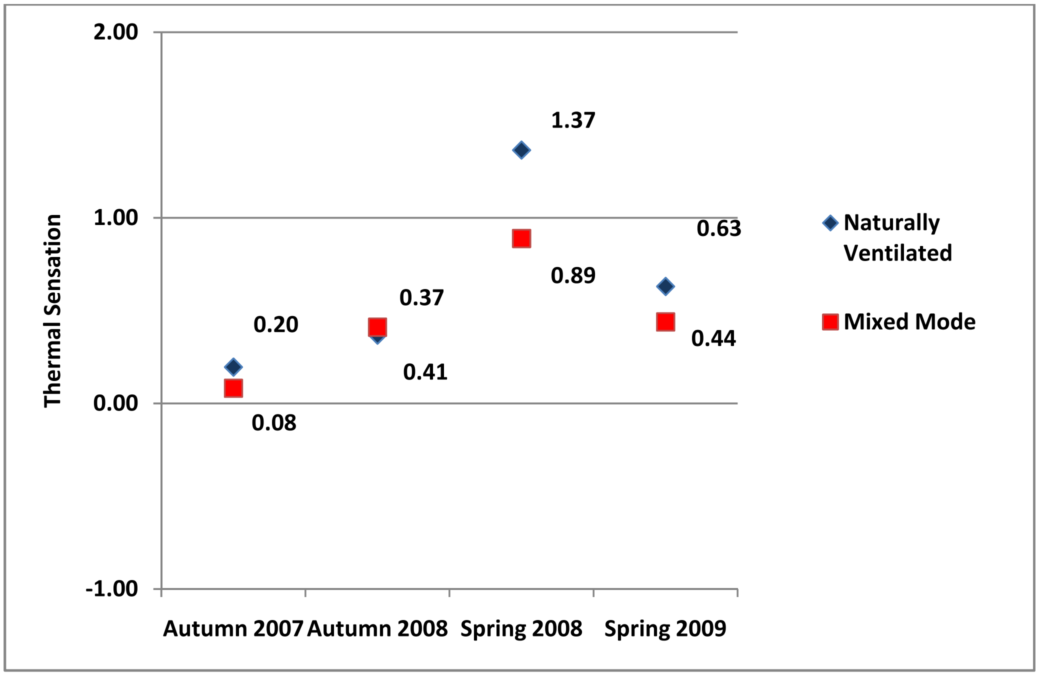

Figure 30: The mean thermal sensation for each type of building for the four seasons of the study

The study took place in a hot dry climate, so the votes corresponding to the cold category of the ASHRAE scale was almost not found. The votes were generally inclined towards the warm zone of the scale.

4.7.2 Thermal preference votes

The distribution of preference votes for both building types across the four seasons of the study are shown in Figure 31. It is obvious that in autumn seasons, the most common preference votes are slightly cooler and unchanged, while in spring seasons, the preference votes reflected the pattern of the sensation votes, i.e the votes seemed to prefer more a cooler environment than in the case of the autumn seasons. The case was the same in both building types.

The cumulative percentage of the preference votes for the different building types across the four seasons of the study is shown in Figure 32. The cumulative percentage for the categories cooler, slightly cooler and unchanged was almost above 80% in all cases, except for the mixed mode spaces in autumn 2007. This emphasised the tendency to prefer cooler environments in all seasons included in the study. The highest cumulative percentage at the vote unchanged is also occurred in the hottest season spring 2008.

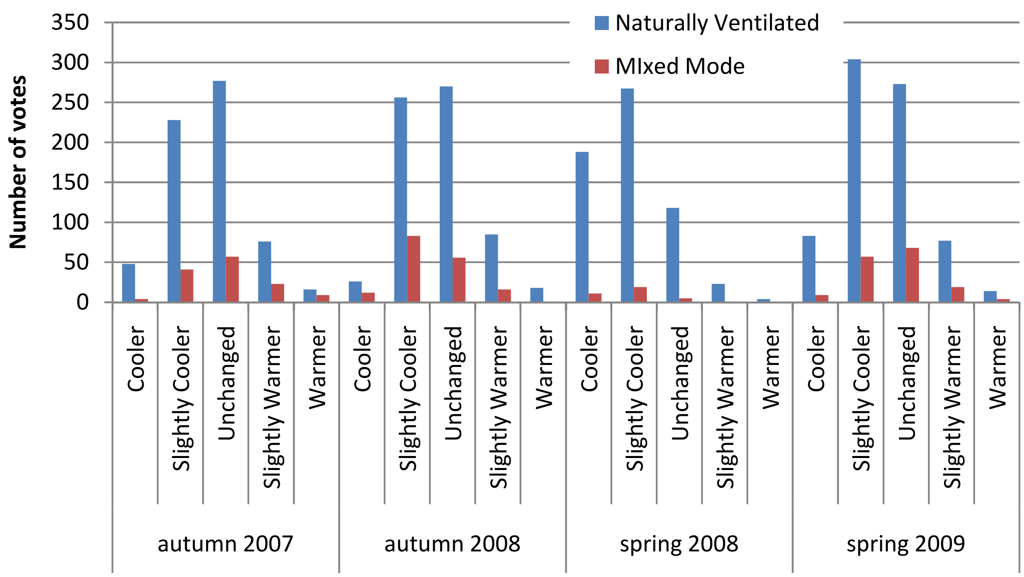

Figure 31: The distribution of preference votes for the different building types across the four seasons of the study

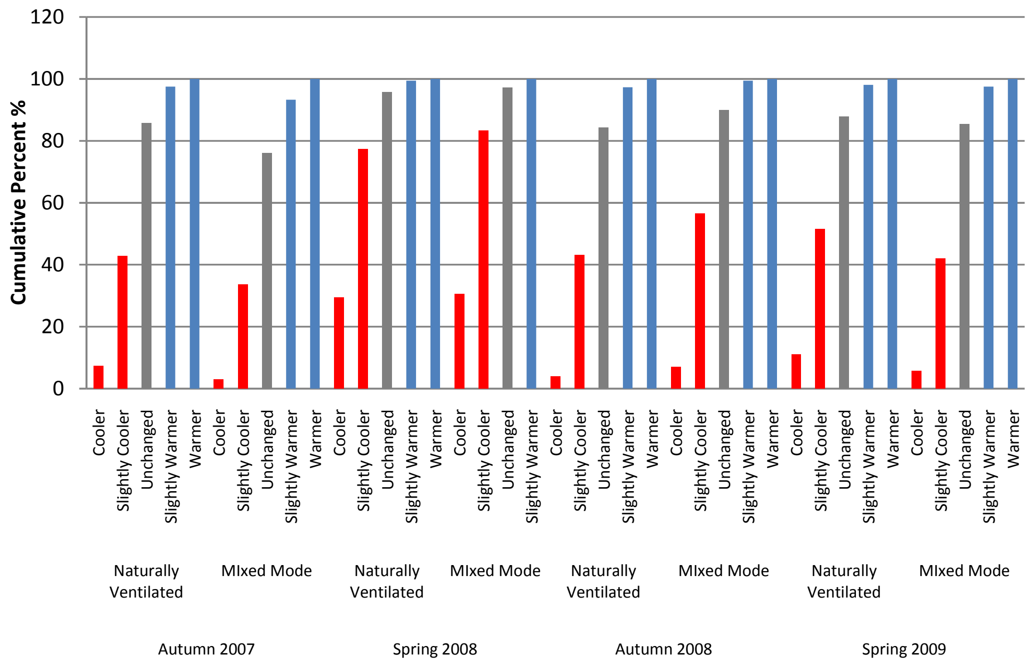

Figure 32: The cumulative percentage (%) of preference votes for different building types across the four seasons of the study

4.7.3 Relation between thermal sensation and thermal preference

The distributions of thermal preference votes across thermal sensation votes are shown in Figure 33 for naturally ventilated buildings and in Figure 34 for mixed mode buildings. The percentage of thermal preference votes across different thermal sensation categories is shown in Table 8 for both types of buildings. In naturally ventilated buildings, in the "just right" category of the thermal sensation scale, 62.1 % of the votes preferred the thermal conditions to be the same, 28.7% preferred cooler conditions while only 9.1% preferred warmer conditions. In mixed mode buildings, for the "just right" thermal sensation category 56.1% of the votes preferred the same thermal conditions, 31.8% preferred cooler conditions, while 12.1% preferred warmer conditions.

The distribution of preference votes across thermal sensation votes followed the logical concept in both types of buildings. In the case where subjects feel "slightly cool or cool or cold" they preferred warmer conditions, and on the contrary when they felt "slightly warm or warm or hot" they preferred cooler conditions.

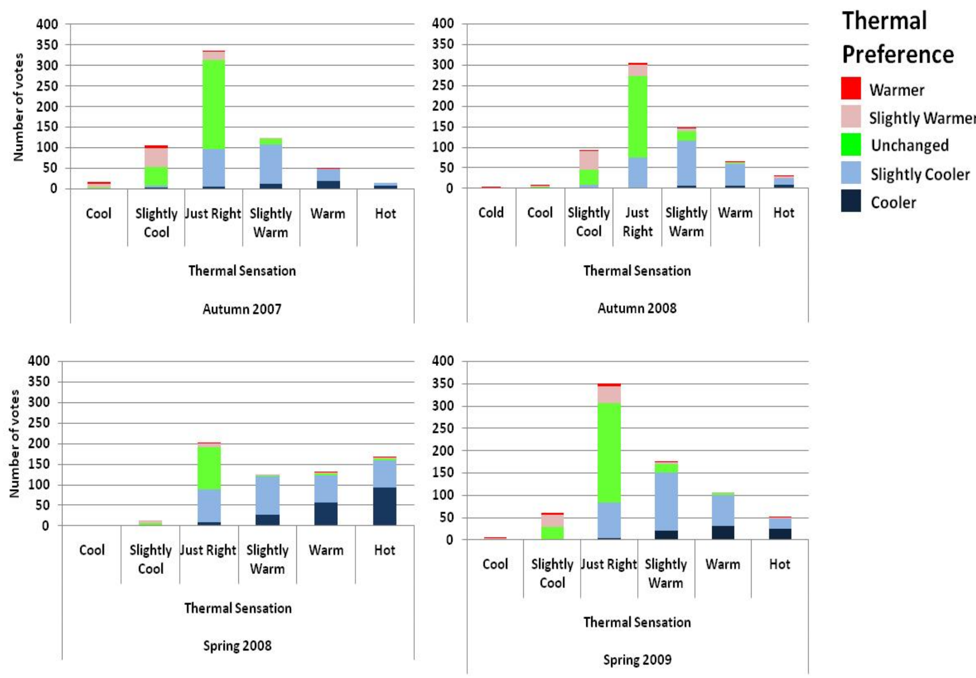

Figure 33: The distribution of thermal preference votes across the thermal sensation votes for naturally ventilated buildings

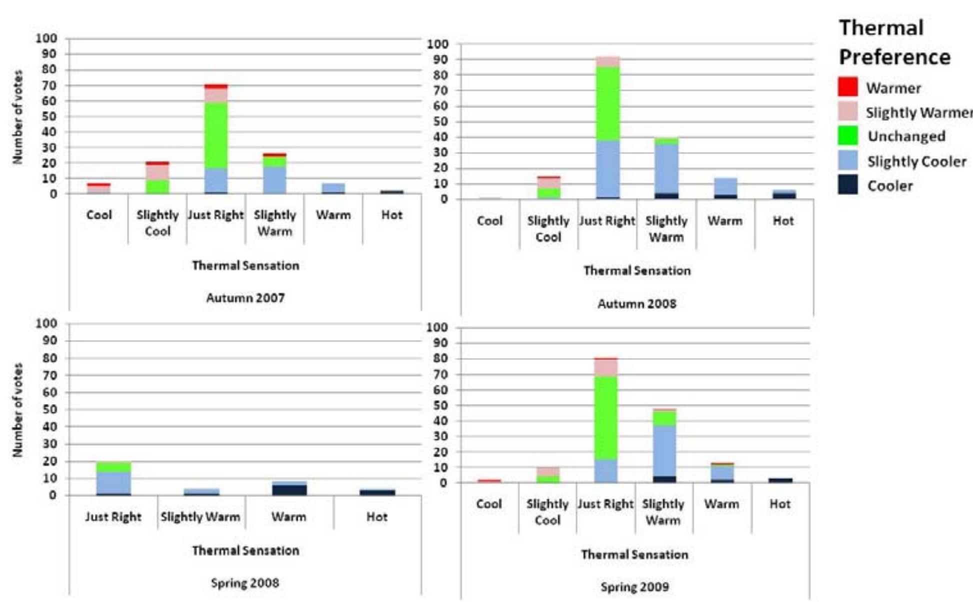

Figure 34: The distribution of thermal preference votes across thermal sensation votes for mixed mode buildings

Table 8: The percentage of thermal preference votes across each category of the thermal sensation scale for both types of buildings

Thermal Sensation * Temperature preference Cross tabulation							
Building Type			Temperature preference				
			cooler	slightly cooler	unchanged	slightly warmer	warmer
Naturally Ventilated	Thermal Sensation	Cold	25.00%	0%	0%	50.00%	25.00%
		Cool	0%	3.00%	18.20%	51.50%	27.30%
		Slightly Cool	0.70%	5.10%	43.60%	45.10%	5.50%
		Just Right	1.80%	26.90%	62.10%	7.70%	1.40%
		Slightly Warm	11.90%	75.30%	9.60%	2.60%	0.50%
		Warm	33.00%	61.50%	3.10%	1.40%	0.90%
		Hot	51.70%	42.20%	1.90%	2.70%	1.50%
Mixed Mode	Thermal Sensation	Cool	0%	10.00%	0%	60.00%	30.00%
		Slightly Cool	0%	2.20%	41.30%	50.00%	6.50%
		Just Right	1.10%	30.70%	56.10%	10.60%	1.50%
		Slightly Warm	7.60%	72.90%	15.30%	1.70%	2.50%
		Warm	28.60%	66.70%	2.40%	0%	2.40%
		Hot	80.00%	20.00%	0%	0%	0%

It seems that there were a percentage of subjects who misunderstood the meaning of the thermal preference question. This category was divided in two groups, the first group includes those subjects who preferred cooler conditions while voting for an existing cold condition in the space (thermal sensation votes “slightly cool or cool or cold”). The second group consists of those subjects who preferred a warmer condition on the preference scale, while voting for “slightly warm or warm or hot” on the thermal sensation scale. This could be checked by adding the thermal preference to the thermal sensation vote for each subject; the logical outcome should present a “just right” condition. The addition of both scales will be named here as the adjusted preferred condition which is shown in Figure 35 for naturally ventilated buildings and in Figure 36 for mixed mode buildings. The “just right” category was represented by 52.8% in naturally ventilated buildings; the same category was represented by 54.9% in mixed mode buildings.The central category “slightly cool, just right and slightly warm”, which is considered the comfort zone in the existing ASHRAE standard -55 2004, was 91.7% in the case of naturally ventilated buildings and 96.1% in the case of mixed mode buildings. This indicates that the probability of misunderstanding the meaning of the two questions asking about the thermal sensation and thermal preference was lower than 10% in both types of buildings and also indicated that people may prefer to feel slightly cool or slightly warm in some cases, this is noted as "semantic artifact" in the thermal sensation scales. When people are in a hot climate they tend to use words like "slightly cool" to describe their preferred thermal sensation, and in cold climate they use words like "slightly warm" to describe their preferred thermal sensation.

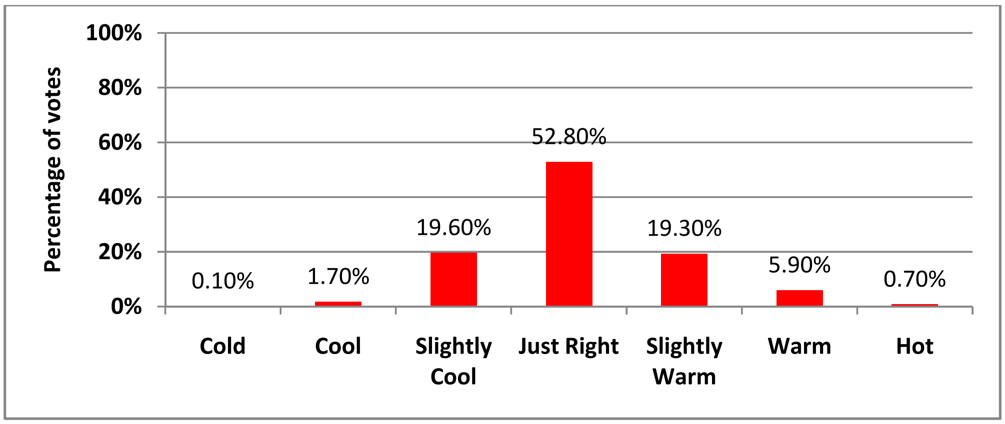

Figure 35: The percentage of adjusted preferred condition in naturally ventilated buildings

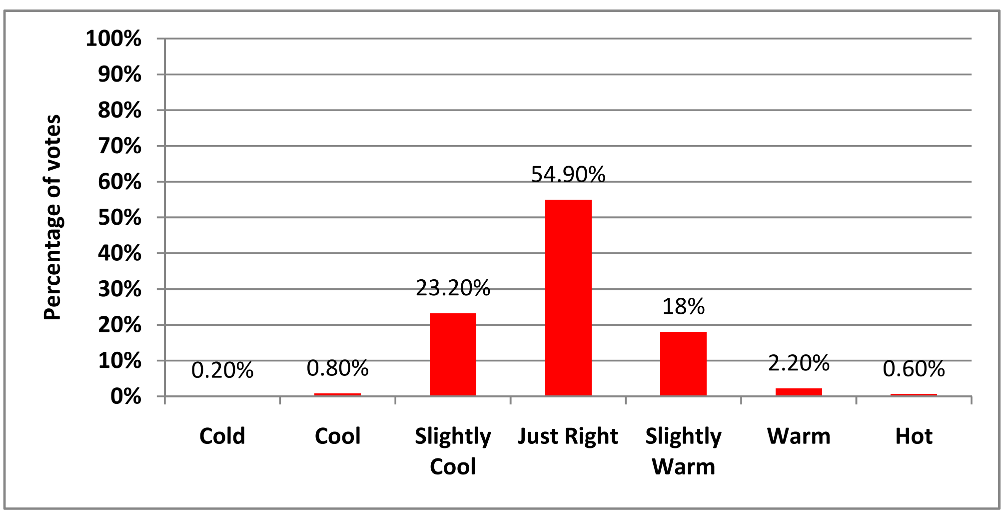

Figure 36: The percentage of adjusted preferred condition in mixed mode buildings

4.7.4 Acceptance votes

The percentage of accepted indoor thermal conditions is shown in Figure 37. The percentage of acceptability was 75 % or more in most cases except for the hottest season of spring 2008; it went down to 50% in the naturally ventilated buildings and 60 % in the mixed mode buildings. The mixed mode buildings showed a higher acceptance of the indoor thermal conditions than the naturally ventilated buildings, although the analysis of variance did not show a great significance between the percentages of acceptance in different building types. The study was carried out in the spring and autumn seasons, when methods of adaptation are almost the same as the usage of air conditioning are not common in both seasons.

Figure 38 shows the actual acceptance percentage for the indoor thermal conditions corresponding to the votes of the central category of the ASHRAE scale (-1, 0, 1). It was 85% or more in all the cases for both types of buildings and in all seasons. This differed from the assumption of the Adaptive Comfort Standard that the percentage of acceptance for this category is 80% (refer to 2.3.1.2.).

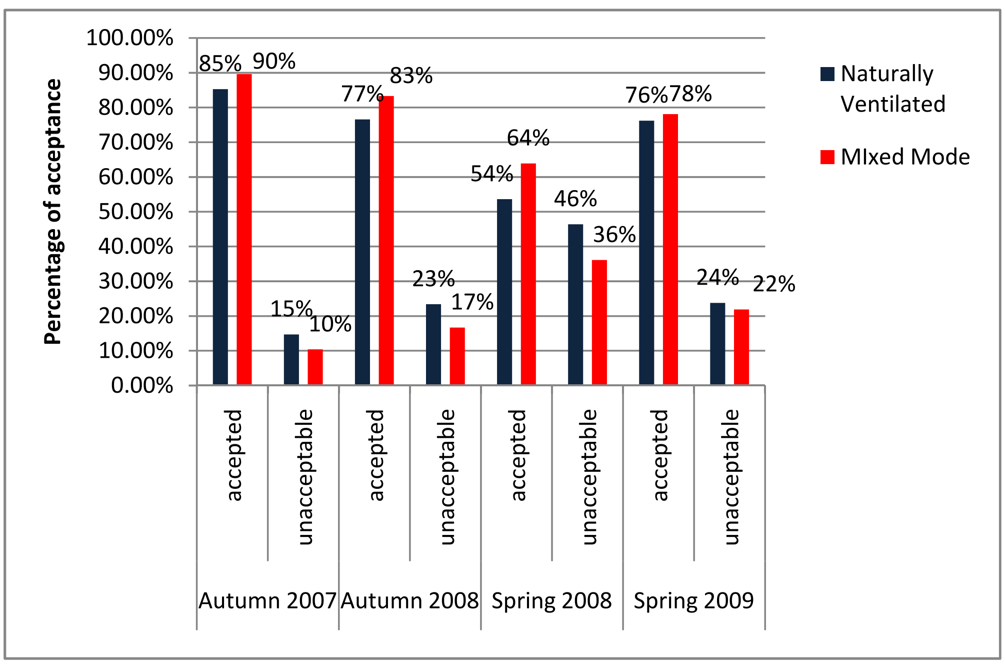

Figure 37: The percentage of acceptance of the indoor thermal conditions for both building types across the four seasons of the study

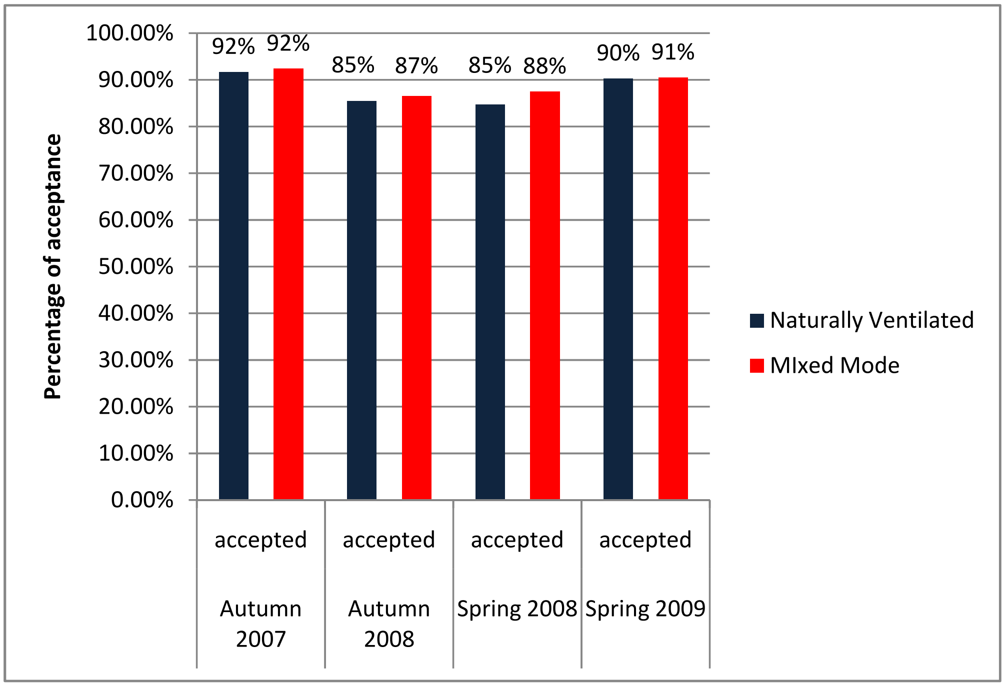

Figure 38: The percentage of acceptance of the indoor thermal conditions for the central thermal sensation categories (-1, 0, 1)

4.7.5 Humidity sensation votes

The percentage of humidity sensation is shown in Figure 39, where the central category (slightly dry, neutral and slightly humid) represents 75 % of the votes in most cases, except for the naturally ventilated buildings in spring 2008. With reference to the thermal environment's characteristics in 4.6.2, it was found that some days in that season were not part of the recommended percentage (between 40 % and 60 %). The analysis of variance showed that there was a difference between both types of buildings in this season, ANOVA $\alpha = 0.05$, $F(1,672) = 8.082$ and $P < 0.05$. The distribution of the humidity sensation votes did not differ between both types of buildings except in spring 2008.

During the study, the respondents' most commonly asked question was how to judge the humidity percentage in the environment. Although it seemed difficult to answer the question of the humidity sensation, the results attained were logical when compared to the measured parameter.

4.7.6 Humidity preference

Figure 40 shows the percentage of the humidity preference for the different building types across the four seasons of the study. The general tendency of the votes was towards the central category (slightly dry, unchanged and slightly humid), except in the season spring 2008.

The analysis of variance showed that the distribution of votes in spring 2008 differed significantly from the other seasons for naturally ventilated buildings, ANOVA $\alpha = 0.05$, $F(3, 3180) = 88.119$ and $P < 0.05$. The least significant difference (LSD) pair wise multiple comparison tests showed that the difference was due to the spring 2008 season as seen in Appendix J. The case did not differ for mixed mode buildings. This reflected the humidity sensation votes and the agreement between both votes.

4.7.7 Humidity acceptance

The percentage of humidity acceptance is shown in Figure 41. The percentage of acceptability was 75% or more in all cases, except for the case of naturally ventilated buildings in the season of spring 2008, it went down to 57%. This finding is coincided with the analysis of the humidity sensation votes and the humidity preference votes. In general, the mixed mode buildings showed a higher indoor humidity acceptance than the naturally ventilated buildings.

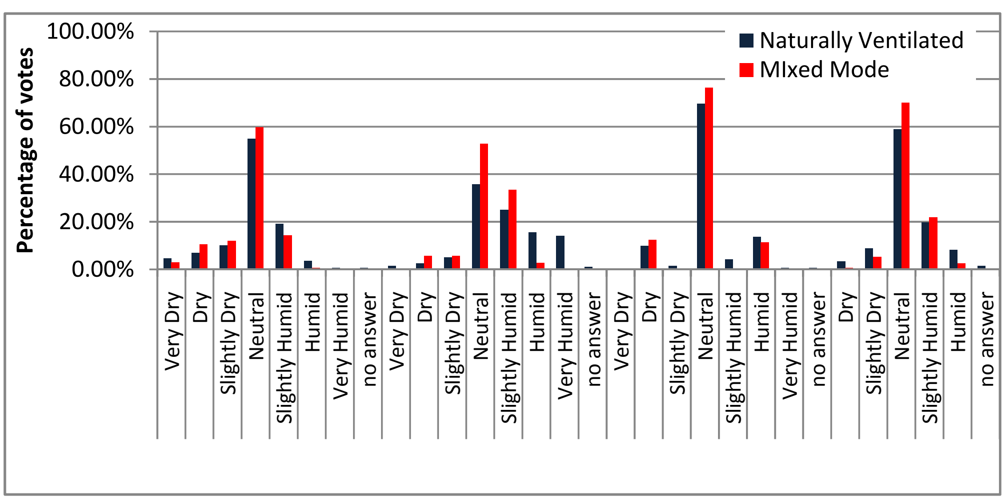

Figure 39: The humidity sensation vote for different building types across the four seasons of the study

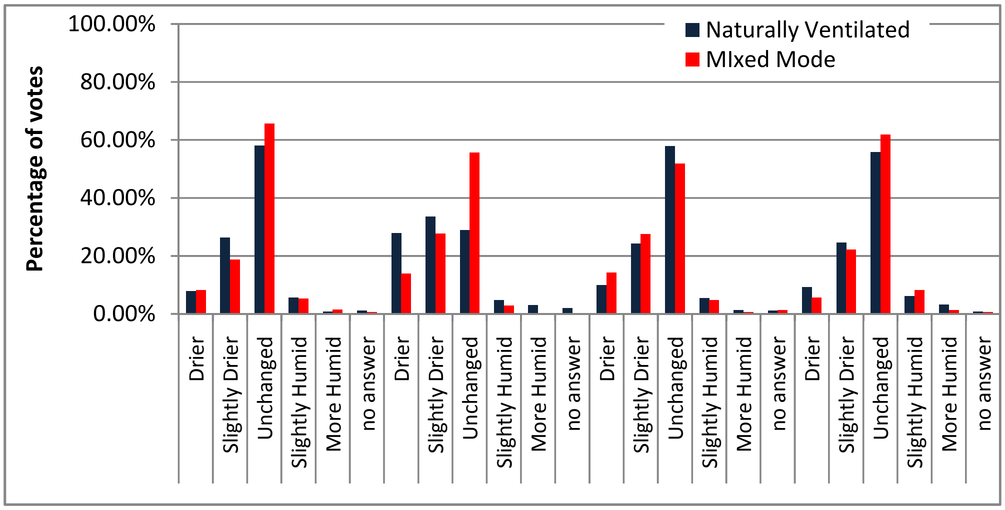

Figure 40: The humidity preference for different building types across the four seasons of the study

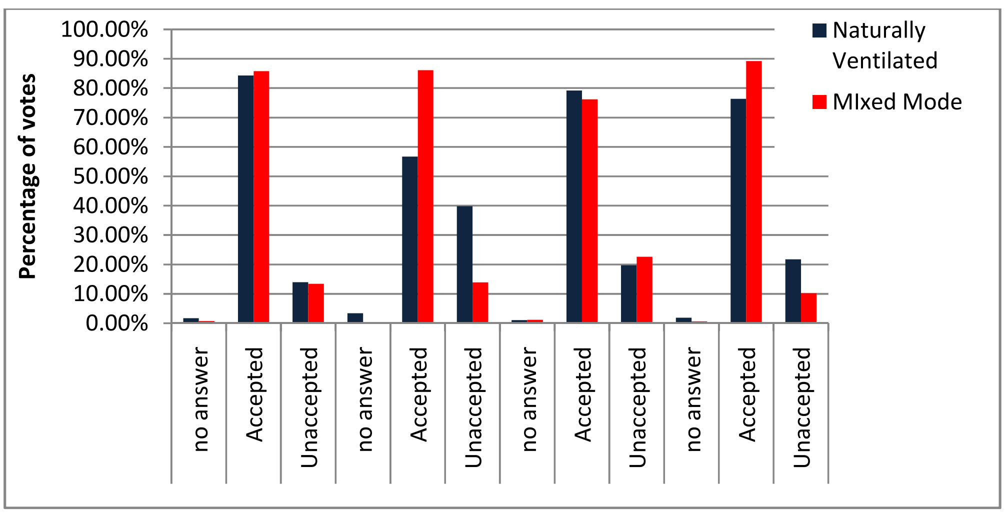

Figure 41: The percentage of humidity acceptance for both building types across the four seasons of the study

4.8 THE MEAN TEMPERATURE FOR DIFFERENT THERMAL SENSATION CATEGORIES

The mean indoor air temperatures for different thermal sensation categories of naturally ventilated buildings for both seasons of the study are shown in Figure 42. The mean indoor air temperature for the category "just right" was 24°C in spring and 26°C in autumn, which indicated the preference of subjects to warmer conditions in the autumn season than in the spring season. The analysis of variance showed that the mean indoor air temperature for the category "just right" differed significantly in the spring and autumn seasons in naturally ventilated buildings, ANOVA $\alpha = 0.05$, $F(1, 1192) = 20.989$ and $P < 0.05$. The mean indoor air temperature of the categories "slightly cool and cool" was lower in the spring season than in the autumn season, as spring was hotter than autumn. The sensitivity to cool conditions in autumn was higher than in the spring season as subjects sensation to cooler conditions in spring was different than in autumn. The contrary appeared in categories of "slightly warm and warm", the mean indoor air temperature for these categories was higher in spring than in autumn, which showed that subjects could accept hotter conditions in spring than in autumn, this may be caused due to their adaptation in different seasons.

The mean indoor air temperature for different thermal sensation categories of mixed mode buildings for both seasons of the study is shown in Figure 43. The mean indoor air temperature for the category "just right" was 23°C in spring and 24°C in autumn; it was higher in autumn than in spring, the same case as in the naturally ventilated buildings. Subjects' sensation was different in warmer conditions and cooler conditions in different seasons.

The mean indoor air temperature for the thermal sensation categories "slightly cool and cool" was lower in spring than in autumn as in naturally ventilated buildings. The mean indoor air temperatures for the thermal sensation categories "slightly warm and warm" coincided in the spring and autumn seasons; it is around 26°C, which might indicate that people using air conditioning as a method of adaptation cannot accept conditions more than 26°C. It was different from the case of naturally ventilated buildings, where the mean indoor air temperature for the thermal sensation "slightly warm" was 28°C in spring and the mean indoor air temperature for the thermal sensation category "warm" was 30°C.

The analysis of variance among the different building types showed a significant difference only in the spring seasons as discussed in 4.7.1. It is the season where air conditioners are used as an adaptive opportunity, while in the autumn season they are rarely used, which means that the adaptive opportunity in both building types were almost the same.

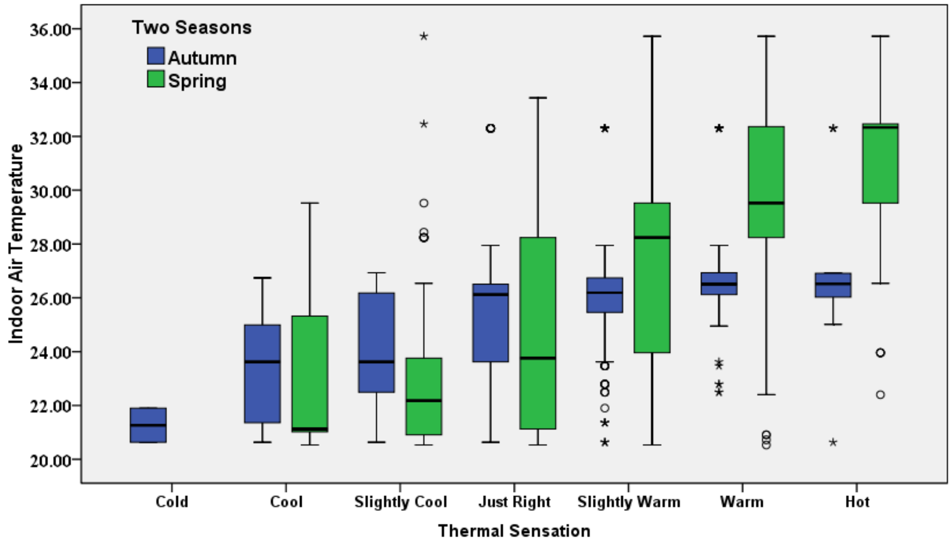

Figure 42: The thermal sensation categories subject to the range of indoor air temperature of each category in naturally ventilated buildings for both seasons of the study. The thick lines in the boxes represent the median values, the colored boxes cover the mean 50%of the values and the thin lines show the whole range of all values except for the small circles indicate outliers of each category

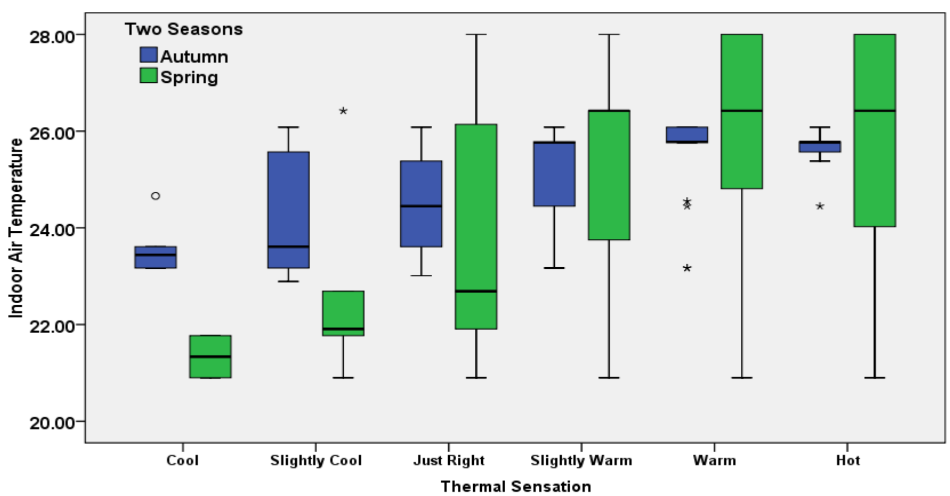

Figure 43: The thermal sensation categories subject to the range of indoor air temperature of each category in mixed mode buildings for both seasons of the study. The thick lines in the boxes represent the median values, the colored boxes cover the mean 50%of the values and the thin lines show the whole range of all values except for the small circles indicate outliers of each category

4.9 THE DISTRIBUTION OF THERMAL SENSATION VOTES FOR CLASSES OF INDOOR AIR TEMPERATURES

The indoor air temperatures were grouped in intervals of 1K and the thermal sensation votes were distributed among these intervals for both building types as indicated in Table 9 and Table 10. In naturally ventilated buildings, the indoor air temperature covered a range of 16 K starting from 21°C up to 36°C, as shown in Figure 44. The percentage of the central thermal sensation category "just right" was over 50% for the range of indoor air temperatures from 21°C up to 26°C, the central category "slightly cool, just right, slightly warm" formed more than 80% of the votes up to the indoor temperature 26°C. This percentage began to decrease starting from the indoor air temperature 27°C.

In mixed mode buildings, the range of indoor air temperature covered 8K, starting from 21°C up to 28°C. The thermal sensation category "just right" was almost 60% for the range of indoor air temperatures from 21°C up to 25°C; the central category "slightly cool, just right and slightly warm" formed about 80% or more for the range of indoor air temperatures 21°C up to 26°C.

Table 9: The distribution of thermal sensation votes subject to the indoor air temperatures for naturally ventilated buildings

		Thermal Sensation in Naturally ventilated buildings						
		Cold	Cool	Slightly Coo	Just Right	Slightly Warr	Warm	Hot
Indoor Air Temperature	21	0.60%	3.30%	20.80%	66.80%	6.90%	1.20%	0.30%
	22	0.90%	0.90%	21.70%	59.00%	15.10%	1.90%	0.50%
	23		1.80%	13.30%	68.10%	13.30%	3.50%	
	24		3.30%	22.70%	50.40%	16.50%	5.40%	1.70%
	25		1.60%	5.90%	56.70%	26.20%	7.50%	2.10%
	26		1.00%	8.30%	53.60%	23.10%	10.60%	3.40%
	27		0.30%	9.30%	39.20%	28.90%	16.20%	6.20%
	28		0.30%	2.00%	34.70%	29.30%	20.30%	13.30%
	29				35.30%	35.30%	20.60%	8.80%
	30		1.10%	1.10%	30.80%	35.20%	17.60%	14.30%
	31				9.80%	19.70%	16.40%	54.10%
	32			0.50%	9.90%	22.60%	34.00%	33.00%
	33				2.90%	8.80%	26.50%	61.80%
	35						42.90%	57.10%
	36			2.30%		9.30%	39.50%	48.80%

Table 10: The distribution of thermal sensation votes subject to the indoor air temperatures for mixed mode buildings

		Thermal Sensation in mixed mode buildings						
		Cold	Cool	Slightly Coo	Just Right	Slightly Warr	Warm	Hot
Indoor Air Temperature	21		4.00%	4.00%	68.00%	12.00%	8.00%	4.00%
	22		2.90%	14.70%	64.70%	14.70%		2.90%
	23		5.90%	21.20%	57.60%	9.40%	5.90%	
	24		2.40%	11.00%	64.60%	19.50%	1.20%	1.20%
	25		1.20%	3.50%	62.80%	25.60%	5.80%	1.20%
	26			6.10%	38.80%	37.00%	13.30%	4.80%
	28				27.80%	16.70%	38.90%	16.70%

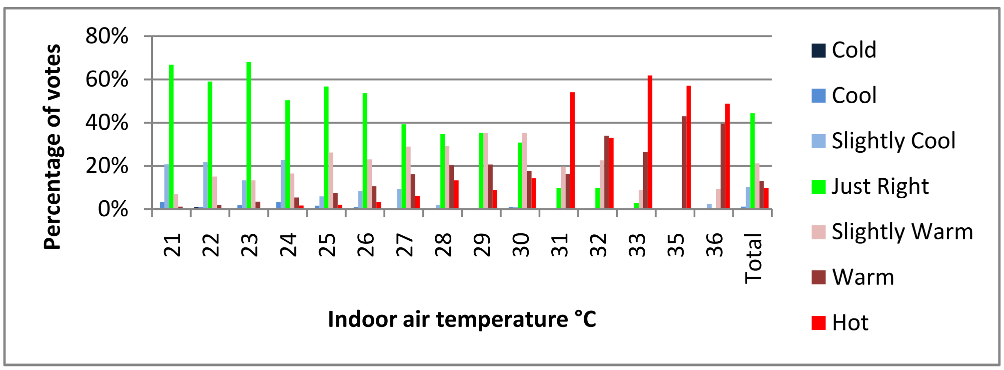

Figure 44: The percentage of thermal sensation votes subject to the indoor air temperatures for naturally ventilated buildings

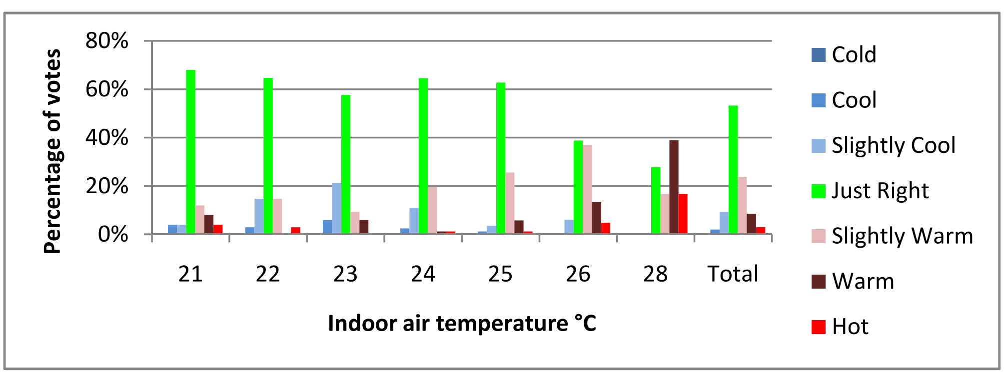

Figure 45: The percentage of thermal sensation votes subject to the indoor air temperatures for mixed mode buildings

4.10 CLO VALUE

The value of the mean clothing insulation "clo" is indicated in Figure 46 for the different building types across the four seasons of the study. The average value was around 0.6 clo, except in the hotter season of spring 2008 where it went below that value. The analysis of variance showed a significant difference between the mean clo values of both building types in the four seasons of the study. ANOVA for autumn 2007, $\alpha = 0.05$, $F(1,776) = 29.935$, $p < 0.05$, ANOVA for spring 2008, $\alpha = 0.05$, $F(1,672) = 8.789$, $p < 0.05$, ANOVA for autumn 2008, $\alpha = 0.05$, $F(1,822) = 7.341$, $p < 0.05$ and ANOVA for spring 2009, $\alpha = 0.05$, $F(1,906) = 3.857$, $p < 0.05$.

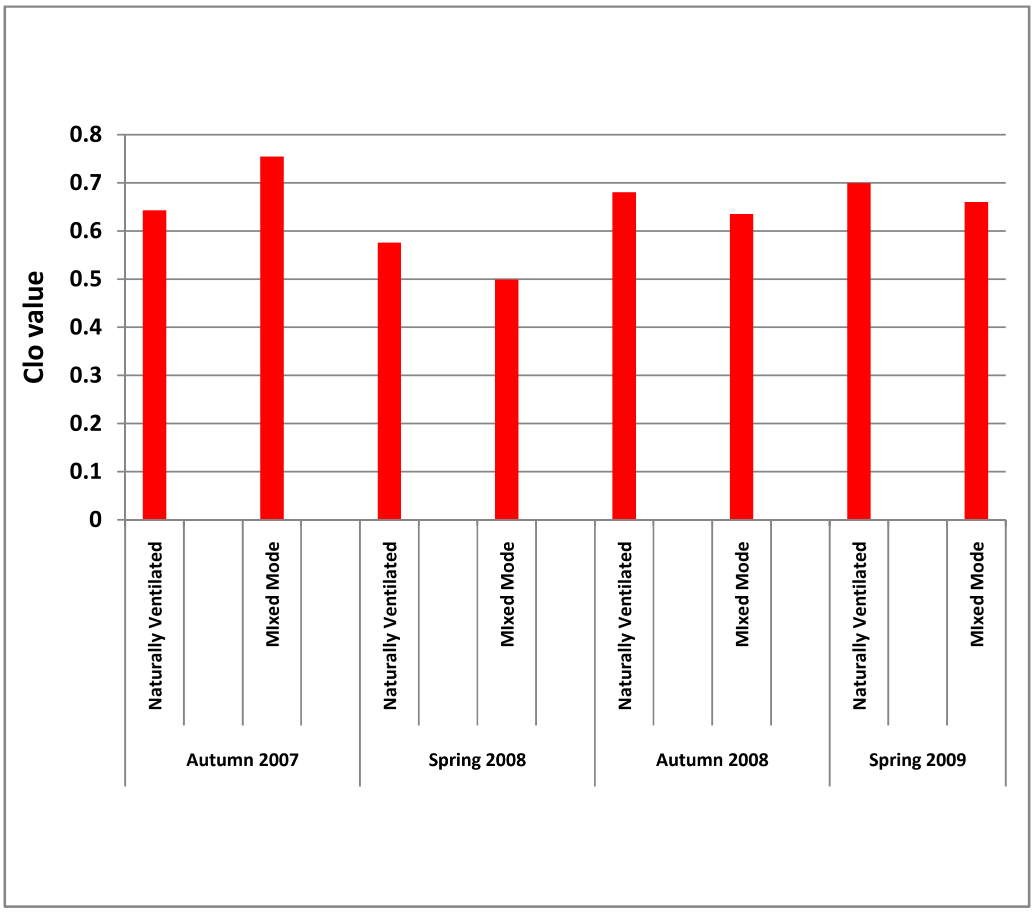

Figure 46: The value of the mean clothing insulation for different building types across the four seasons of the study

4.11 GENERAL SATISFACTION WITH THE METHODS AVAILABLE TO ADAPT TO THE INDOOR CLIMATIC CONDITIONS

A general question was asked about the methods of adaptation to the indoor climate, including opening or closing of windows, doors and internal curtains, controlling ceiling fans, changing the set points of the air conditioners, asking others to do any of the previous actions and finally putting on or taking off clothing. The question was followed by another one asking about the general satisfaction with the available methods to control the indoor climatic conditions. The percentage of the feedback coming from this question is shown in Table 11. The percentage of the categories "very satisfying, satisfying and slightly satisfying" was 64.6% in naturally ventilated buildings, while the same category was 83.4% in mixed mode buildings. This showed that the opportunity of using air conditioners might raise the satisfaction with the methods available to control the climate by 20%.

Table 11: The percentage of general satisfaction with the available methods of controlling the indoor climate in both types of buildings

Building Type	Evaluating satisfaction from the methods of controlling the indoor climate	Percent of votes
Naturally Ventilated	No answer	2.20%
	Very satisfying	16.70%
	Satisfying	35.90%
	Slightly satisfying	12%
	Slightly unsatisfying	12.10%
	Unsatisfying	12.30%
	Totally unsatisfying	8.80%
Mixed Mode	No answer	2.40%
	Very satisfying	33.90%
	Satisfying	40.40%
	Slightly satisfying	9.10%
	Slightly unsatisfying	6.10%
	Unsatisfying	5.30%
	Totally unsatisfying	2.80%

4.12 RELATION BETWEEN OUTDOOR TEMPERATURE EXPECTATION AND THE GENERAL SATISFACTION WITH INDOOR CLIMATIC CONDITIONS

The relation between the expectations of the outdoor climatic conditions and the general satisfaction with the indoor climatic conditions in naturally ventilated buildings is shown in Figure 47. Subjects whose expectations about the outdoor climate met the actual outdoor conditions were much more satisfied with the general indoor climatic conditions. Subjects who found that the outdoor conditions were different from their expectations were generally dissatisfied with the indoor climatic conditions. Pearson correlation between the two parameters was r = + 0.096, n=2689, P < 0.001 (2- tailed), a significant weak correlation.

The relation between the expectations of the outdoor climatic conditions and the general satisfaction with the indoor climatic conditions in mixed mode buildings is shown in Figure 48. Pearson correlation between the two parameters was r = + 0.08, n=495, P = 0.074 (2- tailed), a non significant weak correlation.

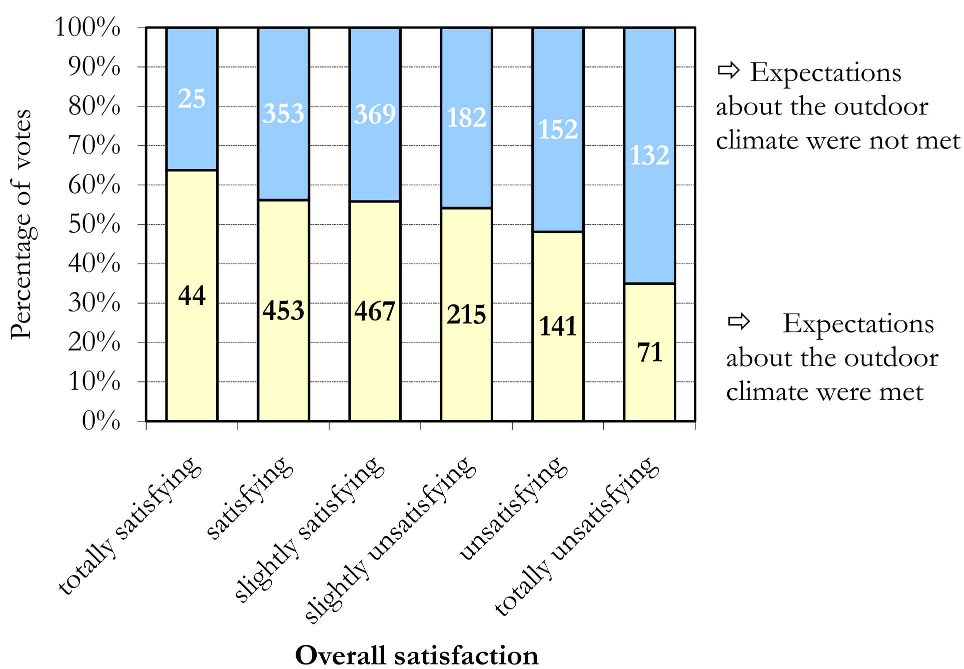

Figure 47: The relation between the outdoor climatic condition expectations and the general satisfaction with the indoor climatic conditions for naturally ventilated buildings

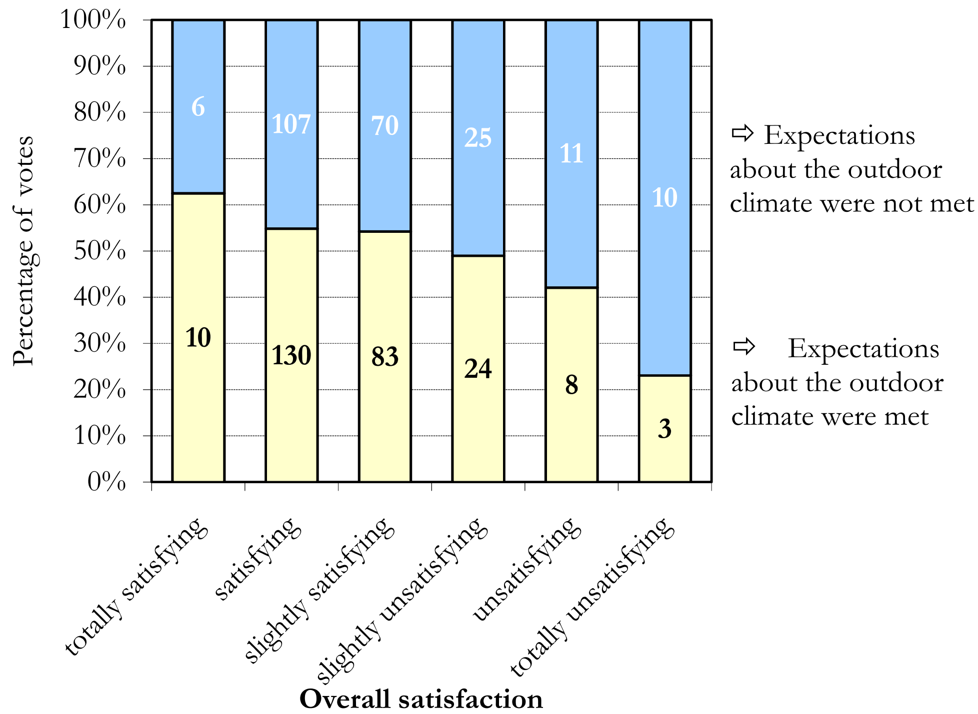

Figure 48: The relation between the outdoor climatic condition expectations and the general satisfaction with the indoor climatic conditions for mixed mode buildings

4.13 RELATION BETWEEN INDOOR TEMPERATURE EXPECTATION AND THE GENERAL SATISFACTION WITH INDOOR CLIMATIC CONDITIONS

The relation between the expectations of the indoor climatic conditions and the general satisfaction with the indoor climatic conditions in naturally ventilated buildings is shown in Figure 49. Subjects whose expectations about the indoor climate met the actual indoor conditions were much more satisfied with the general indoor climatic conditions. Pearson correlation between the two parameters was $r = +0.154$, $n=2689$, $P < 0.001$ (2- tailed), a significant weak correlation.

The relation between the expectations of the indoor climatic conditions and the general satisfaction with the indoor climatic conditions in mixed mode buildings is shown in Figure 50. Pearson correlation between the two parameters was $r = +0.17$, $n= 495$, $P < 0.001$ (2- tailed), a significant weak correlation.

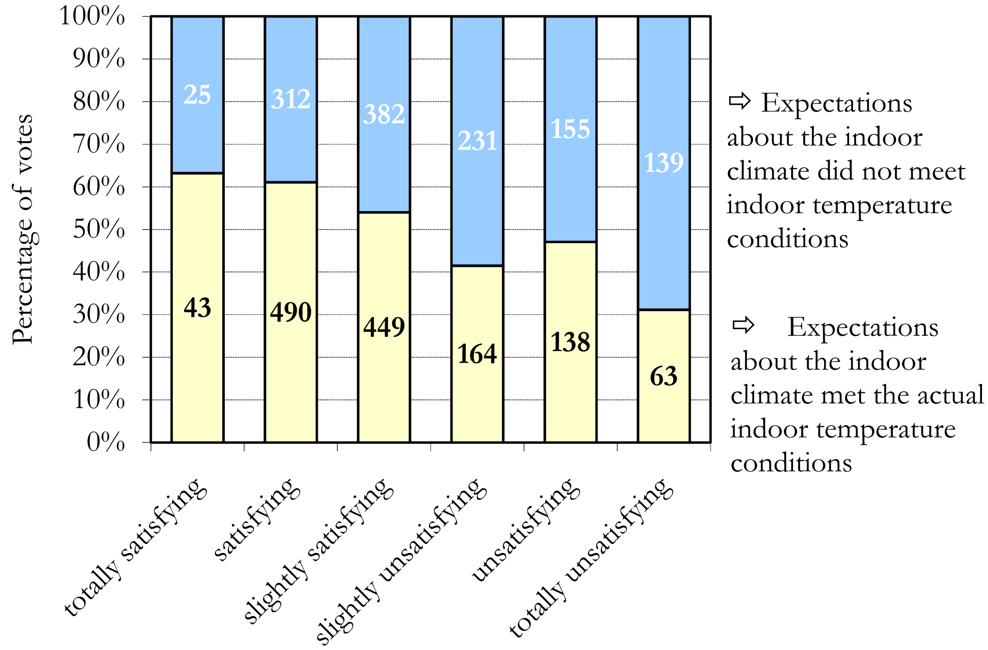

Figure 49: The relation between the indoor climatic condition expectations and the general satisfaction with the indoor climatic conditions for naturally ventilated buildings

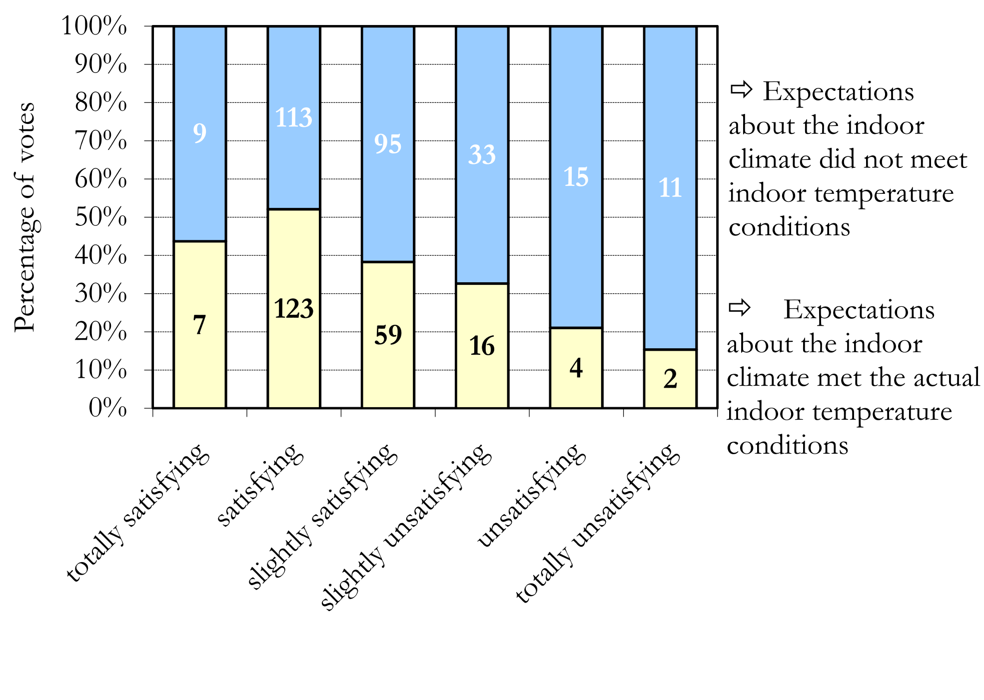

Figure 50: The relation between the indoor climatic condition expectations and the general satisfaction with the indoor climatic conditions for mixed mode buildings

4.14 RELATION BETWEEN THERMAL SENSATION VOTES AND THE GENERAL SATISFACTION WITH INDOOR CLIMATIC CONDITIONS

The relation between the thermal sensation categories and the general satisfaction with the indoor climatic conditions in naturally ventilated buildings is shown in Figure 51, and in mixed mode buildings in Figure 52. People whose thermal sensation votes lay in the central category of "slightly cool, just right and slightly warm" were much more satisfied with the general indoor climatic conditions. In naturally ventilated buildings, the Pearson correlation between the two parameters was r = + 0.426, n=2689, P < 0.001 (2- tailed), a significant good correlation. In mixed mode buildings, the Pearson correlation between the two parameters was r = + 0.339, n=495, P < 0.001 (2- tailed), a significant good correlation.

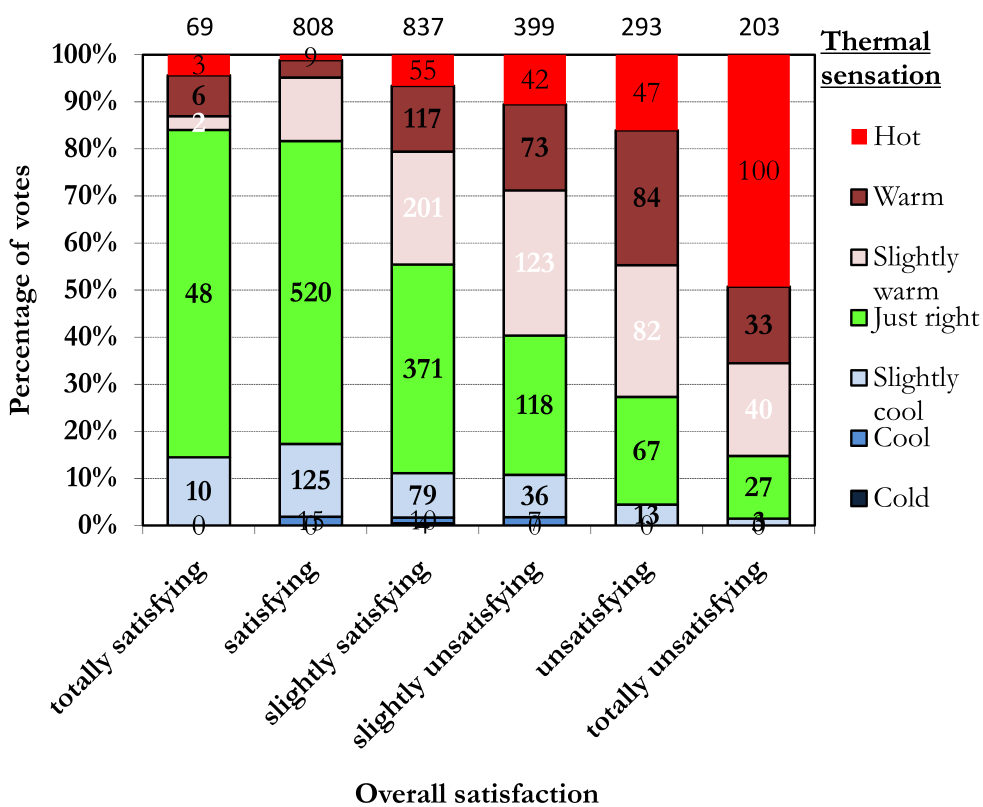

Figure 51: The relation between thermal sensation votes and the general satisfaction with the indoor climatic conditions in naturally ventilated buildings, the numbers indicate the votes corresponding to each category

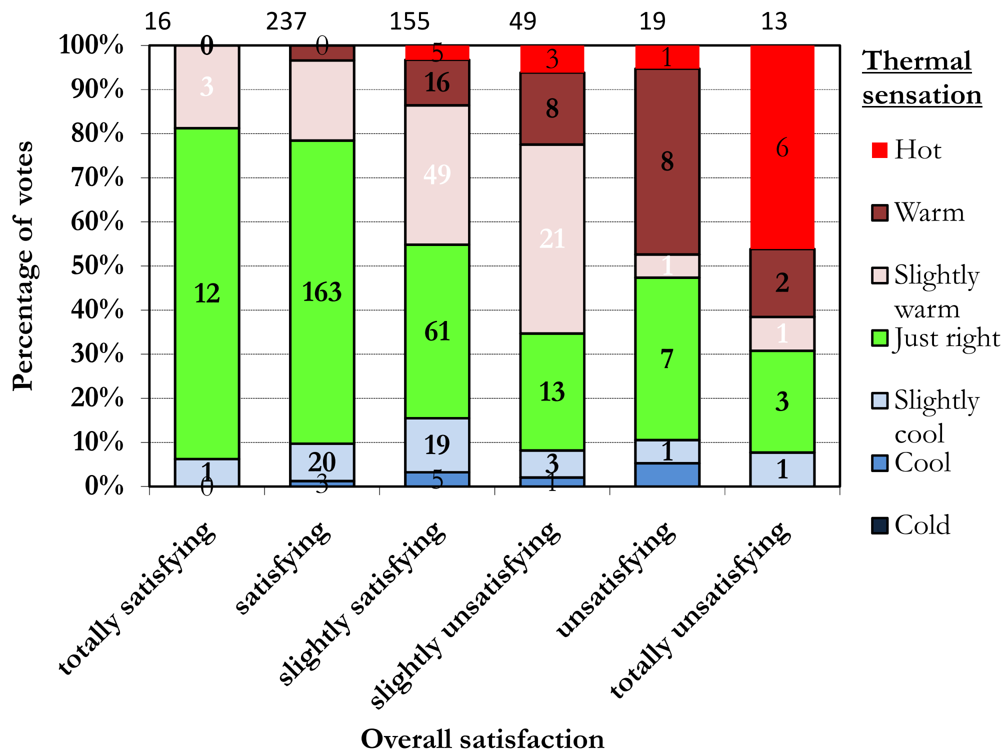

Figure 52: The relation between thermal sensation votes and the general satisfaction with the indoor climatic conditions in mixed mode buildings, the numbers indicate the votes corresponding to each category

4.15 RELATION BETWEEN DIFFERENT PARAMETERS AND BOTH THE GENERAL SATISFACTION WITH INDOOR CLIMATIC CONDITIONS AND THERMAL SENSATION VOTES

The effect of different parameters such as gender, season, building type and hall type on the thermal sensation votes and the general satisfaction with the indoor climate is shown in Figure 53. In general, females voted for warmer mean thermal sensations than males and were more dissatisfied with the internal climatic conditions. The seasons of autumn were better than spring regarding the voting for lower mean thermal sensations as well as more satisfaction with the indoor climatic conditions. Mixed mode buildings were better than naturally ventilated buildings regarding both the mean thermal sensation votes and the mean general satisfaction with the indoor climatic conditions. Regarding the hall types, the labs were the best type, as they had to be controlled using air conditioners for the safe up-keep of computers, followed by drawing halls then by lecture halls, the worst type of spaces were the employees' rooms.

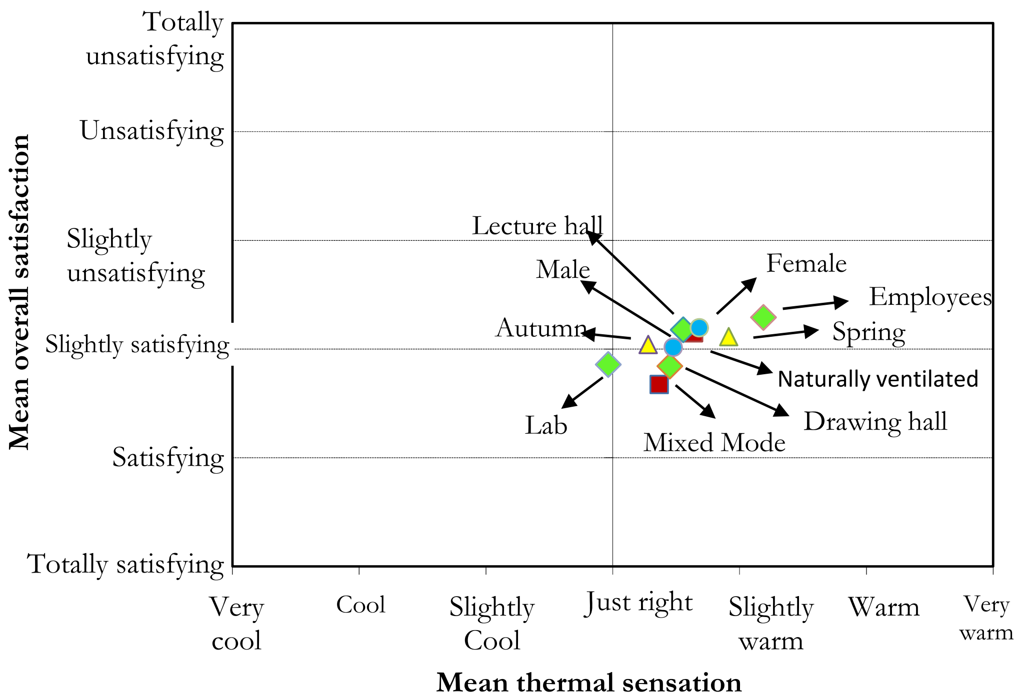

Figure 53: The relation between different parameters and both mean thermal sensation votes and the mean satisfaction with the indoor climatic conditions

4.16 RELATION BETWEEN DESCRIPTION OF THE INTERNAL AIR QUALITY AND THE GENERAL SATISFACTION WITH INDOOR CLIMATIC CONDITIONS

Subjects were asked to describe the indoor air quality using one of the following descriptions, "stifling, muggy, pleasantly dry, dusty, fresh, pure, unpleasant smell or others". The outcome from the answers to this question together with the subjects' votes about their general satisfaction with the indoor climate is shown in Figure 54 for naturally ventilated buildings and in Figure 55 for mixed mode buildings. In general, the selection of fresh, pleasantly dry and pure descriptions was associated with satisfaction votes; the unsatisfied votes were associated with muggy and stifling conditions. In naturally ventilated buildings, the Pearson correlation between the two parameters was r = 0.039, n=2689, P < 0.05 (2- tailed), a significant weak correlation. In mixed mode buildings, the Pearson correlation between the two parameters was r = 0.115, n=495, P < 0.05 (2- tailed), a significant weak correlation.

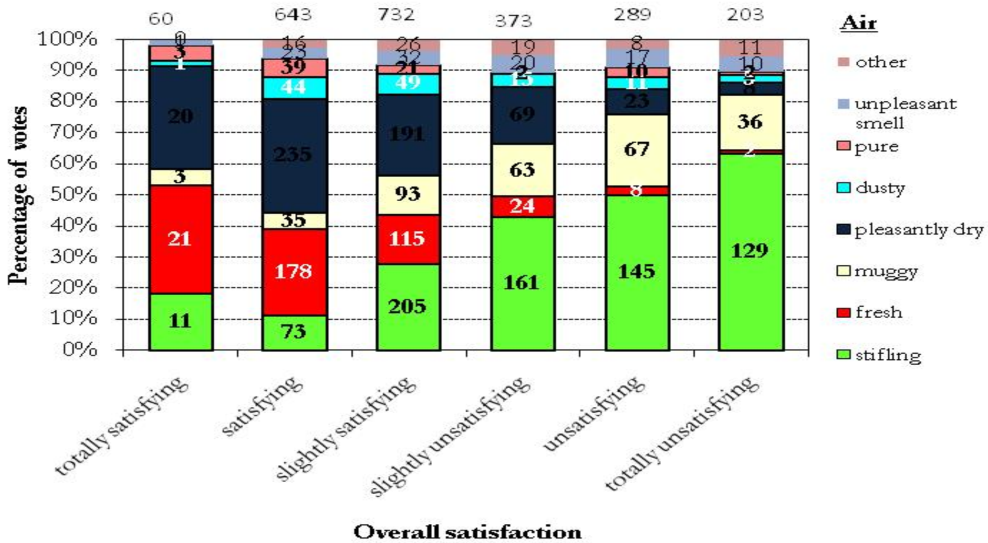

Figure 54: The relation between describing the air quality and the general satisfaction with the indoor climatic conditions in naturally ventilated buildings, the numbers indicate the votes corresponding to each category

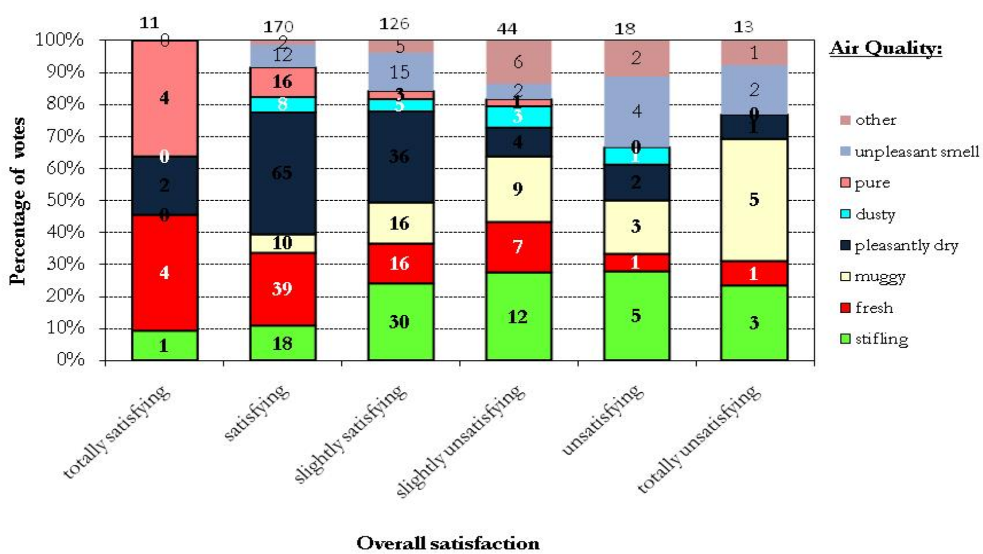

Figure 55: The relation between describing the air quality and the general satisfaction with the indoor climatic conditions in mixed mode buildings

4.17 CORRELATIONS BETWEEN THERMAL SENSATIONS AND INDOOR THERMAL ENVIRONMENT AND OUTDOOR THERMAL ENVIRONMENT

A set of correlations were analyzed to reveal the relation between thermal sensations and the measured indoor and outdoor environmental parameters within the study which resulted in the Pearson correlations for naturally ventilated buildings in Table 12.

Table 12: Pearson correlations between thermal sensation and physical environment of naturally ventilated buildings

Correlation	Thermal sensation : Indoor Air Temperature	Thermal sensation :Outdoor Air Temperature	Thermal sensation : Indoor Relative Humidity	Thermal sensation : Outdoor Relative Humidity
r	0.593	0.536	-0.165	-0.256
n	2689	2689	2689	2689
p	<0.01	<0.01	<0.01	<0.01
Type of correlation	Strong	Strong	Weak	Moderate

For mixed mode buildings, the Pearson correlations between the thermal sensation and different environmental parameters are found in Table 13.

Table 13: Pearson correlations between thermal sensation and physical environment of mixed mode buildings

Correlation	Thermal sensation : Indoor Air Temperature	Thermal sensation :Outdoor Air Temperature	Thermal sensation : Indoor Relative Humidity	Thermal sensation : Outdoor Relative Humidity
r	0.343	0.231	0.022	-0.085
n	495	495	495	495
p	<0.01	<0.01	>0.05	0.06
Type of correlation	Moderate	weak	Non significant	Non significant

In general the correlation between thermal sensation and indoor air temperature was stronger than the correlation between thermal sensation and indoor relative humidity. The correlation between thermal sensation and the indoor parameters was stronger than the correlation between thermal sensation and outdoor parameters for both building types.

4.18 CORRELATION BETWEEN THERMAL SENSATION AND ADAPTIVE OPPORTUNITIES

Question eleven of the questionnaire asked about various adaptive opportunities, the Pearson correlations found between these opportunities and thermal sensation votes in naturally ventilated buildings are shown in Table 14.The exploration of Pearson correlations in mixed mode buildings between the adaptive opportunities and thermal sensation votes showed that fewer adaptive actions resulted in significant correlations with the thermal sensations; this is shown in Table 15.

Table 14: Pearson correlations between thermal sensation and adaptive opportunities in naturally ventilated buildings

Correlation	Thermal sensation : switching on and off of ceiling fans	Thermal sensation :drinking cold things during the last hour	Thermal sensation : closing and opening doors	Thermal sensation :closing and opening windows	Thermal sensation :putting off and wearing extra cloths	Thermal sensation :eating something cold during the last hour	Thermal sensation :eating something hot during the last hour
r	0.283	0.261	0.181	0.128	0.126	-0.048	-0.046
n	2689	2689	2689	2689	2689	2689	2689
p	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Type of correlation	Moderate	Moderate	Weak	Weak	Weak	Weak	Weak

Table 15: Pearson correlations between thermal sensation and adaptive opportunities in mixed mode buildings

Correlation	Thermal sensation :drinking cold things during the last hour	Thermal sensation :eating something cold during the last hour	Thermal sensation :closing and opening windows	Thermal sensation :drinking something hot during the last hour
r	0.125	-0.124	0.112	-0.11
n	495	495	495	495
p	<0.01	<0.01	<0.05	<0.05
Type of correlation	Weak	Weak	Weak	Weak

4.19 THE CALCULATION OF NEUTRAL TEMPERATURES FOR BOTH BUILDING TYPES

The method used to calculate the neutral "comfort" temperatures was regression analysis. This method was used to predict the value of the dependent variable "thermal sensation vote" for a particular value of the independent variable "indoor air temperature". The method assumes a linear relationship between "thermal sensation votes" and "indoor air temperature". The regression of the thermal sensation vote on the indoor air temperature for the whole study and for different seasons was calculated and represented in Table 16.

Table 16: The regression of the thermal sensation vote on the indoor air temperature in all buildings through the different seasons

Type of Building	Season	Neutral Temperature	Regression Model		
			Coefficient	constant	R^2
Naturally Ventilated	Whole study	22.85°C	0.192	- 4.388	0.351
Naturally Ventilated	autumn 2007	24.51°C	0.170	- 4.167	0.187
Naturally Ventilated	spring 2008	23.94°C	0.237	- 5.674	0.406
Naturally Ventilated	autumn 2008	23.20°C	0.204	- 4.733	0.161
Naturally Ventilated	spring 2009	20.98° C	0.173	- 3.630	0.363
Mixed Mode	Whole study	22.55° C	0.190	- 4.284	0.118
Mixed Mode	autumn seasons	24.0°C	0.335	- 8.012	0.164
Mixed Mode	spring seasons	21.0°C	0.157	- 3.285	0.139
ASHRAE standard 55	36 buildings	24.6°C	0.27	- 6.65	0.46

- **The neutral temperature calculated from the 36 buildings involved in the ASHRAE standard 55 was 24.6°C as shown in Equation 10.**
  - TSV = - 6.65 + 0.27 T_{op}.................................. (r^2 = 0.46)

Equation 10: The relation between thermal sensation votes and the indoor air temperature for the 36 significant buildings involved in the ASHRAE database. TSV is the thermal sensation vote and T_{op} is the operative indoor air temperature

The temperature that the subjects found comfortable is noted in the above table as neutral temperature. Comparing to the ASHRAE standard 55-2004, the neutral temperature was lower in the spring 2009 season because the range of indoor air temperatures experienced by the subjects in that season was lower than the other seasons(refer to Table 6). The neutral temperature of the other seasons was near to that calculated in the ASHRAE RP884. The method of linear regression was used here to calculate the comfort temperatures for the data gathered because this was the method used for deriving comfort conditions from the field surveys in the ASHRAE standard 55-2004.

CHAPTER FIVE DISCUSSION

This chapter comments on the results and the data analyzed from the previous chapter. It compares the outcome to other research work done in the same field. The implication of the findings in terms of enhancing the existing adaptive comfort standard is also discussed.

5.1 FREQUENCY OF VOTES AND THEIR DISTRIBUTION

The votes gathered from the four field experiments were distributed among the naturally ventilated buildings and the mixed mode buildings. The naturally ventilated buildings resulted in 2689 votes (84.5 % of total votes) and the mixed mode buildings resulted in 495 votes (15.5 % of total votes). The number of votes in any of the four field experiments conducted in the naturally ventilated buildings throughout the four different seasons exceeded 600 votes in each field experiment, while the number of votes resulted from the field experiments conducted in the mixed mode buildings did not exceed 200 votes in any of the four field experiments.

This led to the ability of treating the experiments conducted in the naturally ventilated buildings as four separate field studies in the calculations and statistical analysis. The small number of votes resulted from the field experiments conducted in the mixed mode buildings led to gathering the votes resulted from similar seasons; autumn 2007 and autumn 2008 represented the autumn season while spring 2008 and spring 2009 represented the spring seasons, to represent a set of data valid for calculations and statistical analysis.

The distribution of votes among different space types showed that the study mainly represented students, where 1702 votes came from students occupied lecture halls (53.5 % of total votes), 1083 votes came from students occupied drawing halls and computer labs (34 % of total votes), this means that 87.5 % of the votes came from students. The number of votes representing employees in their offices was 399 votes (12.5 % of total votes). If results from this study are to be generalized this means that the study mainly represented students in their occupied spaces, more studies are needed to know the opinion and behaviour of employees.

5.2 THERMAL SENSATION VOTES AND THEIR DISTRIBUTION AMONG INDOOR AIR TEMPERATURES

Regression of thermal sensation as a dependent variable on indoor air temperature as an independent variable was performed for both building types; this resulted in the graphs shown in Figure 56 and Figure 57.

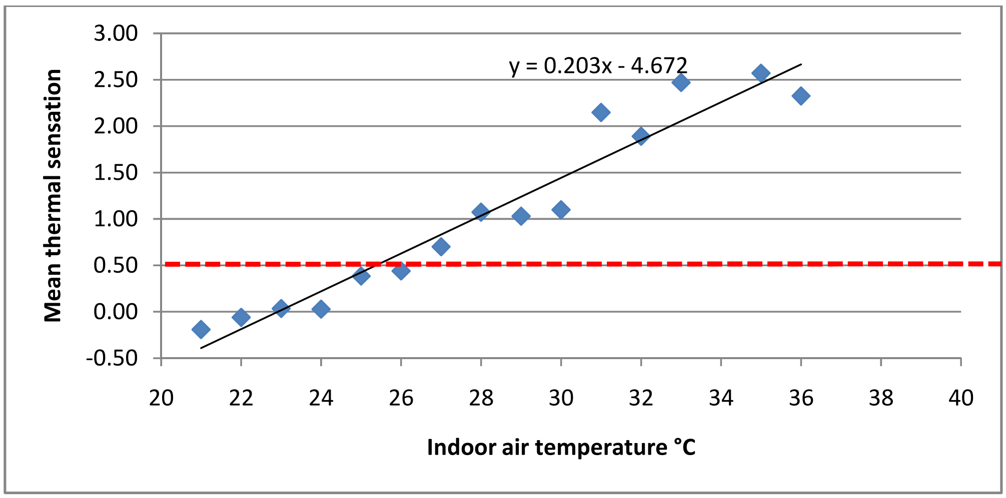

Figure 56: Thermal sensation across indoor air temperature of naturally ventilated buildings

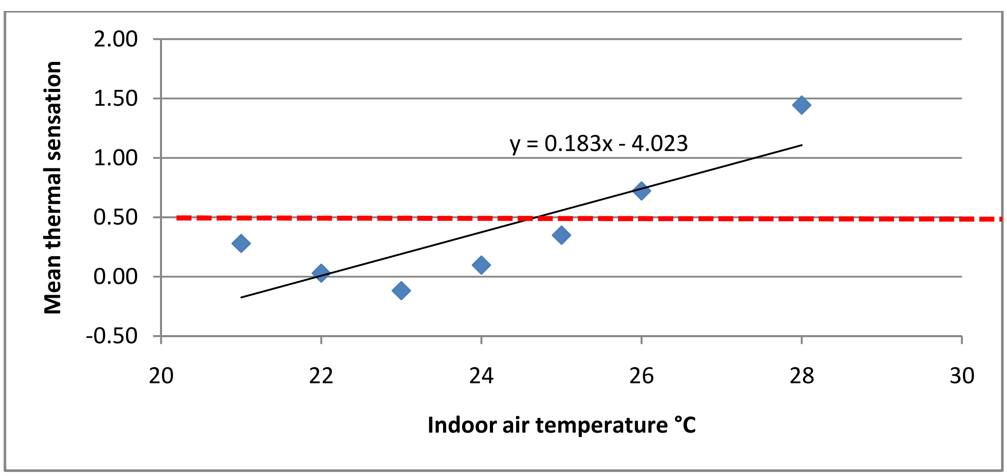

Figure 57: Thermal sensation across indoor air temperature of mixed mode buildings

The red lines indicate the upper limits (0.5) of 90% thermal acceptability according to the PMV model, and this limit coincides with 26°C in naturally ventilated buildings and the same limit coincides with 25°C in mixed mode buildings. This indicates that the occupants of naturally ventilated buildings accepted higher indoor air temperatures than occupants of mixed mode buildings.

The relation between thermal sensation and indoor air temperature resulted in Equation 11 for naturally ventilated buildings and in Equation 12 for mixed mode buildings.

$$TSV = 0.2039\ T_{in} - 4.6724 \ldots\ldots\ldots\ldots r^2 = 0.937$$

Equation 11: The regression of mean thermal sensation vote (TSV) on indoor air temperature (T_{in}) for naturally ventilated buildings

$$TSV = 0.1832 T_{in} - 4.0235 \ldots\ldots\ldots\ldots r^2 = 0.685$$

Equation 12: The regression of mean thermal sensation vote (TSV) on indoor air temperature (T_{in}) for mixed mode buildings

The equations relating the thermal sensation to indoor air temperature in this research are different from those obtained from the Pakistan project, as Equation 13 shows the results from the Pakistan project (Nicol, et al. 1999)

$$TSV = 0.151 T_g + 0.11$$

Equation 13: The regression of mean thermal sensation vote (TSV) on indoor globe temperature (T_g) for Pakistan project

On average, mean thermal sensation changed one unit every 5 degrees of indoor air temperature, whereas in Pakistan project a 6.5 degree change in the indoor globe temperature was needed to shift mean thermal sensations by one unit, this indicate that the occupants in this research were less able to adapt to their indoor environment than their counterparts in the Pakistan project. This finding is reversed compared to the ASHRAE RP884 project, where the equation indicating the relation between thermal sensation and indoor operative temperature is shown in Equation 14, the ability of occupants to adapt to their indoor environment in this research is more than the findings from the ASHRAE RP884 project.

$$TSV = 0.27T_{op} - 6.65$$

Equation 14: The regression of mean thermal sensation vote (TSV) on indoor operative temperature (T_{op}) for naturally ventilated buildings in the ASHRAE RP884 project

The slope of the regression line between the comfort vote and the mean indoor temperature is related not just to the sensitivity to temperature change but also to the extent to which longer –term adaptations have been made to offset its effect, thus the Pakistan project assume that without adaptation the slope of the regression line would be 0.3. The actual slope is less than this value and this implies that the difference is absorbed by the ability of people to adapt.

5.3 THERMAL NEUTRALITY OBTAINED FROM SENSATION VOTES AND PREFERENCE VOTES

Thermal neutrality is defined as the indoor temperature most closely with a mean thermal sensation vote of zero (neutral), where warm buildings had warm neutralities and vice versa. This is shown in section 4.19, from this section the observation support the notion that building occupants' thermal ideals are influenced by their thermal experiences both indoors and outdoors.

Preferred temperature for a particular building did not necessarily coincide with thermal neutrality, and this semantic discrepancy was also found in the ASHRAE RP884 project, where preference was depressed below neutrality in warm climates and elevated above neutrality in cold climates (i.e. people preferred to feel cooler than neutral in warm climates, and warmer than neutral in cold climates.) The same is found in this research, as it represented warm climates, the preferred temperatures in both building types was below the neutral temperature calculated; this is shown in Figure 58 for naturally ventilated buildings and in Figure 59 for mixed mode buildings by solving the two regression lines giving a value of 21.73°C for preferred temperature in mixed mode buildings. The difference in naturally ventilated buildings is about 0.5 °C, and in mixed mode buildings is about 0.7 °C.

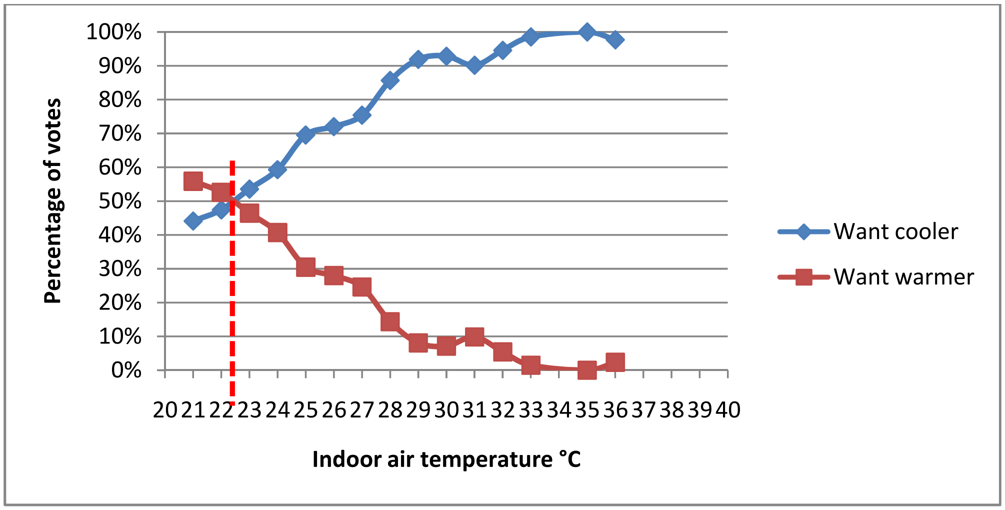

Figure 58: Preferred temperature in naturally ventilated buildings

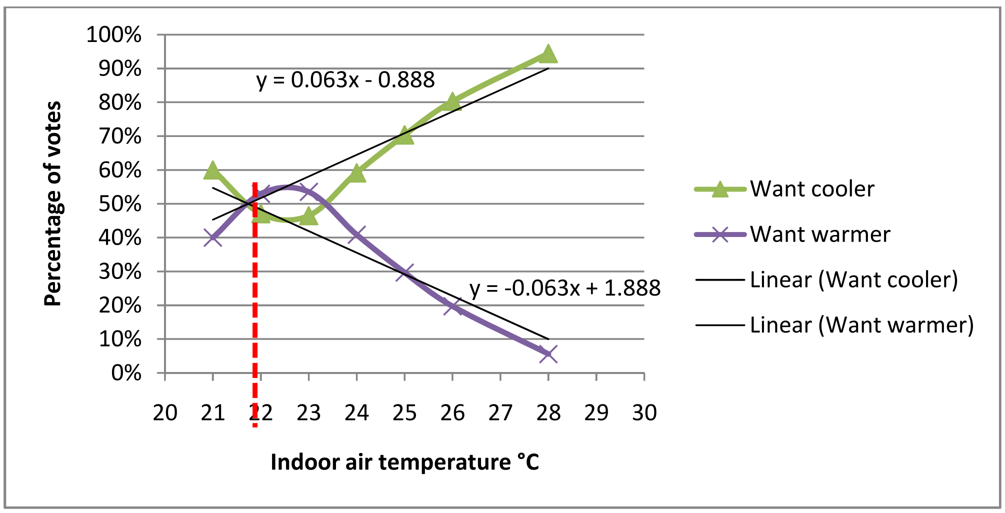

Figure 59: Preferred temperature in mixed mode buildings

5.4 ACCEPTANCE VOTES

Thermal acceptability for this research was obtained directly from the occupants who answered “acceptable” to the questionnaire when asked whether their thermal conditions were acceptable or not. The percentage of actual unacceptable votes for each degree indoor air temperature in both buildings was plotted as a function of the indoor air temperature as shown in Figure 60.

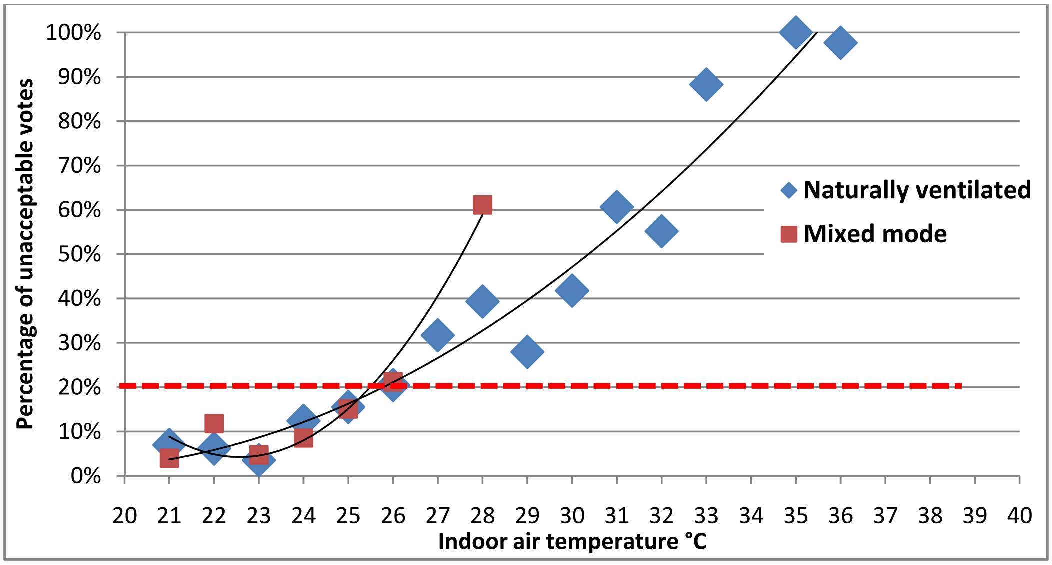

Figure 60: The percentage of unacceptable votes for each degree indoor air temperature in both types of buildings

The findings from the previous graph indicate the up to 26 °C we can obtain about 80% acceptability in both types of buildings. This finding coincides with that from another research conducted in a similar context in Tunis, were 80 % of the votes found the indoor thermal conditions acceptable for temperatures between 16 °C and 26.5 °C (Bouden and Ghrab 2005).

These findings differed from another study based on the ASHRAE database included all ASHRAE studies in which thermal acceptability was measured seeking to determine the acceptability threshold in these buildings (Zhang, Arens and Pasut 2010). Figure 61 and Figure 62 show combined naturally ventilated buildings and mixed mode buildings results, separating winter and summer seasons as the indoor operative temperatures are quiet different in both seasons. In winter, the upper limit at which acceptability drops below 80% occurs at 27.5 °C. In summer, the upper threshold at which acceptability drops below 80% occurs at 30%, 2 K above the limit in winter.

This results shows that there is a high adaptation potential for a so wide temperature range.

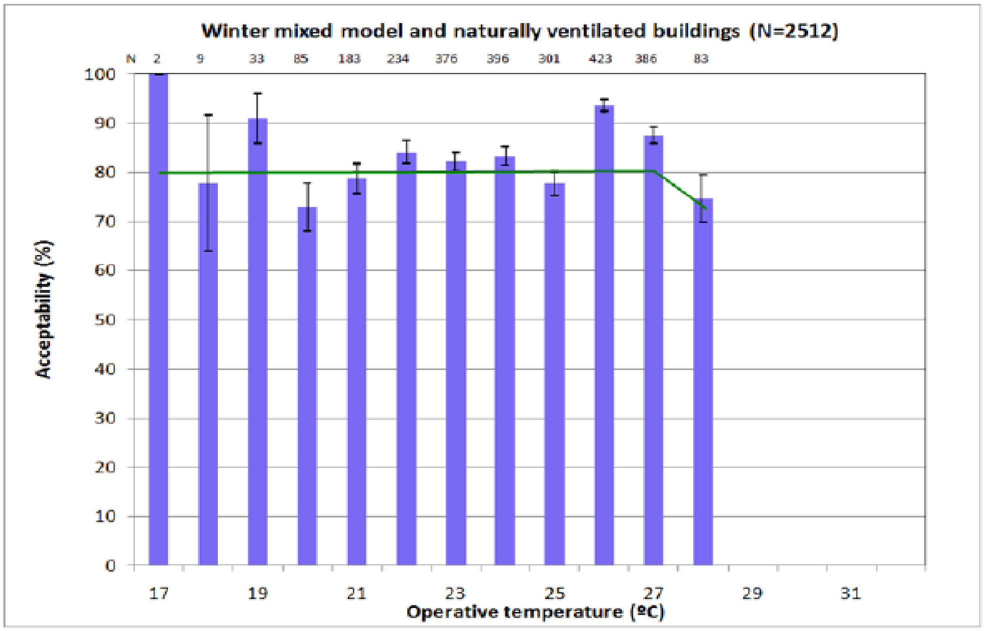

Figure 61: Acceptability against temperature at the workstation; winter; NV and MM buildings in the ASHRAE database, ((Zhang, Arens and Pasut 2010)

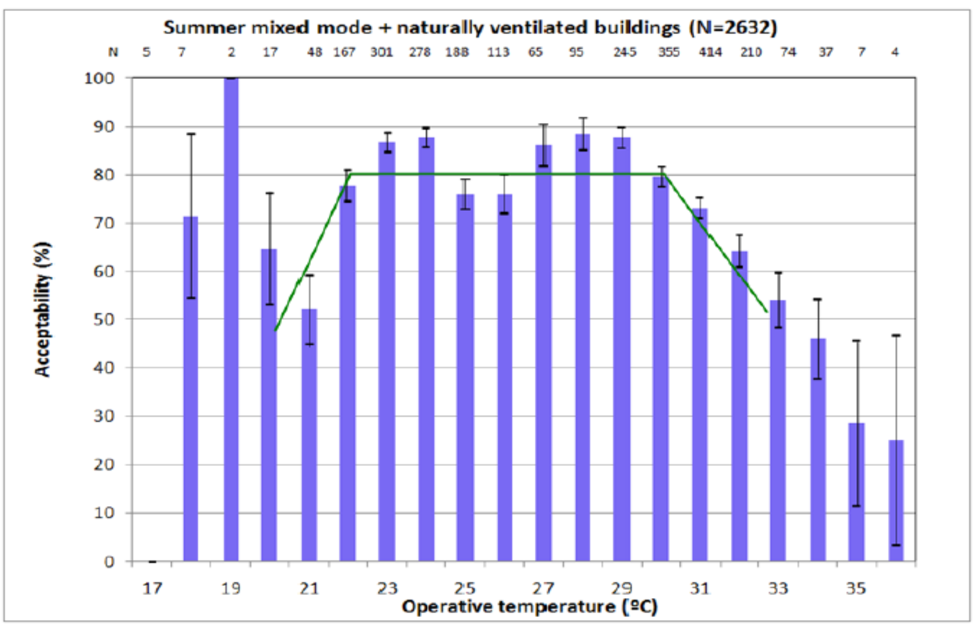

Figure 62: Acceptability against temperature at the workstation; summer; NV and MM buildings in the ASHRAE database, (Zhang, Arens and Pasut 2010)

5.5 CLO VALUE AND THE SOCIAL CONCERNS

The success in achieving thermal comfort over a wide range of temperatures is attributable to adaptive mechanism; one of the most important adaptive opportunities is the flexibility of clothing in a certain community. Table 17 shows the number of garments worn throughout the study in both building types classified by the corresponding indoor air temperature. A pair of socks is reckoned as one garment as is a pair of sandals or shoes. The most common number of garments worn in both types of buildings is four and five pieces. This refers to t-shirt, trouser, socks and shoes describing the four pieces, the five pieces could be achieved by wearing a veil or a body and wearing both will lead to six worn garments.

Table 17: The number of garments worn throughout the study in both building types classified by corresponding indoor air temperature

Building Type	Indoor Air Temperature	Percentage of number of garments worn					
		3	4	5	6	7	8
Naturally Ventilated	21	3.9%	32.3%	35.6%	14.8%	6.3%	6.9%
	22	1.4%	34.0%	50.0%	10.8%	2.4%	1.4%
	23	4.4%	25.7%	46.9%	21.2%	1.8%	
	24	5.8%	45.9%	39.7%	7.9%	.4%	.4%
	25	9.1%	44.9%	25.7%	7.0%	7.5%	5.9%
	26	11.1%	46.9%	32.4%	8.0%	1.6%	
	27	10.1%	42.3%	34.3%	10.6%	2.8%	
	28	8.3%	48.0%	36.7%	6.3%	.7%	
	29	11.8%	60.3%	22.1%	5.9%		
	30	6.6%	48.4%	37.4%	6.6%	1.1%	
	31	11.5%	54.1%	31.1%	3.3%		
	32	7.1%	50.5%	35.8%	5.2%	.9%	.5%
	33	14.7%	58.8%	26.5%			
	35	19.0%	52.4%	19.0%	9.5%		
	36	7.0%	60.5%	30.2%	2.3%		
	Total	7.7%	43.7%	35.7%	9.1%	2.4%	1.5%
MIxed Mode	21		56.0%	32.0%	12.0%		
	22	8.8%	50.0%	35.3%	5.9%		
	23	9.4%	44.7%	31.8%	10.6%	2.4%	1.2%
	24	7.3%	51.2%	32.9%	7.3%	1.2%	
	25	9.3%	47.7%	37.2%	5.8%		
	26	14.5%	56.4%	20.0%	7.3%	1.2%	.6%
	28	33.3%	61.1%	5.6%			
	Total	11.1%	51.7%	28.3%	7.5%	1.0%	.4%

The difference in the number of garments underestimates the real difference, because it takes no account of the weight of garments. Although the checklist describing the clothes worn by the subjects included different weight but the judgment of different people on the weight and length of their clothes is different. One of the problems that evolved while calculating the clo value of the garments is the presence of some pieces that have no reference in the literature, this is for example included the clo value of a veil, body, abaya and flip flop.

The clo value of a veil was taken as a medium head cover found in the Pakistan project (Nicol, et al. 1999) its value was calculated as 0.07 clo. The clo value of a body was estimated to be as a blouse, the heavy weight body was given the value of 0.25 clo and the light weight body was given the value of 0.20 clo. The abaya was treated as a long dress with long sleeves, the heavy weight abaya was given the value of 0.47 clo and the light weight abaya was given the value of 0.33 clo. The flip flop was given the same value as an opened sandal 0.02 clo. These values are a trial to estimate the values of garments found in the Egyptian context and are not found in the ASHRAE list (refer to Appendix B), an attempt was made to measure the clo value of these traditional clothing but it was found that such an attempt is difficult and not easy to be made within the scope of this work.

The value of the mean clothing insulation "clo" in the different building types across the four seasons of the study was around 0.6 clo, and this value is related to the social concerns, short garment are not accepted in the Egyptian context, this is why there are lower clo values recorded in the western context mainly in Europe where the clo value may reach to 0.5 clo and 0.4 clo which is not common in the Egyptian context.

Clo value varies with the outdoor temperature, the relation between the clo value and outdoor temperature in the naturally ventilated buildings in this research is described in Equation 15 . The same analysis has been led by de Dear (de Dear, Brager and Cooper 1997), he has found the expression found by regression and given by Equation 16 . In the Tunisian context (Bouden and Ghrab 2005) the same analysis led to the expression found in Equation 17 . The difference is that in the Egyptian context the coefficient gradient of the outdoor temperature is lower this is due to the social concerns, where in the Egyptian context short and light transparent clothes are not socially accepted.

$$Clo = -0.015\ T_{out} + 1.008 \ldots\ldots\ldots\ldots\ldots\ldots.. (r^2 = 0.12)$$

Equation 15: The relation between the clo value and outdoor temperature in the Egyptian context

$$Clo = -0.04\ T_{out} + 1.73 \ldots\ldots\ldots\ldots\ldots\ldots.. (r^2 = 0.18)$$

Equation 16: The relation between the clo value and outdoor temperature in the ASHRAE database

$$Clo = -0.038\ T_{out} + 1.33 \ldots\ldots\ldots\ldots\ldots\ldots.. (r^2 = 0.49)$$

Equation 17: The relation between the clo value and outdoor temperature in the Tunisian context

5.6 ASHRAE ADAPTIVE MODEL AND THE RESULTS FROM THE STUDY

The outcome of the study was compared to the Adaptive comfort model. The blue line in Figure 63 shows the regression of the indoor air temperature on the mean outdoor air temperature. This data resulted from the votes of thermal sensation "just right" that represent the comfort neutrality in naturally ventilated buildings.

Indoor air temperature = 11.729 + 0.633 Mean outdoor temperature, (r^2= 0.69)

The red line represents the equation of the adaptive comfort model implemented in the ASHRAE Standard 55-2004, the equation was:

Indoor air temperature = 17.8 + 0.31 Mean monthly outdoor temperature

It is obvious from the outcome that subjects in the study could bear higher indoor temperatures compared to the temperatures set in the standard.

The adaptive comfort model is a relation between mean outdoor air temperature and the corresponding acceptable indoor air temperatures. The data concerning the naturally ventilated buildings in the global database were extracted separately, forming a subgroup depending only on naturally ventilated buildings. The statistical analysis underlying the model considered each building as the unit of analysis, and a weighted analysis followed, where the number of votes in each building represented the weight.

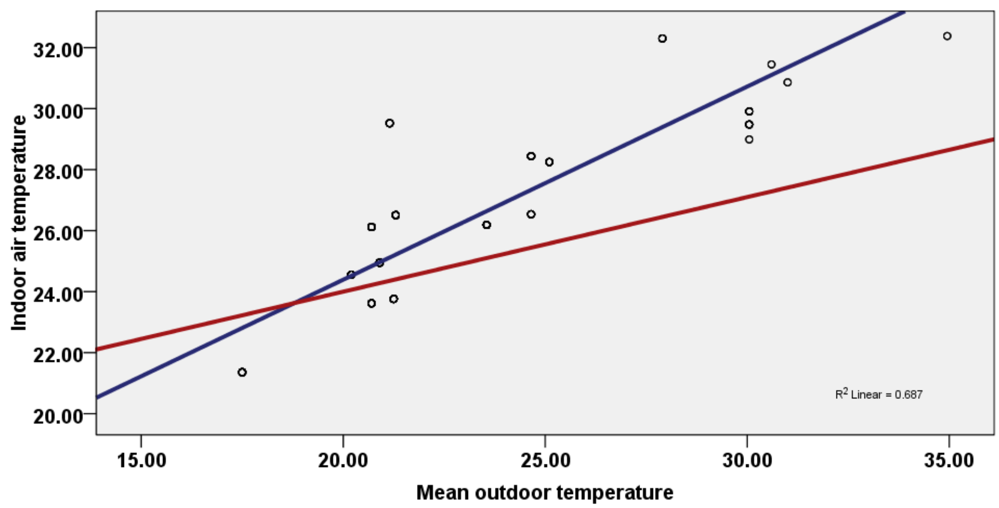

Figure 63: The blue line represent the outcome of the study, it is the regression of the indoor air temperature on the mean outdoor air temperature for the thermal sensation votes "just right" of the naturally ventilated buildings. The red line represents the adaptive comfort standard implemented in the ASHRAE 55-2004

Only statistically significant at ($p < 0.05$) buildings (data points) were considered, forming the data on which the Adaptive Comfort Model was based upon. This criterion in the selection of the database forming the model resulted in 36 significant naturally ventilated building out of 44 naturally ventilated buildings, with almost 8900 subjective votes. The buildings selected covered seven climatic zones, the type of each climatic zones and the number of buildings covering each zone are listed in Table 2.

The following section proposes the idea of thinking in developing a variable standard depending on different climatic zones. To better explain the idea of the proposed development, it is necessary to state the limits of the model that are stated in the ASHRAE -55 -2004. The limits of the adaptive comfort model are the boundaries shown in the graph implemented in the ASHRAE Standard-55, section 5.3(refer to

Figure 9). The range of mean outdoor temperature between 10 ^{0}C and 33 ^{0}C is the limit to apply the model. The limits especially the extreme higher end depend on the actual mean outdoor temperatures originally covered by the buildings underlying the model. The mean outdoor temperature limits may not be extrapolated to temperatures outside that range.

The buildings representing different climatic zones are shown in Figure 64. The ANOVA test of different buildings' neutralities across different climatic zones resulted in a significant difference (ANOVA across different climates $\alpha = 0.05$, $F(1,35) = 11.560$ and $P < 0.001$).

As hinted above, if the limits of the model are the range of mean outdoor temperatures actually measured or covered by the study, it is logical to classify the standard into a variable one regarding different climatic zones. The distinction between different climatic zones, where different physical parameters as humidity and air velocity (e.g. different between Mediterranean and Desert climate at same air temperatures), is necessary. In addition, different adaptive reactions and different methods of control are related to different climates relying on the features of each; taking into consideration that human reactions differ from one climate to the other even in the same air temperatures. In order to satisfy the purpose of this evolving idea, this is to specify the thermal environmental conditions that will be acceptable to the majority of the occupants; the suggested new model needs to be variable depending on different climate zones.

Only two buildings in the adaptive comfort model represented the desert climate, while most of the buildings represented moderate climates. This explains why the comfort temperatures resulting from the study are higher than those implemented in the model. People in desert climates can bear higher temperatures than those in moderate climates.

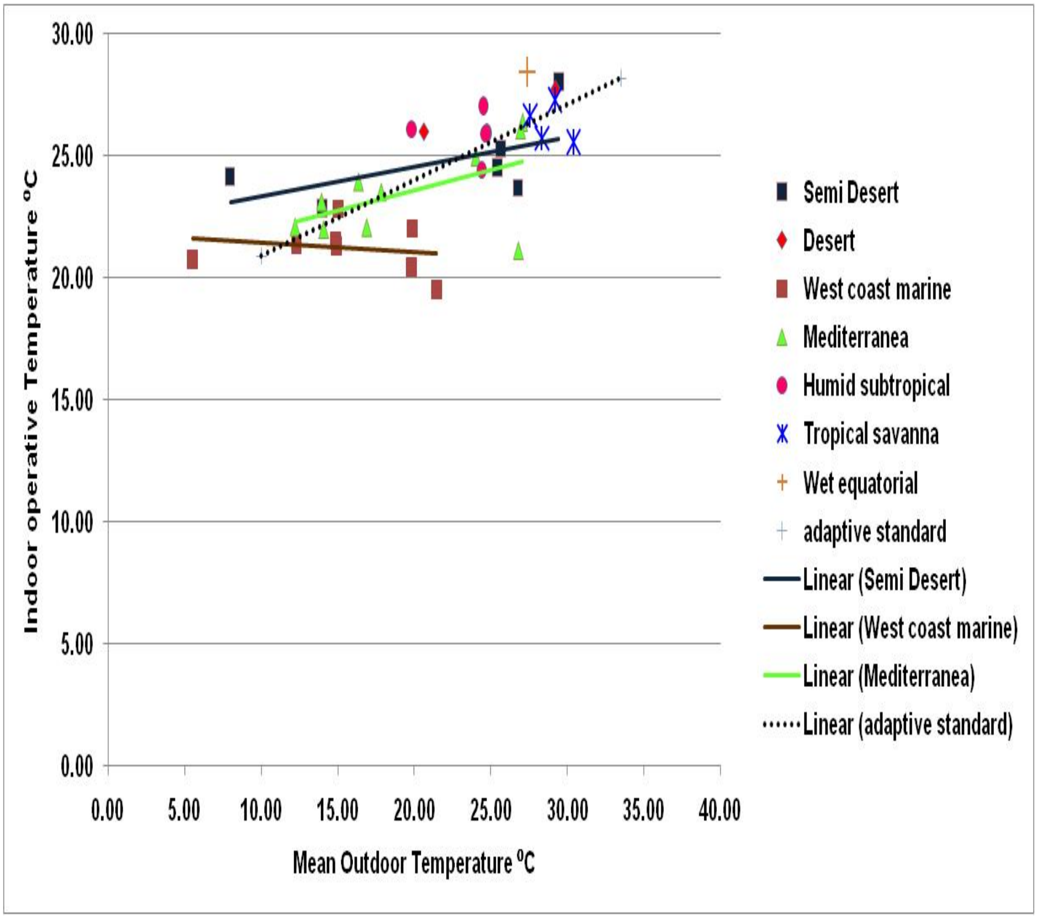

Figure 64: The different buildings of different climatic zones incorporated into the Adaptive Comfort Standard of ASHRAE standard 55-2004

CHAPTER SIX CONCLUSION

The study screened three educational buildings in the Greater Cairo Region, two of them are naturally ventilated and the third is mixed mode. The study focused on the academic calendar and the months included in the study were February, March, April, May, July, November and December. Both students and employees participated in the study. Spaces included drawing halls, lecture spaces and employees' rooms. The next section presents a brief review of the most important findings of the study, and relates these findings to the adaptive theory. The last section will discuss the areas in which research is needed.

6.1 FINDINGS AND IMPLICATIONS

The methodology followed in data gathering was effective and proved its coincidence with other research work. The physical environment were monitored using a set of 10 data loggers. Using the Nomad portable weather station in some days of the field studies revealed that the difference between the air temperature and the radiant air temperature did not exceed one degree Celsius. This justified considering the air temperature measured by the data loggers as the operative temperature, as operative temperature is approximated by the simple average of the air temperature and mean radiant temperature.

In addition, the measurements showed that the air velocity didn't exceed 0.06 m/sec in all the spaces even when using ceiling fans and that was why the air velocity was not measured in the field studies. The data loggers were distributed over the whole space and were placed on the working plane with a stand to adjust their heights to the same level as the students' heads.

The data collected from a paper-based survey filled by the subjects at the end of their classes formed the main database of the study, using this technique resulted in a huge number of documents to be entered to the statistical analysis program which took a long time for the data entry. But this method is probable in the case of subjects moving from one space to another and in the case of aiming to obtain a large number of votes at the same time from each space.

Clothing insulation is a form of physical adaptation that was examined in one of the questions found in Appendix E.The Clo values for every individual respondent were calculated from the clothing garments pointed out by each. The database adopted in the standards lack values corresponding to items of clothing used in Egypt especially the exact values for the veil (Hijab) and Abaya. Even a study concerning the clothing area factors of typical Arabian Gulf ensembles did not provide these values. The veil is mainly made of a large variety of fabrics and colors used as an Islamic head cover to conceal female hair. The Abaya is a traditional silk or wool loose cloak, reflecting the female religious belief, covering the whole body except for the face, palms of hands and toes. Another shortage in the available resources was the clo value of flip-flop slippers.

The traditional language for comfort questionnaires is English, and translation to other languages is not easy as the terms used may have different meanings than the ones used in the English Language questionnaire. In order to overcome such issues and to examine the clarity of semantics, the questionnaire was tested in Karlsruhe on five people whose mother tongue was Arabic, the native language in Egypt. In comfort votes, semantic differential scales are the most popular and are highly-recommended. This type of scaling allows for easy conversion of the results into interval numerical scales. The thermal sensation was assessed using a seven-point scale which is in line with the common practice of many psychological scales. Besides, it is the most common in this field, which means that it will be easily compared to the results of other field studies in this area of research.

In the case of assessing thermal sensation the seven point scale, 3=very warm, 2=warm, 1=slightly warm, 0=neutral, -1=slightly cool, -2=cool and -3 very cool was used. The semantics used differed from that in the ASHRAE scale to facilitate translation to the Arabic language. In particular, the scale is different in the naming of the two extreme values compared to the ASHRAE scale. The word “hot” and “cold” were avoided, and semantics expressing the levels of being cool or warm were used instead as it was easier in translation to choose such a system of progression. The

Arabic language doesn't contain two different words for cool versus cold or for warm versus hot, which made it more practical to use the semantics for slightly cool, cool and very cool as well as using slightly warm, warm and very warm.

The percentage of thermal sensation votes for the central categories (-1, 0, 1) of the ASHRAE scale didn't differ between mixed mode and naturally ventilated buildings in autumn. Air conditions are not used during this period of the year, which resulted in similar indoor conditions for both types of buildings. This percentage differed in spring as a result of using air conditions.

The study showed that the percentage of acceptance for the central categories (-1, 0, 1) on the ASHRAE Scale represented more than 80% in both types of buildings, which differed from the PMV-PPD model, and which is adopted in the ASHRAE Adaptive Comfort Model. This might lead to the revision of the percentage of acceptance of the central category on the ASHRAE scale by studying more field surveys and incorporating a straightforward question about the acceptance of the indoor thermal conditions in the questionnaire templates.

Regarding thermal acceptability, up to 26°C the research obtained about 80% acceptability in both building types. This finding is similar to what was obtained from a research conducted in Tunis, and differed from another study based on the ASHRAE RP884 project, where in the study the limits of obtaining 80% acceptability occurred at higher degrees.

The mean temperature for different thermal sensation categories in the autumn seasons varied from the spring seasons showing the possibility of energy saving in moderate thermal conditions, thereby encouraging the usage of naturally ventilated buildings and incorporating mixed mode strategies in hot arid climates, as far as they can meet modern expectations of thermal comfort.

The percentage of satisfaction from the indoor climate conditions was in general higher in mixed mode buildings than in naturally ventilated buildings, although the voting for thermal sensation was almost the same except in higher indoor temperatures above 26 °C, which shows the psychological effect of the presence of air conditions in mixed mode buildings.

The study showed that in the same building the use of the space may affect the comfort votes and the overall satisfaction. The voting in spaces used as drawing halls showed more satisfaction than voting coming from lecture halls, and voting from both types of space were better than employees' rooms. This shows the need to study the effect of space design and usage on the comfort votes and user satisfaction.

The calculation of neutral temperatures showed the acclimatization of people to the prescriptive climatic conditions, and that the neutral temperature is related to the mean climatic conditions experienced by the population.

The equations relating the mean thermal sensation to indoor air temperature in this research were different from those obtained from the Pakistan project, the Pakistan project population were more able to adapt to the change in their indoor thermal environment, while the population of this research were more able to adapt to their indoor thermal environment than the population of naturally ventilated buildings included in the ASHRAE RP884 project.

The preferred temperature in both building types was below the neutral temperature calculated, the same as in ASHRAE RP884 project where preference was depressed below neutrality in warm climates.

The outcome of the study showed the capability of the studied population to adapt to hotter conditions than that set by the adaptive comfort model implemented in the ASHRAE standard 55-2004.

At the same time the analysis of the adaptive comfort model showed the need of revising the standards to be oriented towards different climatic zones, and to overcome the shortage of data gathered concerning the hot arid climates. The classification of the standard into different climate zones and setting a specific temperature range to each climate may expand the range of acceptable temperatures and gives the opportunity for more energy conservation.

6.2 FURTHER RESEARCH

The measured indoor air temperatures covered a range of 14 K corresponding to mean outdoor temperatures of a range of 19 K. This range of thermal conditions represents a wide range of indoor thermal conditions. While the study showed the influence of various types of adaptive behaviours on the sensation of comfort, research is still needed in terms of in-depth quantification of these relationships. This requires more knowledge on the particular characteristics of each building, construction materials and also cultural and socio-economic issues.

The study involved a transverse survey; a longitudinal survey may confirm the outcomes from the study and also will allow a precise quantification of issues like various types of adaptive opportunities and their frequency.

The development of adaptive standards to be more adequate to the variety of buildings, climatic and cultural situations in hot arid climates is needed.

The influence of non-thermal factors on thermal comfort votes should be investigated and if possible quantified; this may include cultural and socio-economic status, maintenance and decoration, privacy, personal aspirations and other factors.

The study of the relation between energy and thermal comfort implications is needed, it is important to know the effect of various passive and mixed mode strategies, as well as their costs. The study of increasing the efficiency of existing passive techniques and development of new techniques is needed, this may require the research to develop mixed mode techniques whether using local air conditioning devices or using central systems.

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Appendix A: Metabolic Rates

Metabolic Rates for Typical Tasks

Activity	Met Units	Metabolic Rate W/m²	(Btu/h·ft²)
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	45	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	(70)
Office Activities			
Seated, reading, or writing	1.0	60	(18)
Typing	1.1	65	(20)
Filing, seated	1.2	70	(22)
Filing, standing	1.4	80	(26)
Walking about	1.7	100	(31)
Lifting/packing	2.1	120	(39)
Driving/Flying			
Automobile	1.0-2.0	60-115	(18-37)
Aircraft, routine	1.2	70	(22)
Aircraft, instrument landing	1.8	105	(33)
Aircraft, combat	2.4	140	(44)
Heavy vehicle	3.2	185	(59)
Miscellaneous Occupational Activities			
Cooking	1.6-2.0	95-115	(29-37)
House cleaning	2.0-3.4	115-200	(37-63)
Seated, heavy limb movement	2.2	130	(41)
Machine work			
sawing (table saw)	1.8	105	(33)
light (electrical industry)	2.0-2.4	115-140	(37-44)
heavy	4.0	235	(74)
Handling 50 kg (100 lb) bags	4.0	235	(74)
Pick and shovel work	4.0-4.8	235-280	(74-88)
Miscellaneous Leisure Activities			
Dancing, social	2.4-4.4	140-255	(44-81)
Calisthenics/exercise	3.0-4.0	175-235	(55-74)
Tennis, single	3.6-4.0	210-270	(66-74)
Basketball	5.0-7.6	290-440	(92-140)
Wrestling, competitive	7.0-8.7	410-505	(129-160)

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Appendix B: Clothing Insulation Values

Clothing Insulation Values for Typical Ensembles[a]

Clothing Description	Garments Included[b]	I_{cl} (clo)
Trousers	1) Trousers, short-sleeve shirt	0.57
	2) Trousers, long-sleeve shirt	0.61
	3) #2 plus suit jacket	0.96
	4) #2 plus suit jacket, vest, T-shirt	1.14
	5) #2 plus long-sleeve sweater, T-shirt	1.01
	6) #5 plus suit jacket, long underwear bottoms	1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals)	0.54
	8) Knee-length skirt, long-sleeve shirt, full slip	0.67
	9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater	1.10
	10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket	1.04
	11) Ankle-length skirt, long-sleeve shirt, suit jacket	1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt	0.72
	14) Overalls, long-sleeve shirt, T-shirt	0.89
	15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	1.37
Athletic	16) Sweat pants, long-sleeve sweatshirt	0.74
Sleepwear	17) Long-sleeve pajama tops, long pajama trousers, short 3/4 length robe (slippers, no socks)	0.96

a Data are from Chapter 8 in the *2001 ASHRAE Handbook—Fundamentals.*

b All clothing ensembles, except where otherwise indicated in parentheses, include shoes, socks, and briefs or panties. All skirt/dress clothing ensembles include pantyhose and no additional socks.

Garment Insulation[a]

Garment Description[b]	I_{clu} (clo)	Garment Description[b]	I_{clu} (clo)
Underwear		**Dress and Skirts**[c]	
Bra	0.01	Skirt (thin)	0.14
Panties	0.03	Skirt (thick)	0.23
Men's briefs	0.04	Sleeveless, scoop neck (thin)	0.23
T-shirt	0.08	Sleeveless, scoop neck (thick), i.e., jumper	0.27
Half-slip	0.14	Short-sleeve shirtdress (thin)	0.29
Long underwear bottoms	0.15	Long-sleeve shirtdress (thin)	0.33
Full slip	0.16	Long-sleeve shirtdress (thick)	0.47
Long underwear top	0.20	**Sweaters**	
Footwear		Sleeveless vest (thin)	0.13
Ankle-length athletic socks	0.02	Sleeveless vest (thick)	0.22
Pantyhose/stockings	0.02	Long-sleeve (thin)	0.25
Sandals/thongs	0.02	Long-sleeve (thick)	0.36
Shoes	0.02	**Suit Jackets and Vests**[d]	
Slippers (quilted, pile lined)	0.03	Sleeveless vest (thin)	0.10
Calf-length socks	0.03	Sleeveless vest (thick)	0.17
Knee socks (thick)	0.06	Single-breasted (thin)	0.36
Boots	0.10	Single-breasted (thick)	0.42
Shirts and Blouses		Double-breasted (thin)	0.44
Sleeveless/scoop-neck blouse	0.13	Double-breasted (thick)	0.48
Short-sleeve knit sport shirt	0.17	**Sleepwear and Robes**	
Short-sleeve dress shirt	0.19	Sleeveless short gown (thin)	0.18
Long-sleeve dress shirt	0.25	Sleeveless long gown (thin)	0.20
Long-sleeve flannel shirt	0.34	Short-sleeve hospital gown	0.31
Long-sleeve sweatshirt	0.34	Short-sleeve short robe (thin)	0.34
Trousers and Coveralls		Short-sleeve pajamas (thin)	0.42
Short shorts	0.06	Long-sleeve long gown (thick)	0.46
Walking shorts	0.08	Long-sleeve short wrap robe (thick)	0.48
Straight trousers (thin)	0.15	Long-sleeve pajamas (thick)	0.57
Straight trousers (thick)	0.24	Long-sleeve long wrap robe (thick)	0.69
Sweatpants	0.28		
Overalls	0.30		
Coveralls	0.49		

a Data are from Chapter 8 in the *2001 ASHRAE Handbook—Fundamentals*.
b "Thin" refers to garments made of lightweight, thin fabrics often worn in the summer; "thick" refers to garments made of heavyweight, thick fabrics often worn in the winter.
c Knee-length dresses and skirts.
d Lined vests.

Appendix C: The cover page of the questionnaire.

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

Fachgebiet
Bauphysik und Technischer Ausbau (fbta)

Study of building's indoor climate:

Greetings and after,

This research follows a several research work carried out by "FBTA" institute, Architectural Department, University of Karlsruhe in Germany. The research team working in the Institute is interested in the study of existing and new buildings to find solutions for combining rationalizing energy consumption and comfortable internal environment.

Thermal comfort in the building is one of the reasons for user satisfaction inside the building that the research team conducted many research work aimed at improving the internal climate in public buildings. This is one of these researches, and its objective is to find the range of thermal comfort to the user throughout the year within this building. This is to be done by collecting some information on thermal comfort inside the building that will be statistically analyzed.

To conduct the search, one of the researchers will take measurements of temperature, humidity and speed of air inside the space, and asking at the same time your participation, by filling out a questionnaire reflecting your assessment of the indoor climate and comfort within the space. To obtain information throughout the year the same procedure will be repeated in the summer.

We call all whom are present to participate in this scientific research, your participation in this research work is voluntarily, but is very important for the success of the research and obtaining reliable conclusions. The questions concern personal opinion and experience of the user within the space, therefore the researcher intends to conserve your privacy by giving each person a code consisting of:

Last letter of your first name	-----------------------------------
Last letter of your family name	-----------------------------------
Last letter of your place of birth	------------------------------------
Last three numbers of your telephone number	------------------------------------

If you have any questions during filling out the questionnaire, you will find the researcher in response, and in the event of any further questions, you can send to: amgad@fbta.uni-karlsruhe.de, questions will be answered as soon as possible,

Appendix D: The translated cover page of the questionnaire.

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

Fachgebiet
Bauphysik und Technischer Ausbau (fbta)

دراسة عن المناخ الداخلي بالمبنى:

تحية طيبة و بعد،

يتبع هذا البحث عدة ابحاث يقوم بها معهد "building physics and technical services"

قسم العمارة بجامعة كارلسروه بالمانيا، يهتم فريق العمل بالمعهد بدراسة المباني القائمة و الجديدة من اجل ايجاد حلول تجمع بين ترشيد استهلاك الطاقة و توفير بيئة داخلية مريحة.

الراحة الحرارية داخل المبنى تعد من احد اسباب ارتياح المستخدم داخل المبنى لذلك يقوم فريق البحث باجراء كثير من الابحاث التي تهدف الى تحسين المناخ الداخلي بالمبانى العامة. يعد هذا البحث احد هذه الابحاث السابقة و الهدف منه هو ايجاد مجال الراحة الحرارية للمستخدم على مدار العام داخل هذا المبنى ويتم ذلك عن طريق جمع بعض المعلومات الخاصة بمجال الراحة الحرارية داخل المبنى و التي سوف يتم تحليلها احصائيا.

لاجراء البحث، يقوم احد الباحثين باخذ القياسات الخاصة بدرجات الحرارة، الرطوبة و سرعة الهواء داخل الفراغ، و في نفس الوقت يتم مشاركة المستخدم، عن طريق ملئ استبيان يعبر عن تقيمه للمناخ الداخلي و راحته داخل الفراغ و من اجل الحصول على معلومات على مدار العام سيتم تكرار هذا البحث في فصل الصيف. ندعو كل المتواجدين الى الاشتراك في هذا البحث العلمي ، تعتبر مشاركتك فى هذا البحث عمل تطوعي، و لكنه هام جدا من اجل تحقيق نجاح البحث و استنتاج نتائج يمكن الاعتماد عليها،الاسئلة تخص الراي الشخصي و تجربة المستخدم داخل الفراغ، لذلك حرصا من الباحثين على حفظ خصوصيتك و شخصيتك، سيتم اعطاء كل شخص كود مكون من

الحرف الاخير من اسمك	--------------------------
الحرف الاخير من اسم الوالد	--------------------------
الحرف الاخيرمن محل ميلادك	--------------------------
اخر ثلاث ارقام من رقم الهاتف الخاص بك	--------------------------

اذا كان لديك اي استفسار اثناء ملئ الاستبيان ، ستجد الباحث متواجد للرد عليها، و في حال وجود اي استفسارات اخرى يمكن ارسالها الى amgad@fbta.uni_karlsruhe.de و سيتم الرد عليها في اسرع وقت ممكن

شكرا جزيلا

Appendix E: The final version of the questionnaire.

Date: ________ Room ID: __________ Time: ______

1-Type of transportation used today is:

☐	Public transportations, which are not air-conditioned	☐	Private transportations, which are not air-conditioned
☐	Public transportation, which is air-conditioned	☐	Private transportation, which is air-conditioned

2- How did you find the outdoor temperature today:

☐	☐	☐	☐	☐
Much cooler than your expectations	Cooler than your expectations.	As expected	Warmer than your expectations.	Much warmer than your expectations.

3- On entering the space today, you find the indoor temperature:

☐	☐	☐	☐	☐

Much cooler than your expectations	Cooler than your expectations.	As expected	Warmer than your expectations.	Much warmer than your expectations.

4- How do you feel now?

☐	☐	☐	☐	☐	☐	☐
Very Cold	Cold	Slightly cold	Just right	Slightly hot	hot	Very hot

5- You prefer the room temperature to be:

☐	☐	☐	☐	☐
Colder	Slightly colder	As it is	Slightly hotter	hotter

6- In general, the room temperature now, is:

☐	Acceptable	☐	Not acceptable

7- How do you feel the humidity in the space now?

☐	☐	☐	☐	☐	☐	☐
Very dry (very low)	Dry (low)	Slightly dry (slightly low)	Just right	Slightly humid (slightly high)	Humid (high)	Very humid (very High)

8- You prefer the humidity inside the space to be:

☐	☐	☐	☐	☐
Lower humidity	Slightly Lower	As it is	Slightly Higher	Higher humidity

humidity	humidity

9- The humidity now, is:

☐	Acceptable	☐	Not acceptable

10- In general, you feel the atmosphere is: (Please select only one answer)?

☐	Stifling	☐	Fresh
☐	Muggy	☐	Pleasantly dry
☐	Dusty	☐	Purely
☐	Unpleasant smell	Others	Please specify …………………….

11- Did you do any of the following in order to change the indoor climate to satisfy your needs?

☐	Open windows	☐	Close windows
☐	Open doors	☐	Close doors
☐	Open inside curtains	☐	Close inside curtains
☐	Open outside blinds	☐	Close outside blinds
☐	Open ceiling fans	☐	Close ceiling fans
☐	Open portable fans	☐	Close portable fans
☐	Asking someone else to do any of the previous actions	☐	Asking someone else to do any of the previous actions
☐	Putting on more cloth	☐	Taking off some cloth

☐	Changing the set point of the air conditioner	others	Please specify …………………

12- The means available for you to control the indoor climate are considered:

☐	☐
unsatisfying	satisfying

13- You are wearing:

Head covering:		☐ veil	☐ cap
Others:	………………………………………………………………………..		
Garment,	T-shirt / short sleeve	☐ Heavy weight	☐ Light weight
	T-shirt / long sleeve	☐ Heavy weight	☐ Light weight
Shirts / Blouses	Shirt short sleeve	☐ Heavy weight	☐ Light weight
	Shirt long sleeve	☐ Heavy weight	☐ Light weight
	Blouse long sleeve	☐ Heavy weight	☐ Light weight
	Blouse short sleeve	☐ Heavy weight	☐ Light weight
	Body	☐ Heavy weight	☐ Light weight
	Abaya	☐ Heavy weight	☐ Light weight
Others:	………………………………………………………………		
	Short skirt	☐ Heavy weight	☐ Light weight
	Long skirt	☐ Heavy weight	☐ Light weight
	Short Dress /short sleeves	☐ Heavy weight	☐ Light weight
	Long Dress /short sleeves	☐ Heavy weight	☐ Light weight
	Long Dress / short sleeves	☐ Heavy weight	☐ Light weight
	Long Dress / long sleeves	☐ Heavy weight	☐ Light weight
Trousers	Jeans	☐	
	Short trouser	☐ Heavy weight	☐ Light weight
	Normal trouser	☐ Heavy weight	☐ Light weight
Pullover / jackets	pullover	☐ Heavy weight	☐ Light weight
	light suit jacket	☐	
	Heavy suit jacket	☐	
Others:	……………………………………………………………………		

socks	Normal short socks	☐ Heavy weight	☐ Light weight
	Ankle socks	☐ Heavy weight	☐ Light weight
	Long socks	☐ Heavy weight	☐ Light weight
others	…………………………………………………………………….		
shoes	sandal	☐ open	☐ Close
	shoes	☐ Thin soled	☐ Thick soled
	Sports shoe	☐ Flip flop	☐
Others:	……………………………………………………………………..		

14- Within the last hour, you:

☐ Drink something hot

☐ Drink something cold

☐ Eat something hot

☐ Eat something cold

15- Overall, how satisfied are you with the indoor climate conditions (temperature, air velocity, humidity etc...)?

☐	☐	☐	☐
Very unsatisfied	unsatisfied	satisfied	Very satisfied

16- What were you doing during the last hour?

	Sitting (relaxed)	Sitting (working/studying)	Standing	Walking indoors	Walking outdoors	Others, Please specify
Last 30 minutes	☐	☐	☐	☐	☐	☐
From 30 to60 minutes	☐	☐	☐	☐	☐	☐

17- Personal information:

Gender:	☐ Man		☐ Women	
Age:	☐ less than 25 years	☐ 26 to 35	☐ 36 to 45	☐ more than 46

Thanks very much .....

Appendix F: The translated version of the final questionnaire.

التاريخ ________	**رقم الغرفة** ______	**الوقت** _____:_______

إستخدامك اليوم كان لوسيلة مواصلات:	☐ عامة غير مكيفة	☐ عامة مكيفة
	☐ خاصة غير مكيفة	☐ خاصة مكيفة
	اخرى ________________________________	

كيف وجدت درجة الحرارة الخارجية اليوم؟

☐ أدفئ كثيرا مما كنت تتوقعها	☐ أدفئ مما كنت تتوقعها	☐ كما كنت تتوقعها	☐ أبرد مما كنت تتوقعها	☐ أبرد كثيرا مما كنت تتوقعها

عند دخولك هذا المكان اليوم، وجدت درجة الحرارة داخل المكان :

☐ أدفئ كثيرا مما كنت تتوقعها	☐ أدفئ مما كنت تتوقعها	☐ كما كنت تتوقعها	☐ أبرد مما كنت تتوقعها	☐ أبرد كثيرا مما كنت تتوقعها

كيف تجد درجة حرارة المكان الان؟

☐	☐	☐	☐	☐	☐	☐
حار جدا	حار	حار بعض الشئ	معتدلة	بارد بعض الشئ	بارد	بارد جدا

تفضل ان تكون درجة الحرارة داخل المكان:

☐	☐	☐	☐	☐
ادفئ	ادفئ بعض الشئ	كما هي	ابرد بعض الشئ	ابرد

درجة الحرارة داخل المكان الان تعد:

☐ مقبولة ☐ غير مقبولة

كيف تجد الرطوبة داخل المكان الان:

☐	☐	☐	☐	☐
رطب	بعض الشئ رطب	معتدل	بعض الشئ جاف	جاف

تفضل ان تكون الرطوبة داخل المكان:

☐ ☐ ☐ ☐ ☐

اكثر رطوبة	اكثر بعض الشئ	كما هي	اقل بعض الشئ	اقل رطوبة

بوجه عام، الرطوبة داخل المكان الان تعد:

☐ مقبولة	☐ غير مقبولة

بوجه عام، الهواء داخل الفراغ الان يعد

☐ خانق	☐ صافي
☐ رطب حار, مُغم	☐ جاف لطيف
☐ ترابي مغبر	☐ نَقِيّ
☐ رائحته كريهة	اخرى________________________________

هل قمت بعمل اى من الاشياء التالية لتغيير المناخ الداخلي ؟

☐ غلق شباك	☐ فتح شباك
☐ غلق باب	☐ فتح باب
☐ غلق ستائر داخلية	☐ فتح ستائر داخلية
☐ غلق مراوح سقف	☐ فتح مراوح سقف
☐ تغير درجة التكيف	☐ سؤال شخص اخر للقيام باى من الافعال السابقة
☐ خلع بعض الملابس	☐ لبس ملابس اضافية

اخرى ____

بوجه عام،تشعر ان الامكانيات المتاحة لك لتتحكم في المناخ الداخلي تعد

☐ مرضية	☐ غيرمرضية

انت ترتدى الان

غطاء راس نوعه		☐ كاب	☐ طرحه
اخرى			
ملابس الجزءالعلوي	تى شيرت بكم قصير	☐ خفيف	☐ ثقيل
	تى شيرت بكم طويل	☐ خفيف	☐ ثقيل
	بلوزة بكم قصير	☐ خفيف	☐ ثقيل
	بلوزة بكم طويل	☐ خفيف	☐ ثقيل
	قميص بكم قصير	☐ خفيف	☐ ثقيل
	قميص بكم طويل	☐ خفيف	☐ ثقيل
	بودي	☐ بكم قصير	☐ بكم طويل
	عباءة	☐ خفيف	☐ ثقيل
	بلوفر	☐ خفيف	☐ ثقيل
	جاكت	☐ خفيف	☐ ثقيل
	جاكت بدله	☐ خفيف	☐ ثقيل
ملابس الجزءالسفلي	جونله قصيره	☐ خفيف	☐ ثقيل
	جونله طويله	☐ خفيف	☐ ثقيل
	فستان طويل بكم طويل	☐ خفيف	☐ ثقيل
	فستان طويل بكم قصير	☐ خفيف	☐ ثقيل
	فستان قصير- بكم طويل	☐ خفيف	☐ ثقيل
	فستان قصير- بكم قصير	☐ خفيف	☐ ثقيل

	بنطلون جينز	☐		
	بنطلون قصير	☐ خفيف	☐ ثقيل	
	بنطلون طويل	☐ خفيف	☐ ثقيل	
اخرى	________________			
شراب	شراب عادي قصير	☐ خفيف	☐ ثقيل	
	شراب حتى الركبه	☐ خفيف	☐ ثقيل	
	شراب طويل فوق الركبه	☐ خفيف	☐ ثقيل	
حذاء	صندل	☐ مفتوح	☐ مغلق	
	حذاء	☐ نعل رفيع	☐ نعل سميك	
		☐ حذاء رياضي	☐ شبشب	

في خلال الساعة الاخيرة، هل قمت بعمل شئ مما يلي

☐	شرب مشروب ساخن
☐	شرب مشروب بارد
☐	اكل شئ ساخن
☐	اكل شئ بارد

خلال الساعة الماضية، ماذا كنت تفعل؟

	جالس مستكين	جالس (اعمل، اذاكر)	واقف	امشي داخل المبنى	امشي خارج المبنى	اخرى
آخر ٣٠ دقيقة	☐	☐	☐	☐	☐	☐
من ٣٠ حتى ٦٠ دقيقة	☐	☐	☐	☐	☐	☐

بوجه عام، ما مدى رضائك عن الاحوال المناخية داخل المكان ، (درجة الحرارة، الرطوبة، سرعة الهواء.......)؟

☐	☐	☐	☐
غيرمرضية تماما	غيرمرضية	مرضية	مرضية تماما

انثى☐	ذكر ☐	الجنس:

☐	☐	☐	☐	**العمر**
اكثر من ٤٦ عام	من ٣٦ حتى ٤٥ عام	من ٢٥ حتى ٣٥ عام	اقل من ٢٥ عام	

Appendix G: The list of garments included in the study and the clo value of each.

Head covering:		Veil = 0.07 clo	Cap= 0.10 clo
Others:	………………………………………………………………………..		
Garment,	T-shirt / short sleeve	Heavy weight 0.20	Light weight 0.17
	T-shirt / long sleeve	Heavy weight 0.45	Light weight 0.34
Shirts / Blouses	Shirt short sleeve	Heavy weight 0.2	Light weight 0.19
	Shirt long sleeve	Heavy weight 0.34	Light weight 0.25
	Blouse long sleeve	Heavy weight 0.25	Light weight 0.20
	Blouse short sleeve	Heavy weight 0.2	Light weight 0.15
	Body	Heavy weight 0.25	Light weight 0.20
	Abaya	Heavy weight 0.47	Light weight 0.33
Others:	…………………………………………………………………		
	Short skirt	Heavy weight 0.20	Light weight 0.15
	Long skirt	Heavy weight 0.23	Light weight 0.14
	Short Dress /short sleeves	Heavy weight 0.25	Light weight 0.20
	Short Dress /long sleeves	Heavy weight 0.30	Light weight 0.25
	Long Dress / short sleeves	Heavy weight 0.33	Light weight 0.29
	Long Dress / long sleeves	Heavy weight 0.47	Light weight 0.33
Others:	…………………………………………………………………….		
Trousers	Jeans	0.28	
	Short trouser	Heavy weight 0.15	Light weight 0.10
	Normal trouser	Heavy weight 0.24	Light weight 0.15

Others:	……………………………………………………………………		
Pullover / jackets	pullover	Heavy weight 0.25	Light weight 0.20
	light suit jacket	0.36	
	Heavy suit jacket	0.42	
Others:	………………………………………………………………………		
socks	Normal short socks	Heavy weight 0.03	Light weight 0.02
	Ankle socks	Heavy weight 0.06	Light weight 0.03
	Long socks	Heavy weight 0.10	Light weight 0.03
others	……………………………………………………………………….		
shoes	sandal	Open 0.02	Close 0.03
	shoes	Thin soled 0.02	Thick soled 0.04
		Flip flop 0.02	Sports shoe 0.03
Others:	………………………………………………………………………..		

Appendix H: Indoor air temperature and mean outdoor air temperature.

Descriptives of Indoor temperature and outdoor temperature

season = Autumn 2007

Descriptive Statistics(a)

	N	Minimum	Maximum	Mean	Std. Deviation
Indoor air temperature °C	778	21.36	32.30	25.3905	2.32487
Mean outdoor temperature °C	778	17.50	27.90	21.4690	2.30717

season = Spring 2008

Descriptive Statistics(a)

	N	Minimum	Maximum	Mean	Std. Deviation
Indoor air temperature °C	674	23.76	35.72	29.6193	3.30573
Mean outdoor temperature °C	674	20.20	34.95	27.6858	4.90245

season = Autumn 2008

Descriptive Statistics(a)

	N	Minimum	Maximum	Mean	Std. Deviation
Indoor air temperature °C	824	20.63	27.95	24.9960	1.93570
Mean outdoor temperature °C	824	18.80	24.60	21.8695	1.60712

season = Spring 2009

Descriptive Statistics(a)

	N	Minimum	Maximum	Mean	Std. Deviation
Indoor air temperature °C	908	20.53	32.33	24.5064	3.52908
Mean outdoor temperature °C	908	16.10	29.30	21.3079	4.83679

Appendix I: The analysis of variance of the indoor air temperature for different building types, across the four seasons of the study.

ANOVA

Indoor air temperature

season		Sum of Squares	df	Mean Square	F	Sig.
Autumn 2007	Between Groups	218.035	1	218.035	42.494	0.000
	Within Groups	3,981.673	776	5.131		
	Total	4,199.708	777			
Spring 2008	Between Groups	247.164	1	247.164	23.370	0.000
	Within Groups	7,107.264	672	10.576		
	Total	7,354.428	673			
Autumn 2008	Between Groups	0.336	1	0.336	0.090	0.765
	Within Groups	3,083.383	822	3.751		
	Total	3,083.719	823			
Spring 2009	Between Groups	146.635	1	146.635	11.915	0.001
	Within Groups	11,149.515	906	12.306		
	Total	11,296.149	907			

Appendix J: The ANOVA test for the Humidity Preference of naturally ventilated buildings and the least significant difference (LSD) pair wise multiple comparison test.

ANOVA

Humidity Preference

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	68.504	3	22.835	14.531	.000
Within Groups	4219.385	2685	1.571		
Total	4287.888	2688			