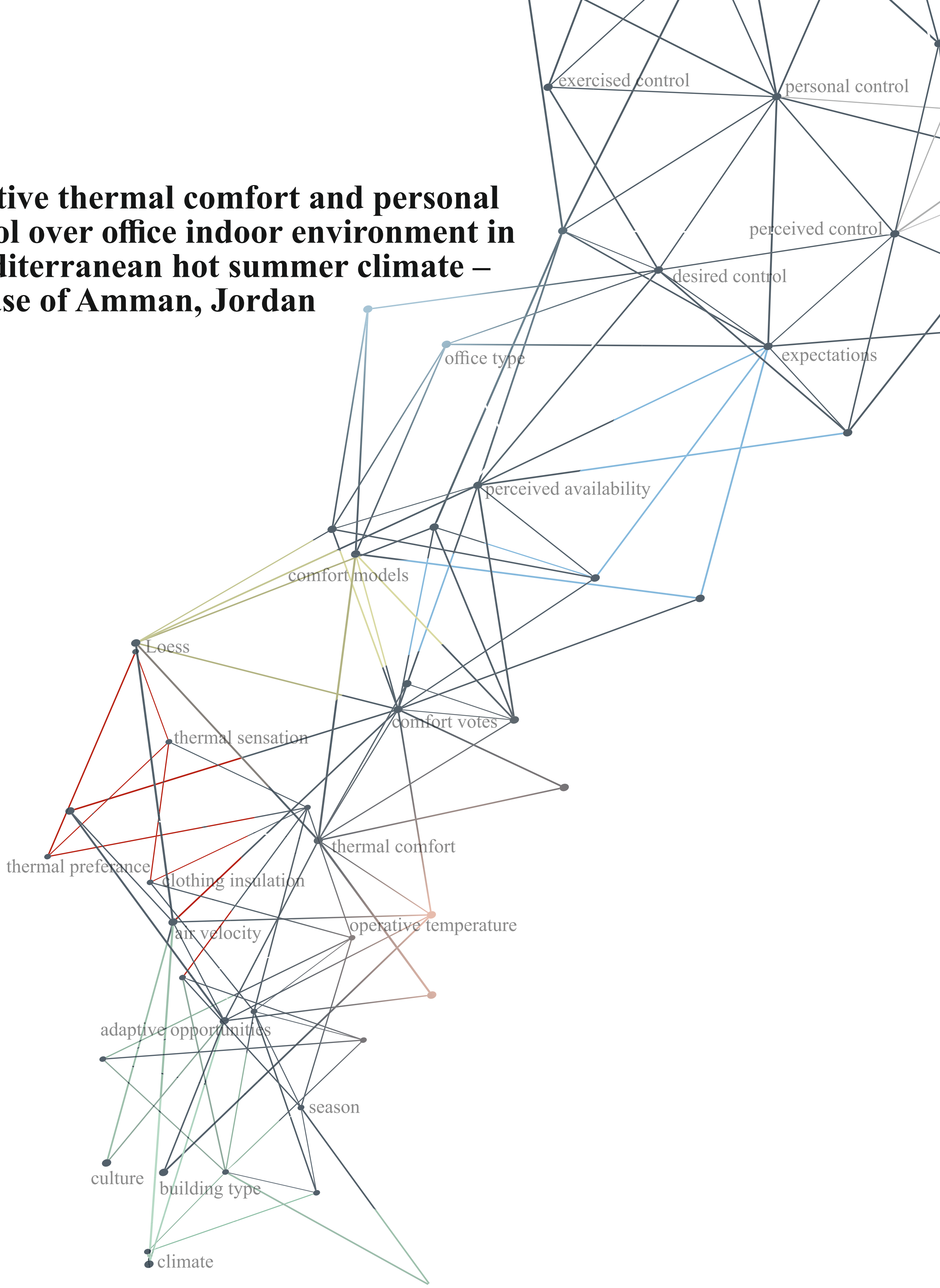
Adaptive thermal comfort and personal control over office indoor environment in a Mediterranean hot summer climate – the case of Amman, Jordan



PhD Dissertation

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Adaptive thermal comfort and personal control over office indoor environment in a Mediterranean hot summer climate – the case of Amman, Jordan

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Dissertation

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Kurzfassung

Zahlreiche Studien untersuchten thermische Behaglichkeit in unterschiedlichen Gebäudetypen und Umgebungen weltweit. Eine Untersuchung von thermischer Behaglichkeit in Bürogebäuden in Jordanien sowie von adaptivem Nutzerverhalten, vom thermischen Behaglichkeits-Temperaturbereich und von persönlicher Kontrolle wurde jedoch noch nie unternommen. Daher ist es das Ziel der vorliegenden Studie, die adaptive thermische Behaglichkeit und persönliche Kontrolle zu untersuchen und somit ein besseres Verständnis über das Innenraumklima in Bürogebäuden in Amman, der Hauptstadt Jordaniens, zu generieren. Die Studie basiert auf Langzeit-Feldversuchen, die in drei Bürogebäuden, nämlich zwei mixed mode Gebäuden und einem frei belüfteten Gebäude, zu vier verschiedenen Jahreszeiten durchgeführt wurden, nämlich im Zeitraum von Frühling 2016 (April) bis Winter 2017 (Januar/ Februar). Es nahmen 119 Gebäudenutzer an den Befragungen zum thermischen Behaglichkeits-Temperaturbereich teil; dabei wurden insgesamt 659 Fragebögen ausgefüllt.

Der erste Teil der Studie widmete sich der thermischen Behaglichkeit und zielte darauf ab, die internen und externen Faktoren für Adaptionsverhalten zum Zwecke der thermischen Behaglichkeit zu untersuchen sowie den thermischen Komfortbereich in den jeweiligen Jahreszeiten zu bestimmen. Des Weiteren wurden das wahrgenommene Wohlbefinden auf thermischen Wahrnehmungsskalen über die verschiedenen Jahreszeiten hinweg untersucht und die gewonnenen Ergebnisse mit vorhandenen adaptiven Modellen und Standards abgeglichen. Im Fall des frei belüfteten Gebäudes gab es Schwankungen der operativen Temperatur im Laufe der vier Jahreszeiten, während die Temperaturen in den mixed mode Gebäuden konstant zwischen 23°C und 24°C lagen. Die Nutzer fühlten sich zu einem hohen Prozentsatz in einem breiten Spektrum thermischen Empfindens von "kühl bis warm" wohl, und dies nicht nur im Fall einer "neutralen" Angabe zum thermischen Empfinden. Darüber hinaus variierte die wahrgenommene Behaglichkeit auf der Skala thermischen Empfindens über die Jahreszeiten hinweg, da die Nutzer es während des Sommers kühler und während des Winters wärmer bevorzugten. Daher konnten Komfortzonen aus den beobachteten operativen Temperaturen in Abhängigkeit der Angaben zum Komfort abgeleitet werden.

Im Falle der mixed mode Gebäuden, ergab eine Loess-Analyse von Behaglichkeitstemperatur und gleitender mittlerer Außentemperatur keine Beziehung zwischen den beiden Variablen, was sich aus den flachen Kurvenverläufen ergibt. Allerdings ist zu bemerken, dass die Kurven im Sommer in Richtung niedrigerer Werte der Behaglichkeitstemperatur verlaufen, nämlich ab ca. 22°C durchschnittlicher Außentemperatur. Im Gegensatz dazu wurde eine lineare Beziehung zwischen thermischer Behaglichkeit und gleitender mittlerer Außentemperatur für das frei belüftete Gebäude festgestellt, was das Konzept der Adaption je nach Außenklima widerspiegelt.

Allerdings veränderte sich die Kurve zu einer flachen Linie ab ca. 24°C gleitender mittlerer Außentemperatur, was darauf hindeutet, dass die Behaglichkeitstemperatur sich ab diesem Schwellenwert nicht weiter mit der Außentemperatur erhöht.

Der zweite Teil der Studie beschäftigte sich mit persönlicher Kontrolle am Arbeitsplatz. Das Ziel war die den Nutzern zur Verfügung stehenden Adaptionsmöglichkeiten zu analysieren. Dabei wurden Wechselbeziehungen zwischen wahrgenommener Verfügbarkeit und gewünschter Kontrollmöglichkeit untersucht. Außerdem wurde erhoben, wie oft diese Arten der Kontrollmöglichkeit genutzt wurden (ausgeübte Kontrolle). Darüber hinaus wurden die Gründe für das Nichtausüben zur Verfügung stehender Kontrollmöglichkeiten und die Auswirkung der Gebäudetypen und Jahreszeiten auf wahrgenommene Kontrollmöglichkeiten untersucht sowie der Einfluss von wahrgenommener Kontrolle auf das thermische Behaglichkeitsempfinden und Luftqualität bestimmt.

Im Rahmen eines longitudinalen und analytischen Ansatzes wurden neue Variablen eingeführt, nämlich die Konsistenz zwischen wahrgenommener und objektiver Verfügbarkeit sowie die Erwartungskonformität. Bedienbare Fenster und anpassbare Temperaturregler stellten die am meisten gewünschten Adaptionsmöglichkeiten dar. Als häufigster Grund für die Nichtnutzung der Adaptionsmöglichkeiten wurde 'keine Änderung nötig' genannt. Die Ergebnisse zeigen eine signifikante Korrelation zwischen Gebäudetypus und wahrgenommener Kontrollmöglichkeit, während hingegen keine signifikante Beziehung zwischen Jahreszeit und wahrgenommener Kontrolle gefunden wurde. Die wahrgenommene Kontrolle korreliert positiv mit dem thermischen Behaglichkeitsempfinden der Nutzer. Die in dieser Studie zur Anwendung gekommenen Ansätze und methodischen Analysen bieten die Möglichkeit für weitere Forschung auf ähnlichen Gebieten.

Abstract

Numerous studies have investigated thermal comfort in different building types and environments worldwide. However, there has never been an investigation into office thermal comfort, occupant adaptive behaviours, comfortable temperature zones and personal control in Jordan. This study aims to investigate adaptive thermal comfort and increase understanding of the role of personal control over indoor climate in office working environments located in Amman, the capital city of Jordan. The study is based on longitudinal field surveys which were conducted in three office buildings, two mixed mode buildings and a naturally ventilated building, over a period of four seasons starting from spring 2016, undertaken, in April until winter 2017, undertaken in January and February. A total of 119 occupants participated in the thermal comfort surveys and completed 659 questionnaires.

The first part of the study, which relates to thermal comfort, aimed to investigate the internal and external drivers that affect adaptive thermal comfort, determine the comfort temperature zones of the four seasons, compare the results developed from this study with other adaptive models and standards and investigate the perception of feeling comfortable on thermal perception scales over the different seasons. The free running building experienced a variation in operative temperature during the four seasons, while temperatures were around 23 to 24°C during all seasons in the mixed-mode buildings. Occupants felt comfortable in a broader range of thermal sensations ‘cool to warm’, not only in the case of a ‘neutral’ thermal sensation vote, and with high comfort percentages. Furthermore, the perception of feeling comfortable on the thermal sensation scale differed between the different seasons, as occupants preferred feeling towards the cool zone in summer and towards the warm zone in winter. Therefore, comfort zones were derived from the observed operative temperatures related to the comfort votes with respect to each season.

The loess analysis between the comfort temperature and the running mean outdoor temperature indicated no relation between the two variables in the mixed-mode buildings, as the curves were almost flat, but they evolved towards lower comfort temperature values in summer, at appr. 22°C running mean outdoor temperature. In the free running building, the curve had a linear relation between comfort and running mean outdoor temperature, which reflects the concept of adaptation to the outdoor climate, but the curve changed into a flat line at 24°C running mean outdoor temperature, indicating that the comfort temperature will not further increase with an increasing running mean outdoor temperature.

The second part of the study, which relates to personal control, aimed to analyse the adaptive opportunities available to the occupants, and the interrelations between perceived availability and desired control and also to map how often these controls were used (exercised control). It also aimed to analyse the reasons for not exercising the available adaptive opportunities, the effect of office types and seasons on perceived control and determine the impact of perceived control on thermal comfort perception and air quality.

A longitudinal analytical approach was applied, and new variables have been introduced: consistency of perceived and objective availability and conformity to expectation. Operable windows and adjustable thermostats were found to be the most desired adaptive opportunities. The most frequently stated reason for not exercising available adaptive opportunities was ‘no need to change’. The study found significant correlations between office types and perceived control. On the other hand, no significant correlation was found between seasons and perceived control. Perceived control correlates positively with occupants’ thermal comfort perception. The approaches and methods of assessment followed in this study can be applied for future similar research areas.

Dedicated to my beloved parents

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I wish to express my gratitude to all those involved directly and indirectly in the realization of this dissertation.

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Contents

1 Introduction

1.1 Problem statement

One of Jordan's most important and critical environmental issues is energy use. Unlike other countries in the Middle East, Jordan is a non-oil producing country. It is a net energy importer, importing 95% of its total energy, according to the Ministry of Energy and Mineral Resources (2016).

In recent years, the economic stress of dependence on imported energy has been aggravated by the rapid and significant increase in energy prices. Government, organizations, private and public sectors as well as individuals have to allocate more of their budgets to energy expenses (e.g. transportation, heating and cooling). Additionally, the Jordanian government has eliminated any subsidies on gas and other energy products to mitigate the impact of energy prices on the government budget (Ministry of Energy and Mineral Resources, 2016). Therefore, reducing the energy demand in buildings is currently a prime objective for the Jordanian government and Jordanians, to mitigate the impact of energy prices on the Jordanian economy. This will also reduce environmental pollution, through decreased greenhouse emissions, as energy is the largest contributor to emissions in Jordan according to the Ministry of Environment of Jordan (2009).

Furthermore, installation of air conditioning (AC) units has increased rapidly in the last few years, mainly due to improved living standards and rising global temperatures, combined with a higher frequency of heat waves. As a result, most buildings are now mixed mode building types, which use air conditioning split units or decentralised heating ventilation and air conditioning systems (HVAC) combined with natural ventilation. This has resulted in a continual increase in the primary energy demand, by 5.5% per year, together with a corresponding growth in the electricity generation capacity, 7.5% annually, according to the Ministry of Planning and International Cooperation (2013).

Codes related to energy efficiency have been developed to face the energy challenges that Jordan has recently encountered, e.g. the energy efficiency buildings code, solar energy code, thermal insulation code and the green building guideline. In addition, certified LEED buildings have appeared in the commercial sector to save energy. Despite drawing attention to developing energy efficiency codes and the appearance of internationally green certified buildings, there has not been a rigorous investigation into thermal comfort, occupant adaptive behaviours, comfortable zones of temperatures and personal control in Jordanian buildings.

Many studies have investigated thermal comfort and occupants' behaviour in different building types and environments worldwide. Interest and research into the "adaptive" theory of thermal comfort first began in the mid-70's, in response to the oil- price-shocks, and has recently regained importance due to increasing concerns over human impact on the global climatic environment (Humphreys, 1976) (Auliciems, 1981) (de Dear et al. 1997). Examples of international standards that have incorporated evaluative methods based on an adaptive approach are ANSI/ASHRAE Standard 55, which has been the standard in North America dealing with adaptive thermal comfort since 2004, (ASHRAE Standard 55, 2017), and the European Standard EN 15251 (EN 15251, 2007), which covers thermal comfort as well as other indoor environmental parameters. These adaptive approaches are used for the evaluation of thermal comfort in various environments, in which occupants interact with their thermal environment with a certain degree of control to achieve comfort, rather than just being passive recipients of the given thermal environment (Brager and de Dear, 1998).

Based on the adaptive theory, people play a powerful role in developing their own thermal preferences, which can be achieved either through the way they interact with their environment and modify their own behaviour, or because contextual factors and their past thermal history change their expectations and thermal preferences. There are several benefits to be gained from understanding the influence of adaptation on thermal comfort in the built environment. These include improved predictive models and standards, promoting opportunities for personal control, increased levels of thermal comfort and acceptability among occupants, as well as reduced energy consumption, and encouraging climate responsive building design (de Dear et al. 1997). Therefore, the ‘adaptive approach’ is expected to adequately reflect human thermal comfort in the investigated buildings in Jordan where occupants have adaptation opportunities, e.g. operable windows, operable indoor/ outdoor doors, blinds, fans, heaters, adjustable thermostats, and relatively flexible clothing insulation, allowing them to play an active role, by adjusting their behaviours and the surrounding thermal environment to make themselves more comfortable. Nevertheless, whether the comfort zone defined by the ASHRAE 55’s adaptive comfort standard or the EN 15251 standard can be directly applied to the building context in Jordan is somewhat questionable, as most modern buildings are mixed mode buildings. Furthermore, although personal control has a considerable impact on individual perception of and satisfaction with the indoor climate, little is known about which aspects are important to determine personal control (Gossauer & Wagner 2007, Boerstra et al., 2013, Hellwig 2015). Such aspects might include available adaptive opportunities, reasons for not exercising adaptive opportunities, office type, season, and occupants’ expectations, as well as the psychological issue of both the belief of having access to the adaptive opportunities and the effectiveness of having this access.

This study focused on investigating office buildings and personal control in offices in the capital city Amman, where most of the construction in Jordan has taken place in recent years, as a starting point for thermal comfort and occupant behaviour studies in Jordan.

1.2 Aims and Objectives

Drawing on the problem statement above, to the researcher's knowledge, no studies related to thermal comfort and occupant's behaviour have been previously conducted in Amman. This study mostly focuses on the adaptive thermal comfort and personal control over indoor climate in office buildings located in Amman. However, little is known about the behaviours undertaken by the occupants, their interactions with the adaptive opportunities they have to achieve thermal comfort, and the parameters affecting thermal comfort. To address these issues, this study aims to propose a framework to understand thermal comfort and personal control, based on building occupants' responses to the questionnaires developed for this study, which can be subsequently applied for future studies in a similar research surveys. The context of this research is set in office buildings under natural settings while participants perform everyday activities.

The aims of the study are as follows (Figure 1-1):

- to investigate thermal comfort and the applicability of the adaptive models in office buildings located in Jordan, specifically Amman.
- to increase understanding of personal control in office workplaces.

The first aim above was converted into the following objectives:

- to investigate the internal and external drivers that affect adaptive thermal comfort;
- to determine the comfort temperature zones of the four seasons;
- to compare the results obtained from this study with those obtained from other adaptive models;
- to investigate the perception of feeling comfortable with the thermal sensation scale, since feeling comfortable on the same thermal sensation vote might differ between the different seasons.

The second aim of the thesis was translated into the following objectives:

- to analyse the adaptive opportunities available for the occupants, how they perceive these adaptive opportunities (perceived control), and their desire to have these opportunities (desired control),
- to map how often the adaptive opportunities were used (exercised control),
- to analyse the reasons for not exercising available adaptive opportunities,
- to analyse the effect of office types and seasons on perceived control,

- to determine the impact of perceived control on thermal comfort and air quality perception.

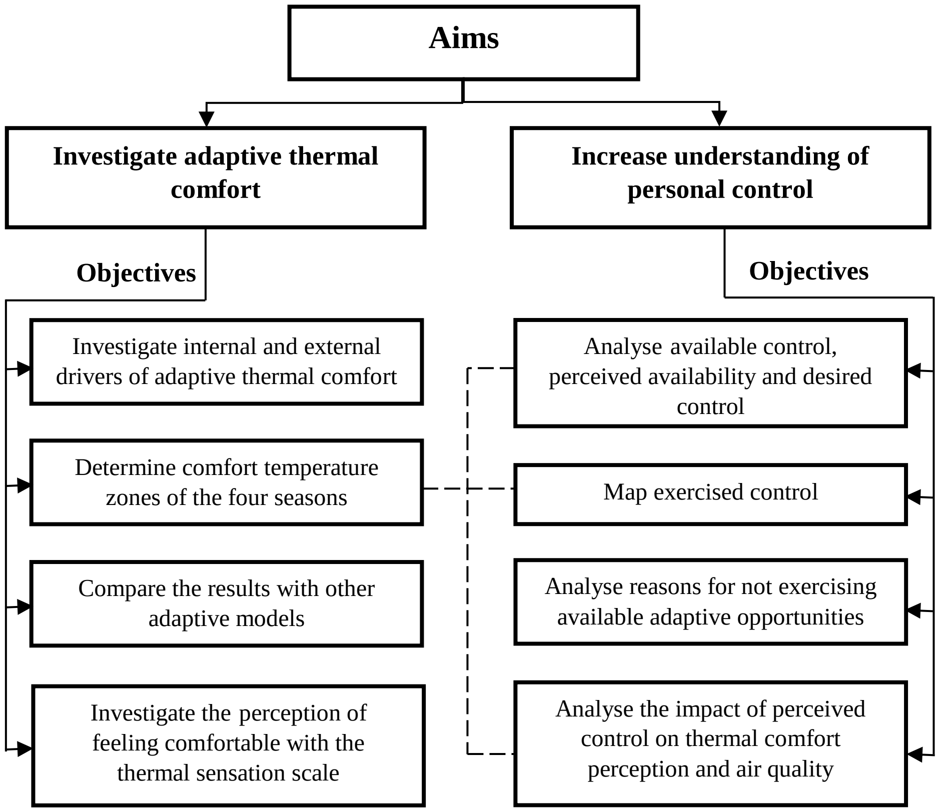


Figure 1-1 Diagram of aims and objectives of the thesis.

1.3 Thesis Structure

This thesis has been structured in order to achieve the aims and objectives mentioned above. The thesis is organised in the following way (Figure 1-2):

Chapter 1 Introduction

The present chapter has presented the background and problem statement of the study together with the aims and objectives of the research.

Chapter 2 Literature review

Chapter 2 provides an overview of the research setting, and current knowledge in the field. It is divided into two main parts: the first part is devoted to a review of recent studies and research related to thermal comfort, thermal comfort approaches, and adaptive thermal comfort standards and data bases. The second part reviews the existing research on personal control and covers important issues and aspects related to personal control over indoor climate.

Chapter 3 Research approach and methodology

This chapter describes the research approach used to achieve the proposed aim and objectives. It describes the case studies which have been chosen in this study, as well as the occupant sample of the study. It also describes the main methods and tools of data collection which were employed in order to reach the aims, including measurements of individual parameters, questionnaires and instrumentation. Furthermore, it explains the statistical analysis applied in the research.

Chapter 4 and chapter 5 Results

These chapters report the results and analyse of the study. The results are divided into two main chapters in order to address the main objectives of the research. The first chapter covers analyses related to thermal comfort while the second focuses on personal control over indoor environment.

Chapter 6 Discussion

This chapter is based on the results of the investigations in the previous chapters and discusses these results in relation to the literature reviewed in Chapter 2.

Chapter 7 Conclusion

Chapter 7 summarises the combined findings, identifies their limitations, examines their implication for standards and finally offers recommendations for future research.

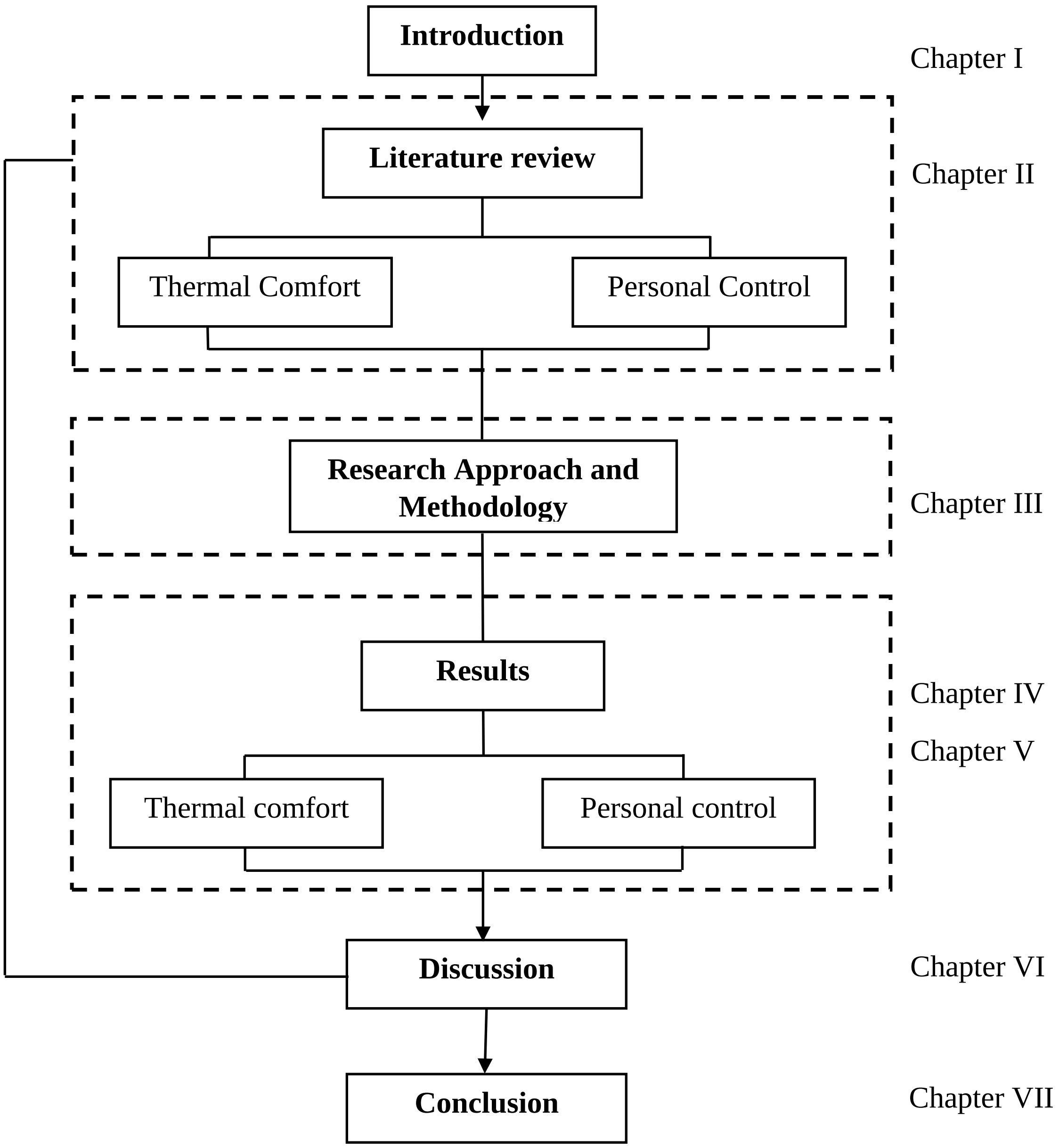


Figure 1-2. Diagram of the structure of the thesis.

2 Literature

The aim of this chapter is to review the theory of thermal comfort and personal control within buildings, in particular, offices. This chapter explores the fundamental principles of thermal comfort, summarises existing approaches and provides an overview of the main standards developed to date. It provides a background, and an overview of the research and studies undertaken, together with the historical development of the area of personal control over indoor climate. The chapter includes four sub-sections: the first is a literature review of thermal comfort and the second section covers the revised thermal comfort approach. The third section explains the adaptive thermal comfort standards and databases, while the fourth section reviews the existing research on personal control.

2.1 Thermal comfort

In economically developed countries, most people spend at least 80% of their time indoors, therefore the quality of the indoor environment has a great impact on occupants' comfort, health, productivity, and overall sense of well-being (de Dear et al., 1997). This means achieving a high quality of indoor environment has become a dominant issue in architectural design. Thermal comfort is one of the most important aspects of the quality of the indoor environment and has thus gained a great deal of interest from many researchers in investigating the occupants' thermal comfort in order to improve the indoor environment conditions.

2.1.1 Definition of thermal comfort

An internationally accepted definition of thermal comfort used by the ASHRAE standard 55 is 'that condition of mind which expresses satisfaction with the thermal environment' (ASHRAE 55, 2004). However, this definition appears to have prompted controversy, due to its lack of precision and has been subject to several criticisms. Heijs (1994) points out that the definition has not clearly defined the 'condition of mind', which could be the consequence of either a process of perception or a state of knowledge or a common feeling or attitude based on a psychological point of view. It might also vary from one person to another in different forms of behaviours and feelings of wellbeing. Furthermore, he argues that considering comfort as a subjective mental state will make it indefinable, as it relates to many objective features which are difficult to measure and is continuously changing, depending on various factors. Accordingly, he suggested that thermal comfort should be considered as "an environmental property, determining the satisfaction of thermal needs both physiologically and psychologically". This environmental property relates to thermal climate, thermal environment and thermal control. However, Mayer (1993) also argued whether the 'satisfaction with the thermal environment' is an objective criterion.

Thermal comfort has been defined by researchers in several ways. For example, Benzinger (1979) defined thermal comfort as ‘a state in which there are no driving impulses to correct the environment by behaviour’, while Markus & Morris (1980) defined it as ‘that state in which a person will judge the environment to be neither too cold nor too warm— a kind of neutral point defined by the absence of any feeling of discomfort’. However, Evans (1980) emphasised that it is a subjective sensation: ‘there is no such thing as a perfect combination of conditions for comfort since it is not possible to satisfy everyone at the same time; even when the optimum thermal conditions are achieved, only 50 to 70% of the population may feel comfortable, with the remainder feeling either slightly warm or slightly cool’. Limb (1992) defined thermal comfort as ‘a condition of satisfaction expressed by occupants within a building to their thermal environment’. In agreement with this, Givoni (1998) stated that thermal comfort refers to ‘the range of climatic conditions considered comfortable and acceptable inside buildings’. Bischof et al. (2007) analysed data from ProKlimA study-phase II to investigate the effect of extra-thermal parameters on thermal sensation and thermal comfort. They found that the nonenvironmental factors affect thermal comfort but have almost no influence on thermal sensation.

Based on these definitions, it can be suggested that thermal comfort is influenced by individual differences which are affected by physical, physiological, psychological, cultural, and social factors, among others. As a result, there is no absolute value of thermal comfort, but it will be relative to a comfort zone within the surrounding thermal environment which depends on the individual’s experience and expectations, as well as the thermal climate.

2.1.2 Importance of Thermal Comfort Research

According to Nicol (1993), there are three reasons for the importance of thermal comfort research in buildings. Firstly, to deliver satisfactory conditions for occupants; secondly, to control energy consumption and consequently, to propose and set standards for such thermal circumstances.

Thus, Raw & Oseland (1994) identified six advantages from conducting research in the area of thermal comfort:

1- increasing opportunity for personal control,
2- improving the internal air quality,
3- achieving energy savings,
4- reducing the harm to the environment by reducing CO_2 production,
5- enhancing the efficiency of the building’s occupants,
6- improving or changing standards based on reasonable recommendations.

All elements of buildings need to be designed to respond to the climate and to provide comfortable conditions for occupants, because, in general, human comfort levels will be at their peak when they are in their optimum state and they will decrease in an unfavourable climate (Hunting, 1951).

Parsons (1993) suggests several consequences of not achieving thermal comfort, including the effect on health and productivity and reducing morale which may result in workers refusing to work in an uncomfortable environment. For these reasons, since the twentieth century, and often before that period, there has been an active interest in research into the conditions that produce thermal comfort. The main emphasis has been to understand the conditions which produce thermal comfort, acceptable thermal environments and satisfaction for the occupant.

2.1.3 Thermal comfort parameters

Gagge (1936) was the first to apply the law of thermodynamics between human body and his environment. He introduced the ‘Two-node model’ which assumes that the sum of convection, radiation, evaporation, and storage must equal in magnitude the energy metabolism. His work has a remarkable impact in the fields of thermal comfort.

Various authors, Fanger (1972), McIntyre (1980) and Gagge (1986), agree on six basic parameters that directly affect the human perception of thermal comfort, which can be divided into four basic environmental variables and two personal parameters. These are defined and described as follows.

Environmental parameters

The four environmental parameters are air temperature, mean radiant temperature, air velocity and relative humidity.

Air temperature is the most important environmental parameter. It refers to the temperature of the air that a person is in contact with. Air velocity affects the exchange of heat between the person and the air, the faster the air is moving, the greater the heat exchange (convection). The humidity of the air affects evaporative cooling. The higher the relative humidity, the more difficult it is to lose heat through the evaporation of sweat. The mean radiant temperature is a weighted average of the temperature of the surfaces surrounding a person. These factors will be explained in detail in section 3.6.

Personal parameters

Personal parameters are activity level or metabolic rate M (units: 1 met = 58 W/m^2) and clothing insulation I_{cl} (units: 1 clo = 0.155 $m^2.K/W$) (ASHRAE 55, 2017).

Metabolism is a biological process performed by the human body to obtain the energy needed from food and store it as chemical energy. This process generates energy for human activities. If work or physical activity are performed, most of the energy released is in the form of heat and mechanical work. The rate of this transformation per unit of skin surface area is called the ‘metabolic rate’ which increases in order to produce the energy needed for the various physical activities. The energy required for mechanical work will vary from about zero for many activities to no more than 25% of the total metabolic rate. The metabolic rate depends on the activity level, age, and sex, and is proportionate to the weight and size of the body (Parsons 2003). The method for the estimation and determination of metabolic rate in this study is described in section 3.6.

Clothing insulation is a property of the clothing itself, representing the resistance to heat transfer between the skin and the clothing surface. The rate of heat transfer through clothing is affected by conduction, which depends on the surface area (m^2), the temperature gradient (K) between the skin and clothing surface and the thermal conductivity $W/(m^2.K)$ of the clothing (Parsons, 2003).

The Clo unit was first suggested by Gagge et al. (1941) to replace the physical unit with something visually easier to explain and related to clothing worn over the whole human body. One Clo is the thermal insulation required to keep a sedentary person comfortable at 21°C, where 1 clo is equivalent to 0.155 m^2K/W and represents the insulation of a typical business suit. It is important to note that the Clo value gives an estimate of insulation as if any clothing were distributed evenly over the whole body.

Furthermore, clothing has an important role in the behavioural adaptations of individuals, as it is often modified and adapted according to the changes in seasons and outdoor weather conditions and differs also among cultures (Humphreys et al., 2015). The method for the determination and estimation of clothing insulation values is described in section 3.6.2.

2.2 Thermal comfort approach

The two main approaches to thermal comfort, which are the rational or heat balance approach and the adaptive approach, will be reviewed in the following sections. The heat balance approach is based on laboratory and chamber studies, while the adaptive approach derives from field studies.

2.2.1 The heat balance approach

The heat balance approach is based on physical and physiological properties and undertaken in controlled laboratory conditions (Gagge, 1936). The most notable model is that of Fanger (1970). The heat balance approach is based on the fact that a human being needs to maintain a constant core temperature of 37^{o}C, where relatively small changes in this temperature represent a threat to health and even life. In order to maintain this temperature within the appropriate limits, humans have a complex system to regulate the body temperature. The body interacts with its surrounding environment by generating and exchanging the internal heat through evaporation, radiation and conduction (Fanger, 1970). Fanger defines the conditions in which the whole-body will be in thermal comfort thus: the body should be in heat balance, sweat rate is within comfort limits; and mean skin temperature is within comfort limits.

The heat balance of the human body during the heat exchange with the surrounding environment can be expressed by the following equation.

$$M - W = E + R + C + K + S \qquad \textit{Equation 2-1}$$

where,

M = rate of metabolic heat production, Wm^{-2}

W = rate of mechanical work accomplished, Wm^{-2}

E = rate of evaporation heat loss from skin and respiration, Wm^{-2}

R = rate of radiation heat loss from skin, Wm^{-2}

C = rate of convection heat loss from skin and respiration, Wm^{-2}

K = rate of conduction heat loss through clothing, Wm^{-2}

S = rate of heat storage in the skin and core, Wm^{-2}

The thermal equilibrium maintained at a normal level of mean body temperature represents zero or low physiological strain. Insufficient heat loss to the body results in the body overheating (hyperthermia) while excessive heat loss from the body leads to body overcooling (hypothermia). The concept behind this heat balance equation was used by Fanger (1972) to establish the predictive mean vote (PMV) model. Predicted Mean Vote (PMV) is a method to measure the level of occupant thermal sensation. It is often translated into Predicted Percentage Dissatisfied (PPD), which is a measure used for benchmarks (Equation 2-2).

$$PPD = 100 - 95 * e^{-(0.03353*PMV^4+0.2179*PMV^2)} \qquad \textit{Equation 2-2}$$

Fanger's Predicted Mean Vote (PMV) model was derived from laboratory and climate chamber studies. In these studies, participants were dressed in standardised clothing and completed standardised activities, while exposed to different thermal environments. A seven-point thermal comfort scale is used to describe PMV, ranging from (-3) cold to (+3) hot as shown in Table 2-1 while Table 2-2 shows predicted percentage dissatisfied (PPD), based on the predicted mean vote. This approach is described in ASHRAE 55, EN15251 and ISO 7730.

Table 2-1. ASHRAE seven-point thermal sensation scale (ASHRAE Standard 55 2004, ISO 7730:2005).

cold	cool	slightly cool	neutral	slightly warm	warm	hot
-3	-2	-1	0	+1	+2	+3

Table 2-2. Predicted percentage dissatisfied (PPD), based on the predicted mean vote (ISO 7730:2005, Annex A).

comfort	PPD	range of PMV
Cat. A	<6	-0.2<PMV<0.2
Cat. B	<10	-0.5<PMV<0.5
Cat. B	<15	-0.7<PMV<0.7

2.2.2 The adaptive approach

The adaptive comfort theory was first proposed in the 1970s in response to the oil crisis and has gained importance due to increasing attention to human impact on the global climatic environment. It is based on the idea that people play an important role in creating their own thermal preferences through the way they interact with the environment, or adjust their own behaviour, or because their past thermal history has changed their expectations and thermal preferences (de Dear et al., 1997). Adaptive models are derived from statistical analysis of empirical field survey results, and suppose that occupants' preferred indoor temperature varies with outdoor conditions (Humphreys, 1976; Auliciems, 1981). The adaptive approach to thermal comfort proposes that occupants' behaviour may vary according to different factors which are beyond the fundamental physics and physiology, such as demographics (gender, age, economic status), context (building design, building function, season, climate, semantics, social conditioning), and cognition (attitude, preference, and expectations) (de Dear et al., 1997).

According to de Dear et al. (1997), three categories of adaptation can be distinguished as follows: behavioural adjustment, physiological adaptation and psychological adaptation.

1- Behavioural adjustment

This includes all conscious or unconscious modifications a person might make to modify the heat and mass fluxes controlling the body's thermal balance. It has three sub-categories as follows:

- personal adjustment: adjusting to the surroundings by changing personal variables, such as adjusting clothing, activity level, eating/ drinking hot/cold food or beverages or moving to another location;
- environmental adjustment: modifying the surroundings themselves, when control is available, such as opening/ closing windows or blinds, turning on fans or heating, operating HVAC controls, etc.;
- cultural adjustments: including scheduling activities, afternoon rest and dress codes.

2- Physiological adaptation

Physiological adaptation refers to all changes in the physiological responses which result from exposure to thermal environmental factors and which lead to a gradual reduction in the strain induced by such exposure. It can be divided into two subcategories:

- genetic adaptation: alterations which become part of the genetic heritage of an individual or group of people, but developing at time scales beyond that of an individual's lifetime;
- acclimatization: changes in the physiological thermoregulation system over a period of days or weeks by exposure to thermal environmental stressors, leading to a gradually declining strain from such exposure.

3. Psychological adaptation

This refers to an altered perception and reaction to sensory information. Thermal perceptions are directly and significantly attenuated by an individual's experiences and expectations of the indoor climate. This adaptation involves building occupants' "comfort setpoints", which may vary across time and space.

The adaptive principle links the comfort temperatures to the context in which occupants find themselves. Comfort temperatures are a result of the interaction between the occupants and the thermal environment they are occupying.

In general, the adaptive models are essentially in the form of a regression equation which relates indoor comfortable ranges of temperature to outdoor climatological parameters. The main input of the adaptive models is the outdoor temperature, as comfort temperature range can then be determined. Since adaptive models are based mainly on occupants' behaviour and outdoor climate conditions, they depend on conducting thermal surveys in real buildings. From extensive databases (de Dear et al. 1997, McCartney & Nicol 2002) of past field studies, adaptive comfort models and standards have been proposed to calculate the optimum comfort temperature as:

$$T_c = C * T_{a, out} + D \qquad \textit{Equation 2-3}$$

where T_c is comfort temperature °C; $T_{a, out}$ is outdoor air temperature °C; and C and D are constants.

Adaptive models are used as part of several standards, including ASHRAE Standard 55, EN15251. These standards will be explained in the following sections.

2.2.3 Comfort zone

ASHRAE standard (2004) defines the thermal zone as the range of operative temperatures that provide acceptable thermal environmental conditions or in terms of the combinations of air temperature and mean radiant temperature that occupants find thermally acceptable. Accordingly, the comfort zone may be determined from given values of humidity, air speed, metabolic rate, and clothing insulation.

Based on this definition, if great effort is required to adjust the surroundings or the person's physiological responses, this indicates a lower level of comfort with the thermal conditions. Where no adjustment or less effort is needed, this reflects more thermal comfort is being experienced. This range of temperatures is also affected by many other psychological and physiological factors which are beyond physiology and physics, such as culture, expectation, etc. as mentioned above.

Comfort is a subjective experience; therefore not all occupants are likely to agree on the optimal comfort temperature. To overcome this, it is necessary to define some kind of 'comfort zone'. The main factors which should be addressed to determine the comfort zone are air temperature, radiant temperature, relative humidity, air velocity, clothing insulation and metabolic rate (ASHRAE standard 55, 2004). De dear and Brager (2002) mentioned that '*Satisfaction is associated with thermal sensations of ''slightly warm'', ''neutral'', and ''slightly cool''.*' These votes are represented in the middle part of the thermal sensation scale. The level of a respondent's thermal sensation is the most commonly asked question in both laboratory and field studies of thermal comfort (de Dear & Brager 2002). A number of scales have been developed; some of these are shown in Table 2-3.

Table 2-3. Thermal sensation scales. Source (Rosenlund 2000).

	ASHRAE	Fanger	Rohles & Nevins	Gagge's DISC	SET* (°C)
painful			+5	+5	
very hot			+4	+4	37.5-
hot	7	+3	+3	+3	34.5 – 37.5
warm	6	+2	+2	+2	30.0 – 34.5
slightly warm	5	+1	+1	+1	25.6 – 30.0
neutral	4	0	0	± 0.5	22.2 – 25.6

slightly cool	3	-1	-1	-1	17.5 – 22.2
cool	2	-2	-2	-2	14.5 – 17.5
cold	1	-3	-3	-3	10.0 – 14.5
very cold			-4	-4	

*SET: Standard effective temperature.

The convention used in ASHRAE standard 55 is that comfort temperature is the operative temperature at which either the average person will be thermally neutral or at which the largest proportion of a group of people will be comfortable. A person in comfort is taken to be one who is ‘slightly cool’, ‘neutral’ or ‘slightly warm’ on the ASHRAE scale.

Equation 2-4 shows the relationship between TSVs and operative temperature through regression analysis, as defined in the ASHRAE 55 standards. In comfort studies, the gradient of the regression model is typically interpreted as being inversely related to occupants’ thermal adaptability. In other words, the steeper the regression line is, the more sensitive (or the less tolerant) the occupants are to temperature variations (de Dear et al. 2018).

$$TSV = A * T_{op} + B \qquad \textit{Equation 2-4}$$

where TSV is the thermal sensation vote, T_{op} is the operative temperature, A is the regression coefficient and B is a constant.

2.3 Adaptive thermal comfort standards and databases

The adaptive approach is described and explained in several standards which were obtained from intensively conducted field studies from various climatic zones.

EN 15251 is the commonly-used standards for evaluating thermal comfort in Europe. The American society of heating, refrigerating, and air conditioning engineers (ASHRAE) Standard 55 was developed for thermal environmental conditions for human occupancy. This internationally practiced standard deals with thermal comfort. The ASHRAE 55 and EN 15251 standards, together with the main databases related to adaptive thermal comfort, are introduced in this section.

2.3.1 ASHRAE Standard 55

ASHRAE Standard 55 (thermal environmental conditions for human occupancy) was the first international standard to include an adaptive component. It is based on extensive global field surveys assembled in ASHRAE project RP884 (de Dear et al., 1997).

The ASHRAE Standard 55 was developed from findings from different field surveys. As de Dear and Brager (2002) point out, integrating the findings from research into a thermal comfort standard is a different process from conducting the research itself. Guidelines and standards must balance scientific evidence and academic interest with practical experience and expert ruling. The ASHRAE Committee (SSPC 55) responsible for revising this standard was very diverse, representing stakeholders, building owners and users, and researchers. The first published standard which included the concept of adaptation was Standard 55-2004 which was a revision of Standard 55-1992. The main changes included the addition of the PMV/PPD calculation methods and the concept of adaptation. The purpose of ASHRAE Standard 55 is '*to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space*' (ASHRAE standard 55, 2004). As mentioned above, the adaptive theory is based on the idea that occupants are not passive in relation to their environment but tend to make themselves comfortable by making adjustments to their clothing, activity, and their thermal environment. The adaptive thermal model in this standard was derived from a global database of 21,000 measurements taken primarily in office buildings. The standard uses the relationship between indoor operative temperature and outdoor temperature, as shown in Figure 2-1 which includes the acceptable operative temperature ranges. The figure includes two ranges, one for 80% acceptability and the other for 90% acceptability. The 80% range is for typical applications while the 90% range is applicable when higher standards of thermal comfort are desired (ASHRAE standard 55, 2017).

$T_{op} = 17.8 + 0.31 * t_{pma\,(out)}$ *Equation 2-5*

where: T_{op} is the indoor operative temperature (°C), and $t_{pma\,(out)}$ is the prevailing mean outdoor air temperature

There are two ranges:

90% acceptability limit: $t_o = 0.31 * t_{pma\,(out)} + 17.8 \pm 2.5$

80% acceptability limit: $t_o = 0.31 * t_{pma\,(out)} + 17.8 \pm 3.5$

The 90% acceptability limit was determined by solving the regression equation for TSV of ± 0.5 and ± 0.85 for 80% acceptability limits. The logic behind this definition was directly derived from Fanger's PMV-PPD relationship, in which PPD reaches 10% when the group mean thermal sensation, PMV, equals ±0.5, and 20% when the group mean thermal sensation (PMV) equals ±0.85 (Fanger, 1970).

Applying these criteria produced a comfort zone band of 5 K for 90% acceptability, and 7 K for 80% acceptability (de Dear & Brager, 2002).

This model is applicable for $t_{pma\,(out)}$ ranging from 10°C to 33.5°C.

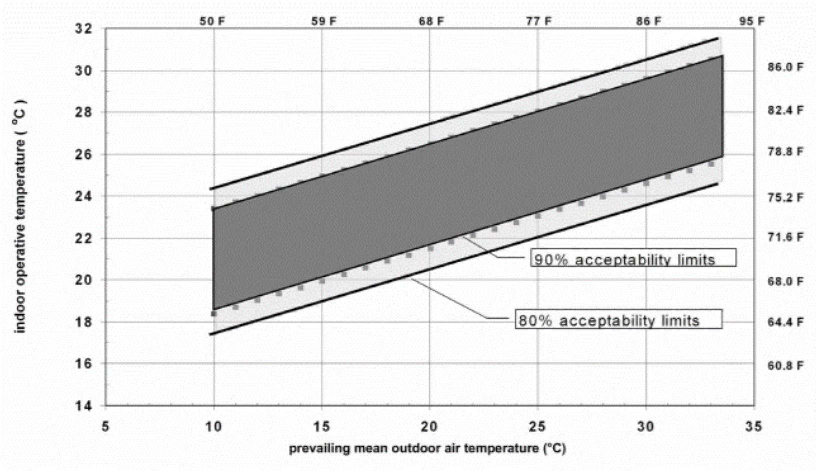


Figure 2-1. Acceptable operative temperature ranges. Source: ASHRAE 55, 2017.

2.3.2 EN 15251

The European standard EN15251 specifies indoor environmental input parameters for design and assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting and acoustics. It is applicable mainly in non-industrial buildings, such as single-family houses, apartment buildings, offices, educational buildings, hospitals, hotels and restaurants and sports facilities where the criteria for indoor environment are set by human occupancy and where the process does not have a major impact on the indoor environment. It determines methods for long term evaluation of the indoor environment achieved as a result of calculations or measurements. This standard does not define design methods but provides input parameters to the design of buildings' heating, cooling, ventilation and lighting systems. It was adopted to define acceptable indoor temperatures as the basis for energy calculation. It depends on extensive information from field surveys and the results of the SCATs project (McCartney & Nicol 2002) to define a comfortable range of indoor temperature according to outdoor climatic conditions. This standard defines three categories of buildings, according to the occupants' level of expectations. Table 2-4 shows these categories and their related limits of the comfort zones (EN 15251, 2007).

Table 2-4. Suggested applicability for the categories and their associated acceptable temperature ranges.

category	description	limits of the comfort zones
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements, such as those who are handicapped, sick, very young children and elderly persons.	$t_o = 0{,}33\ T_{rm} + 18{,}8 \pm 2$
II	Normal level of expectation for new buildings and renovations	$t_o = 0{,}33\ T_{rm} + 18{,}8 \pm 3$

III	Acceptable, moderate level of expectation (may be used for existing buildings)	$t_o = 0{,}33\ T_{rm} + 18{,}8 \pm 4$
IV	Values outside the criteria for the above categories. It is only acceptable for limited periods.	

In this table, t_o is the operative temperature (°C) and T_{rm} is the running mean outdoor over the previous seven days (°C). This method gives higher weightings on recent days and is calculated as follows:

$$T_{rm} = (1 - \alpha)\left\{T_{d-1} + \alpha\, T_{d-2} + \alpha^2\, T_{d-3} \ldots\right\}$$ *Equation 2-6*

T_{d-1} represents the mean daily outdoor air temperature for the previous day of the survey. α is a constant between 0 and 1 and it is recommended to use a value of 0.8.

This model is applicable when occupants are engaged in nearly sedentary physical activities (1 to 1.3 met), with running mean temperature 10°C to 30°C for the upper limit of acceptable temperature and from 15°C to 30°C for the lower limit.

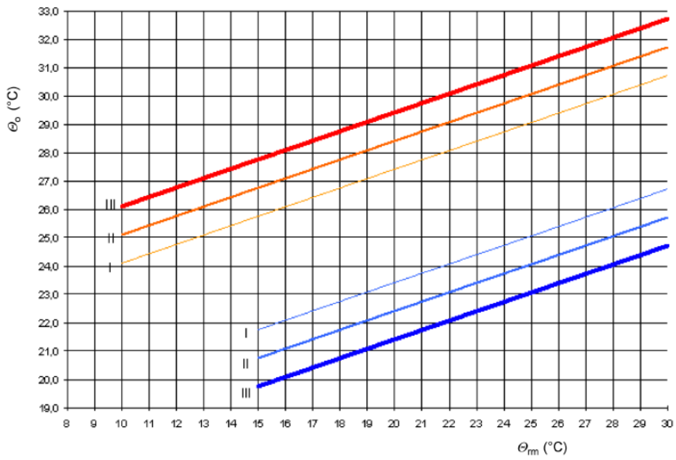


Figure 2-2. Acceptable indoor operative temperature ranges depending on the running mean outdoor temperature. Source: EN 15251, 2007.

2.3.3 ASHRAE RP 884

In the mid-1980s, ASHRAE began funding thermal comfort research which focused on field studies conducted in real buildings, occupied by real subjects going about their normal day-to-day activities. They followed a standardized protocol developed in ASHRAE RP-462. Since that time, both physical and subjective thermal comfort data have been collected from field studies by researchers adopting the same or similar procedures. In 1995, ASHRAE RP-884 began collecting raw field data from several projects around the world that had followed this standardized protocol. This led to collecting a high-quality database which contains approximately 21,000 sets of raw data from 160 different office buildings located on four continents, and covering a wide spectrum of climate zones (de Dear & Brager 2002).

The RP 884 template was divided into the following groups of variables:

- basic identifiers such as building code, subject personal information and date;
- thermal questionnaire including sensation, acceptability and preference scales, as well as activity, metabolic rates, clothing and chair insulation;
- indoor climate physical parameters such as: air temperature, globe temperature, air velocity, relative humidity and plane radiant asymmetry temperature.
- calculated indices such as operative temperature, predicted mean vote and predicted percentage dissatisfied;
- personal environmental control, including questions about perceived control and specific adaptive opportunities like windows, internal doors, external doors, thermostats, curtains/blinds, local heaters and fans;
- outdoor climatic data including outdoor temperatures and relative humidities (de Dear et al., 1997).

The adaptive model findings by RP-884 led to the development of the adaptive thermal comfort model in ASHRAE Standard 55.

2.3.4 SCATs Project

The Smart Controls and Thermal Comfort (SCATs) project ran from December 1997 to December 2000 (McCartney & Nicol 2002). It was funded by the European Union. It was based on conducting thermal comfort surveys in five offices in each of five European countries, London in the UK, Athens in Greece, Lisbon/Porto in Portugal, Lyon France and Malmö Gothenburg in Sweden. There was also a variety of buildings' function, construction, size and use.

The main aim of the project was to save energy by implementing variable indoor set-point temperatures for buildings, based on the theory of adaptive thermal comfort and developing control systems for both air-conditioned and naturally ventilated buildings that would incorporate the adaptive algorithm. It was also aimed to encourage the use of naturally ventilated buildings, which typically use less energy through the development of control systems for indoor temperature which use this adaptive effect.

It was planned that the buildings would be a mixture of "Air Conditioned" and "Naturally Ventilated" but it was hard to achieve that in all countries. In Sweden it was impossible to find buildings with no air conditioning; in France all office buildings must by law be mechanically ventilated, though not necessarily cooled; in Greece it was difficult to locate office buildings with no cooling in summer, although few buildings were centrally air conditioned and in Portugal few offices were air conditioned.

In total, 800 subjects yielded 4,655 sets of comfort votes and environmental readings were collected over the 12 months of surveys. Two types of questionnaire were used in the field studies: transverse and longitudinal. The questionnaires were developed in English and were translated into French, Greek, Portuguese and Swedish.

- The subjects were asked to give a subjective assessment of:
- Temperature - comfort vote (7-point scale) and preference (5-point scale);
- Air movement - comfort vote (7-point scale) and preference (5-point scale);
- Humidity -comfort vote (7-point scale) and preference (5-point scale);
- Lighting - comfort vote (7-point scale) and preference (5-point scale);
- Noise - comfort vote (7-point scale) and preference (5-point scale);
- Air quality vote (7-point scale);
- Overall comfort (6-point scale);
- Perceived productivity (5-point scale).

Information about clothing insulation and activity over the last hour, as well as the use being made of controls – doors, heating/air conditioning, windows, blinds, lights, fans – at the time of the survey were collected.

The following environmental parameters were measured: Air temperature, globe temperature, relative humidity, air velocity, illuminance, noise level and CO_2 concentration.

The adaptive control algorithm was derived from the following procedure: the comfort temperature was calculated according to Equation 2-7. Globe temperature was used as an approximation of the operative temperature.

$$T_c = T_g – 2(CV - 4) \qquad \textit{Equation 2-7}$$

where T_C is comfort temperature, T_g is globe temperature and CV is comfort vote from the ASHRAE scale, based on the ASHRAE scale numbered from 1 to 7 (cold to hot) and a comfort temperature which occurs at point 4, when the comfort vote is ‘neutral’.

Then the indoor comfortable operative temperature was plotted for all countries against the running mean outdoor temperature. Figure 2-3 shows the Lowess line, which is an exploratory method which can be used to determine the overall structure of a relationship. It can be seen that an approximately constant value of Tc is predicted for T_{rm} less than 10°C. With T_{rm} > 10°C, the comfort temperature follows an approximately linear relationship.

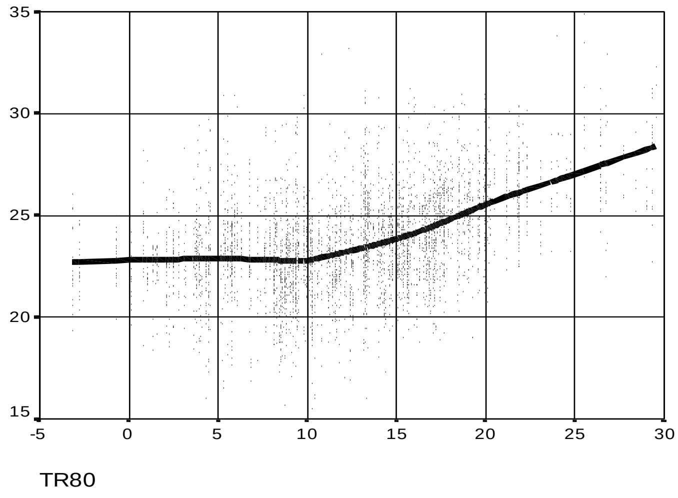


Figure 2-3. Change of the indoor comfortable operative temperature with running mean temperature (50% and three iterations). Source: (McCartney & Nicol, 2002).

According to Figure 2-3 the comfort temperature can be taken as a constant if the running mean outdoor temperature is below 10°C. Applying regression analysis on the data presented above yields the following:

$T_c = 22.9\ ^{\circ}C$ for $T_{rm} < 10^{\circ}C$ *Equation 2-8*

$T_c = 0.302 * T_{rm} + 19.39$ for $T_{rm} > 10^{\circ}C$ *Equation 2-9*

where T_{rm} is the running mean temperature with $\alpha = 0.80$.

The above analysis was repeated separately for each of the five countries. The overall shape of the regression appeared to be quite robust, as little change occurs in Tc with outdoor temperature when outside temperature is below 10°C, followed by a general increase when outside temperature is above 10°C. However, each country seems to have a different characteristic shape. The data from Portugal and Sweden seem to have no kink at 10°C. For Portugal, the occupants continued to adapt at cold temperatures; however, an average outside temperature of less than 10°C is rare. Greece has no records, as the running mean outside temperature did not fall below 10°C. All buildings related to Sweden used in the study had closely controlled air-conditioning systems, which may have reduced the level of adaptive behaviour. The UK has slightly more kink, while France is very close to the overall shape, as shown in Figure 2-4.

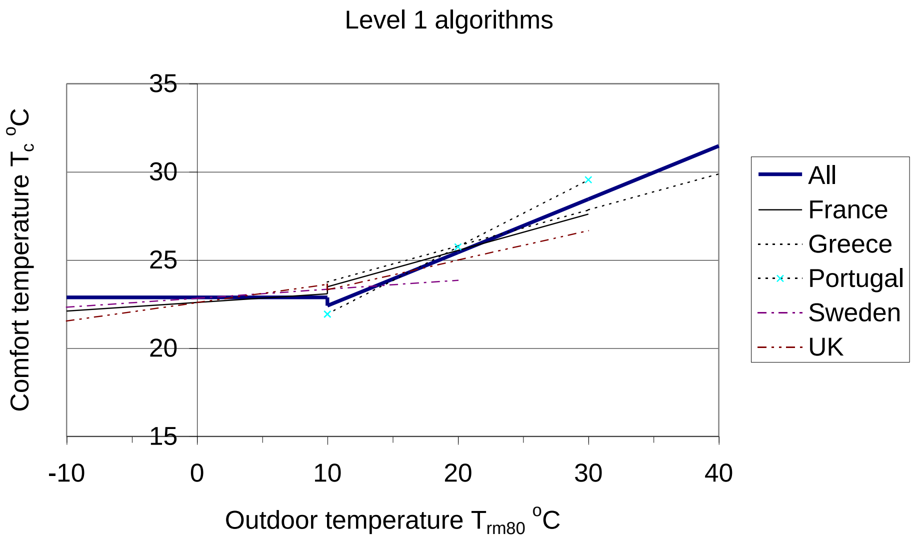


Figure 2-4. The adaptive control algorithm (ACAs) for individual countries. Source: (McCartney & Nicol 2002).

Table 2-5 gives the equations for each country and for each survey divided between the results when T_{rm} is above and below 10°C (McCartney & Nicol 2002).

Table 2-5. Adaptive control algorithm equations for T_{rm} above and below 10°C.

county	adaptive control algorithm	
	$T_{rm} < 10$	$T_{rm} > 10$
France	$0.049\ T_{rm} + 22.58$	$0.206\ T_{rm} + 21.42$
Greece	not applicable	$0.205\ T_{rm} + 21.69$
Portugal	$0.381\ T_{rm} + 18.12$	
Sweden	$0.051\ T_{rm} + 22.83$	
UK	$0.104\ T_{rm} + 22.58$	$0.168\ T_{rm} + 21.63$
All	**22.88**	**$0.302\ T_{rm} + 19.39$**

2.4 Personal control

Personal control has a considerable impact on individual perception and satisfaction with the indoor environment. Currently, building service system designers evidently doubt the benefits of personal control over indoor climate and often choose to avoid operable windows, adjustable thermostats and other control opportunities. Most probably, they lack knowledge about the comfort, health and productivity benefits of indoor control opportunities or at least do not assign much weight to these occupant effects during the building design process (van Hoof et al., 2010). As a result, buildings have become centrally controlled instead of occupant-controlled; in particular those sealed buildings which depend on centrally operated HVAC systems.

However, little is known about which aspects (e.g. available adaptive opportunities, reasons for not exercising adaptive opportunities, office type, season, occupants' expectations as well as the psychological issue of both the belief of having access to the adaptive opportunities and the effectiveness of having this access) are important to determine the effects of personal control (Gossauer & Wagner 2006, Boerstra et al., 2013, Hellwig 2015). This section will introduce personal control and the reasons for its importance and review related studies to understand the effect of personal control over indoor climate.

2.4.1 Definition of personal control

Paciuk (1990) distinguishes three levels of personal control: available, exercised, and perceived control.

Available control:

refers to the type of control opportunities available to the occupants in their office environment, such as operable windows, interior/ exterior doors, blinds, personal fans, personal heaters and thermostat. It could also include the dress code and other factors which influence the interaction between the occupant and the building.

Exercised control:

refers to the relative frequency with which the building occupants engage in indoor environmental adaptive behaviours in order to reach the comfort needed. Occupants can exercise control by adjusting the available control opportunities.

Perceived control:

refers to the degree to which building occupants believe they can cause desired changes in the indoor environment.

Hellwig (2015) defines personal control as having the opportunity to adjust occupants' indoor environment according to their needs and preferences, in the case of discomfort. When occupants have the knowledge of their ability to change the surrounding indoor environment, according to their previous experience, they will be more confident in the potential to become comfortable in their offices, if discomfort should occur.

2.4.2 Importance of personal control

Personal control refers to the behavioural adjustment of adaptation, in particular to the technological or environmental adjustment in which occupants are modifying the surroundings through the available control opportunities, such as opening/closing windows or doors or shades, turning on fans or heaters, or adjusting the thermostats. The adaptive model reflects a ‘give and take’ relationship between the environment and the building occupants, as occupants are no longer simply passive recipients of the given thermal environment, but instead are active delegates interacting with and adjusting the thermal indoor environment (Brager & Dear, 1998).

The adaptive model in ASHRAE Standard 55 specifies two ranges of acceptability 90% and 80%. Fanger (2001) pointed out the importance of personal control, which is one of the main success factors for healthy individual control. He explained ‘Of course 100% satisfaction with indoor climate can be achieved, it just means that you have to offer effective personal control right there where people are’. Furthermore, Brager and Olesen wrote, “While the standard specifies conditions that will satisfy 80% of the occupants, that may still leave 20% dissatisfied. The best way to improve upon this level of acceptability is to provide occupants with personal control of their thermal environment, enabling them to compensate for inter- and intra-individual differences in preference” (Brager and Olesen 2004).

According to Aronoff and Kaplan (1995), it is important to give occupants personal control over the indoor environment at their offices. They wrote, “*Because the thermal conditions that individuals find comfortable are so variable, the ideal solution would be to allow everyone to set the conditions that they find comfortable*.” As a result, personal control does not only allow people to make adjustments to their individual preferences, but they will be generally more satisfied when they perceive that they have control over their environment. In addition, personal control enhances the quality of the work environment. Heerwagen (2000) identified numerous benefits of personal control, based on the review of several personal control studies, such as increasing perceived productivity, fewer symptoms of illness, less absenteeism, enhanced work performance, improved comfort and acceptability, reduced time to achieve comfort, fewer coping behaviours, and fewer complaints to building managers.

A major barrier to the use of personal controls is the design of the user interface, which can cause a problem if occupants do not know how they work, as some designs are ambiguous in intent, poorly labelled, lack clarity of design intent or fail to show whether anything has changed. Personal controls should have these six usability criteria in order to produce the desired results: clarity of purpose, intuitive switching, usefulness of labelling and annotation, ease of use, indication of system response and degree of fine control (Bordass et al. 2007). Further to these technological reasons, there are several other aspects which affect the use of the available personal controls, such as the design of the building, building management regulations, office layout, how far these controls are from the occupants and if prior agreement is needed before any adjustment. It can be drawn from these points that there is a difference between the availability and the use of personal controls. These issues will be addressed later in this study.

2.4.3 Effects of personal control over indoor climate

Over recent years, various researchers have studied the effects of personal control over indoor climate on comfort and satisfaction, work productivity and health. These relevant studies are introduced chronologically.

Paciuk (1990) pointed out the important issue of ‘perceived’ versus ‘actual’ control over thermal conditions. She found that ‘perceived’ control over the thermal environment was associated with comfort and satisfaction. Her work investigated the effect of the presence or absence of adaptive opportunities on thermal comfort and satisfaction in office buildings. It was found that the number of control options available turned out to have a positive impact on thermal comfort and satisfaction. However, when considering exercised control, a negative impact was found on comfort. When occupants were relatively often engaged in making adjustments to the available control options (adjusting clothing, opening/closing windows, adjusting thermostats etc.), they were slightly less comfortable and less satisfied with their thermal environment.

Heerwagen and Diamond (1992) evaluated the post-occupancy of seven energy efficient buildings in the Pacific Northwest. Their research addressed personal control and how occupants coped with thermal conditions, lighting, acoustical considerations and air quality. They distinguished three types of coping behaviours which are related to the built environment.

1- Environmental coping, where adjustment is taking place in order to change the surrounding environment, e.g. opening/closing windows, adding a fan;

2-Behavioural coping, by changing one’s own behaviour, e.g. moving to another room, adjusting clothes, drinking something hot or cold;

3-Psychological or emotional coping by adjusting the situation, e.g. managing one’s thoughts about the situation.

A total of 268 subjects participated in this research. Heerwagen and Diamond came to the conclusion that many of the adjustments people make to enhance personal comfort are related to the environmental adjustment and are relatively simple (opening/closing blinds, turning lights on/off; adding fans or heaters). Most of these practices provided rapid and noticeable changes in the environmental conditions occupants experience in their offices. Coping behaviours were less likely to solve the problem quickly or to create a noticeable change. Psychological coping, like ignoring the problem or trying to concentrate harder on work, was associated with negative indications such as headaches, as the problem was not addressed.

Baker and Standeven conducted comfort surveys in 1993 and 1994, mainly in Athens, which provided information on room and local thermal conditions, and simultaneous subjective responses. They found that if the adaptive opportunity was not available, any departure from the neutral zone immediately caused stress or dissatisfaction. This indicates that insufficient adaptive opportunities are a potential key factor in causing dissatisfaction (Baker & Standeven 1996).

Five ‘killer variables’ were identified by Leaman & Bordass (1999), which were found to have the most impact on perceived productivity in buildings. These are: comfort, including personal control, responsiveness to need, including comfort, ventilation type, the layout of the space plan and the workgroups, and the design intent, and how this is communicated to users and occupants. Personal control is the first killer variable on the list based, on their field studies, which showed that the more control options are available to the occupants, the more tolerant and productive they are. The authors reanalysed the data from field studies which were conducted in 11 UK office buildings in 1996 and 1997. They found that self-assessed productivity was significantly and positively associated with perceptions of control in 7 out of 11 buildings. The overall perception of control was measured by the average of five variables for perceived control over heating, cooling, lighting, ventilation and noise.

In the ProKlimA study (Bischof et al., 2003), 14 German office buildings with 4596 respondents were analysed. The main focus of the study related to sick building syndrome in mechanically ventilated or air-conditioned and naturally ventilated but centrally heated buildings. The influence of the indoor climate, as well as psychological factors, on illness symptoms was evaluated. They found that 85% of office workers wish to have control over their indoor environment.

Hellwig (2005) reanalysed the data and found that the occupants’ perceived control over temperature and air movement in naturally ventilated offices with radiators, operable windows and light switch was 87%, while just 7% reported having control over the air-movement in sealed and central air-conditioning office buildings. The results showed a strong significant interrelation between personal control and satisfaction.

A European research project known as the HOPE project, ‘Health Optimisation Protocol for Energy-efficient Building’, aimed to specify a set of qualitative and quantitative performance criteria for healthy and energy efficient buildings. The buildings were located in the Czech Republic, Denmark, Finland, Germany, Italy, the Netherlands, Portugal, Switzerland and the United Kingdom. 96 apartment buildings and 64 office buildings were investigated. Around 75% of these had been designed to be energy-efficient. A minimum sample of 50 occupants was required per each building for the survey. 6000 valid questionnaires were collected for analysis and were used to determine satisfaction with comfort (thermal visual, acoustic and indoor air quality (IAQ) and also their health (Sick Building Syndrome and allergies). Strong correlations were found between perceived IAQ, thermal, acoustic and lighting comfort. Significant correlations between the perceived comfort and building-related symptoms were also found, more comfortable and healthier buildings being well distinguished from uncomfortable ones. Differences of perceived comfort or health between low- and high-energy buildings show that it is possible to design buildings that are healthy, comfortable and energy efficient (Roulet et al., 2006).

In the ‘report on interrelation between different comfort parameters and their importance in occupant satisfaction’, Wagner and Gossauer (2008) analysed 17 German office buildings. The main aim was to investigate the correlations between different satisfaction parameters and their influence on overall comfort at the workplace. The results were based mainly on a post-occupancy study conducted in 16 German office buildings beginning in January 2004 (Gossauer et al, 2006). The surveys were carried out in both summer and winter to consider the impact of diverse climate conditions on the occupants' judgement. Approximately 1500 questionnaires were analysed, together with measurements which were taken during the surveys. They found a strong correlation between satisfaction with the indoor temperature and the perceived effectiveness of attempted temperature changes. Occupants were more satisfied when they were able to realize significant change in their indoor environment. An important result of this study was that the indoor temperature perception was found to have a minor influence on the satisfaction with the indoor temperature in the winter season, whereas in summer this influence was stronger but definitely not a dominant factor.

Haldi and Robinson (2008) conducted a longitudinal field study with 60 occupants in eight Swiss office buildings during the warm summer of 2006. The main focus was on the behaviour and adaptive actions of the occupants in relation to thermal satisfaction. They found that the comfort temperature depended on the availability and quality of indoor climate controls. Comfort temperatures where higher at around 27 °C when more control options were available, such as operable windows and doors, adjustable blinds, fans, and access to cold drinks. On the other hand, the average comfort temperature turned out to be around 24 °C when occupants had no control options.

A database based on several Danish field surveys of office buildings showed a disparity in the degree of perceived control between mechanical and naturally ventilated buildings. The impact on occupants’ perceptions and prevalence of symptoms was also analysed. The database was obtained from a total of 1272 responses collected in 24 buildings, of which 15 had mechanical ventilation (997 responses) and nine had natural ventilation (275 responses). It was found that occupants of mechanically ventilated buildings had more building related symptoms than occupants of naturally ventilated buildings. The prevalence of adverse perceptions and symptoms was strongly affected by the degree of perceived control satisfaction with environmental control. Furthermore, buildings with operable windows and adjustable thermostats had the highest perceived control by occupants compared with other buildings (Toftum, 2010). These results are in line with those of Bischof et al., 2003 and Hedge et al. (1989), who found that building related symptoms in air-conditioned buildings without operable windows were significantly higher than those in naturally ventilated buildings with operable windows. Their results were based on field studies which were carried out in 47 English office buildings.

Based on experiments conducted in an experimental facility (btga box) at the University of Wuppertal, an experimental design with special settings with respect to differences in outside conditions and the number of control opportunities was developed. The focus was to evaluate the effect of the three types of adaptive processes to warm indoor conditions. The authors found an increase in the satisfaction with the thermal conditions when interaction with the built environment through using a fan or opening a window was permitted (Schweiker et al. 2012).

Boerstra et al. (2013) reanalysed the data from the HOPE database in order to discover the impact of available controls like operable windows and thermostats on perceived control and also the effect of perceived control on comfort and health in office buildings. Selected related questions were used from the HOPE building checklist to achieve these objectives. They found no significant correlations between available controls and perceived control, with the exception of solar shading. On the other hand, regarding the relation between perceived control and comfort, many significant correlations were found, as follows:

- a significant positive correlation was found between perceived control over temperature and overall comfort in winter and summer, and perceived temperature in winter and perceived air quality in both winter and summer;
- a significant positive correlation was found between perceived control over ventilation and perceived air quality in winter and summer and overall comfort in summer.

As a result, occupants were more comfortable and more satisfied with their indoor environment when they felt they were in control over their indoor climate.

Boerstra (2016) analysed historic data from the database 'BBA Binnenmilieu', where 5-15 surveys a year were conducted in 21 Dutch office buildings from 2005-2010. The database involved 1612 occupants. Boerstra aimed to investigate the relationships between available and perceived control over the indoor environment, as well as the effects on office occupants' comfort and health. Occupants who answered with higher control scores were more comfortable and productive and had lower symptom incidence as well as less sick leave. At least from the building occupants' assessment, it appeared that if they were provided with effective available operable windows and adjustable thermostats, they were generally more comfortable and productive.

Boerstra (2016) used the results of the database analyses to design a field study. The field study was conducted during the winter of 2011/2012 in 9 Dutch office buildings, with a total of 236 occupants participating in a questionnaire while 161 occupants were interviewed. The questionnaire included questions related to perceived control, exercised control, thermal comfort, comfort perceptions, building symptoms, self-assessed productivity and sick leave. The field study results revealed that only about 1 out of 3 of these Dutch office occupants were satisfied with the amount of control they had over the indoor environment.

The perceived control over temperature was lower than that over sun penetration and light. Positive significant correlations were found between perceived control and comfort perception, overall satisfaction with the indoor climate and self-assessed productivity. Furthermore, the results identified two factors that have a positive and significant effect on perceived control over the indoor environments: 1- having access to an operable window, and 2- use of controls such as thermostats and operable windows without experiencing any organizational prohibition.

3 Research Approach and Methodology

This chapter describes and explains the research approach and methodology used in this study, including the methods and tools for gathering and analysing data concerning the physical measurements and subjective responses. It presents the case studies, external climatic conditions, research design requirements, sampling, field surveys, design of questionnaires, field measurements, instruments and method of statistical analysis.

This research uses a social and physical realist approach, which is considered to be appropriate to answer its aims and objectives. A realist approach can be either qualitative or quantitative (Wagner et al. 2018). However, in this study, a quantitative approach is employed, which allows the researcher to observe and record the real signs of people's thermal comfort and the selected occupant behaviour parameters.

There are two main approaches to determine thermal comfort, namely, through climate chamber experiments or through field study observations. Climate chamber experiments are based on a research design for experiments which has been applied by various researchers to the questions raised by the adaptive hypothesis. They can be conducted in laboratory settings where the thermal environment is carefully controlled. In contrast, field studies are conducted in real buildings occupied by real occupants going about their normal day- to-day activities (de Dear et al. 1997). Field studies have the advantage of analysing the real conditions of thermal environment, as the occupants provide responses in their everyday habitats, wearing their everyday clothing and behaving without any additional restrictions (De Dear & Brager 1998). The approach in this research has, therefore, been to focus on research conducted in real office buildings.

The field data collected were classified into three classes, according to the RP-884 project standard of instrumentation and procedures used for indoor climatic measurements. The measurements in this study are related to class II.

- Class III: Field studies in this class are based on simple measurements of indoor temperature and possibly humidity, which are measured at one level above the floor. It is possible that physical (temperature etc.) and subjective (questionnaire) measurements may not occur at the same time.
- Class II: Field experiments in which all six indoor physical environmental variables (T_a, T_{rm}, Va, RH, I_{cl}, met) are collected at the same time and place where the thermal questionnaires were administered. However, it should be noted that in this study measurements in this class were not always made at the three heights above floor level as specified in ASHRAE Standard 55 (1992) (0.1, 1.1 and 1.7 m).
- Class I: Field experiments in which all sensors and procedures were in conformity with all specifications set out in ASHRAE Standard 55 (1992). The measurements are taken at three heights level with laboratory-grade instrumentation.

According to Nicol (1993), there are also three levels of field studies. Level one, is based on simple measurements of temperature in occupied space, without subjective responses. Level two involves physical measurements of the thermal environment and their subjective responses. Level three involves all factors needed to calculate the heat exchange between occupants and the occupied environment measured together with the subjective response.

Field studies can be longitudinal or transverse. Longitudinal surveys involve repeated observations of the same variables of a relatively small number of subjects over a period of time. Transverse surveys in which a larger group of subjects is polled on a smaller number of occasions (Ogoli, 2007). This study is based on longitudinal field surveys, employing questionnaires and physical measurements to collect the data required, as well as the researcher's observations during the field studies. These observations included reporting the type of clothing and garments worn by the participants and the state of the adaptive opportunities. Observations in the field help to increase the data quality.

3.1 Case studies

The selection of these three case studies aimed for detailed investigations related to thermal comfort and occupant's behaviour which can be derived from the field surveys in order to achieve the aims and objectives of the research. This study was looking for buildings which offer many adaptive opportunities to their occupants, such as: operable windows, operable indoor/ outdoor doors, operable blinds and decentralized HVAC systems with room-wise adjustable thermostats, and also where the occupants can have their personal fans/ heaters and the clothing code is relatively flexible. Buildings with such opportunities provide a good basis to investigate thermal comfort as well as to understand the occupants' adaptive behaviours to achieve thermal comfort. In the early stages of the research, the aim was to investigate naturally ventilated office buildings, as the adaptive thermal model relied on data collected from naturally ventilated buildings. However, it was almost impossible to find this kind of office buildings with an adequate sample size, as they rarely exist in Amman because the modern nature of office buildings is related to mixed mode buildings which use air conditioning split units or HVAC systems combined with natural ventilation.

Nevertheless, even if most residential or commercial buildings nowadays have mechanical ventilation mechanisms, they are not totally dependent on them, as these mechanisms are combined with natural ventilation through operable windows. Three buildings were chosen for the study, two of them are mixed mode buildings while the third one is a free running building. The free running building is a small traditional office with a small sample, but it was still important to investigate this kind of buildings, as it is one of the few office buildings which still does not provide the opportunity for active cooling and heating in Amman. The HVAC systems in both mixed mode buildings were designed to offer room-wise adjustable thermostats, hence thermostat was considered as an adaptive opportunity in this study. Occupants can control the state of the thermostat by switching it on/off and adjust the set point temperatures according to their preferences.

The case studies were selected based on the following criteria: 1) located in Amman and not far away from each other, to ensure the same outdoor climate during the time of the surveys as well as the same thermal history; 2) all buildings must have adaptive opportunities and natural ventilation; 3) representing the recently built contemporary office buildings in Amman, in the case of mixed mode buildings 4) typical in terms of design and material, as far as possible, in the case of the mixed mode buildings, as the free running building has different characteristics from the modern buildings. Although these criteria were considered for the case study selection process, the choice was constrained by the availability and accessibility of the buildings and the number of employees, as well as the availability of the instrument devices.

The studies were carried out in three buildings: the Middle East Insurance Company (MEI), World Health Organization (WHO) and Yaghmour Architects. These buildings are located in Amman which has the GPS coordinates of 31° 57' 47.3688" N and 35° 55' 49.2924" E, and are distributed within a radius of 2.5 kilometres. The maximum distance between the case study buildings was five kilometres as shown in Figure 3-1.

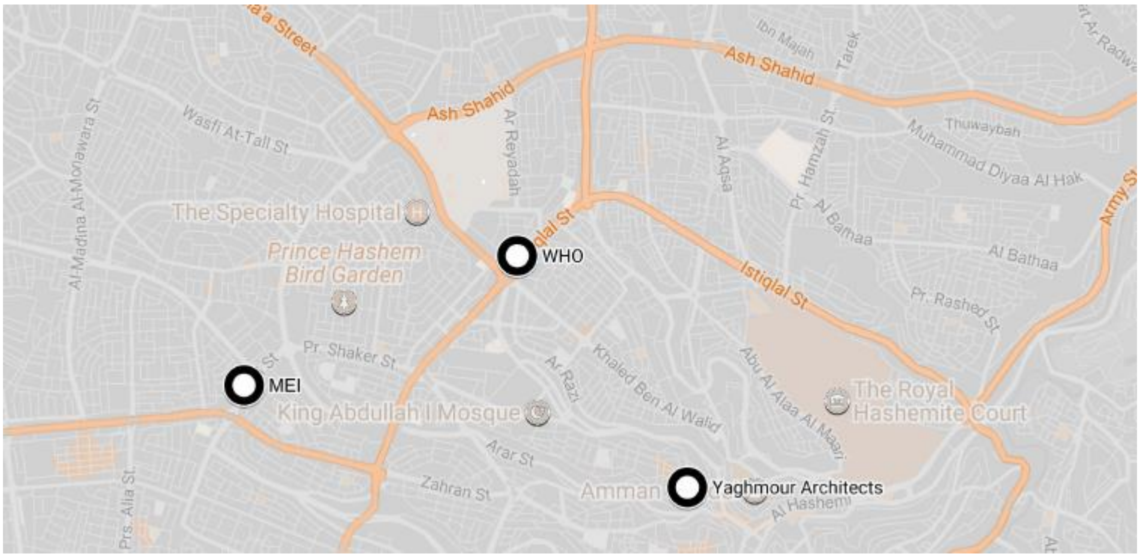


Figure 3-1. Map of the distribution of the locations of the case studies in Amman. Source: Google Maps, 2018.

3.1.1 Building 1

The Middle East Insurance Company Building (MEI) is one of Jordan's newest high-profile commercial buildings in Amman, which is situated at No. 14 Zahran Street. It was the second building in Jordan after the WHO regional headquarters to receive a LEED certification gold rating by the US Green Building Council.

The building was constructed using LEED strategies to achieve high performance in human and environmental health, sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. 20% of the materials were manufactured regionally. Grey water reuse and rainwater harvesting have allowed the building to achieve a 50% reduction in potable landscape water use, a reduction of 40% in indoor water use, and a 50% reduction in wastewater generation. In March 2014, it has been awarded 95 out of a possible 110 LEED BD+C: New Construction v3 - LEED 2009 points.

Table 3-1 shows the LEED Scorecard of the MEI, according to the U.S. Green Building Council of 'energy and atmosphere' and 'indoor environmental quality' sections. Credits related to thermal comfort and personal control are controllability of systems- Lighting, controllability of systems- thermal comfort, thermal comfort design and verification. Controllability of systems- Lighting requires providing individual lighting controls for 90% of the building occupants to enable adjustments to suit individual task needs and preferences. Controllability of systems- thermal comfort requires providing individual comfort controls for 50% of the building occupants to enable adjustments to meet individual needs and preferences as well as providing comfort system controls for all shared multi-occupant spaces to enable adjustments that meet group needs and preferences. Thermal comfort design refers to design heating, ventilating and air conditioning (HVAC) systems and the building envelope to meet the requirements of one of ASHRAE standard 55-2004 or EN 15251: 2007. Thermal comfort verification to provide for the assessment of building occupant thermal comfort over time. Agree to conduct a thermal comfort survey of building occupants within 6 to 18 months after occupancy. To provide for the assessment of building occupant thermal comfort over time. See Appendix I for the LEED Scorecard of all sections.

It is a 14-story building with a total floor area of 25,600 m^2, designed by Faris Bagaeen Architects. The surveys took place on the second and third floors. Figure 3-3 shows the floors where the surveys were conducted. The hatched areas indicate the offices where the measurements took place and the questionnaires were conducted (surveyed offices).

The building includes single, shared and open plan offices, meeting rooms, a café and service areas. The modern design of the facades combines curtain walls, stone and metal materials. It has exterior and interior shading elements and double-glazed windows. The detailed elevations and sections are shown in Appendix I. This building is referred to as Building 1 henceforth.

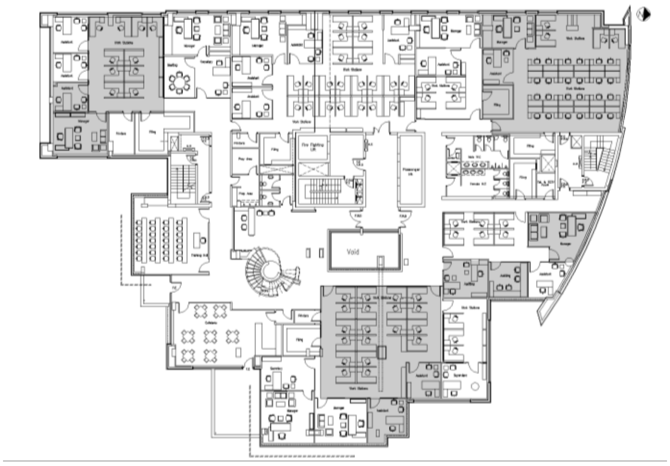
Table 3-1. The LEED Scorecard of building 1 according to the U.S. Green Building Council of ‘Energy and atmosphere‘ and ‘indoor environmental quality’ sections.

ENERGY & ATMOSPHERE		**AWARDED: 14 / 35**
EAc1	Optimize energy performance	8 / 19
EAc2	On-site renewable energy	1 / 7
EAc3	Enhanced commissioning	0 / 2
EAc4	Enhanced refrigerant Mgmt	2 / 2
EAc5	Measurement and verification	3 / 3
EAc6	Green power	0 / 2

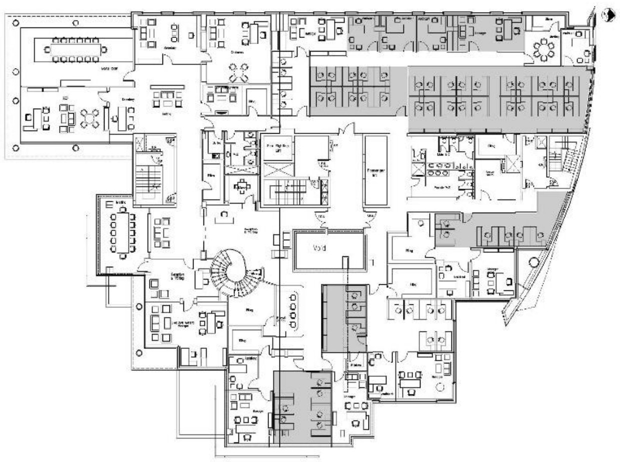
INDOOR ENVIRONMENTAL QUALITY		**AWARDED: 8 / 22**
EQc1	Outdoor air delivery monitoring	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	0 / 1
EQc6.2	Controllability of systems - thermal comfort	0 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	0 / 1
EQc8.2	Daylight and views - views	0 / 1
EQpc124	Performance-based IAQ design and assessment	required

LEED BD+C: New Construction v3 - LEED 2009.

Figure 3-2. Photos of building 1. Source of the first photo:
http://www.venturemagazine.me/2015/10/jordans-greenest-buildings/



(a) Second floor



(b) Third floor

Figure 3-3. Floors where the surveys were conducted in building 1. Hatched areas related to the offices where measurements questionnaires took place.

3.1.2 Building 2

The World Health Organization Regional Office Building was the first to be awarded a gold LEED rating for the entire Eastern Mediterranean region. The building was constructed with almost half of the materials being sourced locally and using environmentally-friendly features aimed at improving energy efficiency by 22.5% and saving water by 60%. Set in the heart of Amman in Mohammad Jamjoum Street, it occupies an area of 2,500 m^2 which was designed by Engicon company with a total floor area of 4890.99 m^2. It has a basement for common services and parking, three main office floors and a roof area. The total floor built area is 4094.83 m^2. It was awarded 42 out of a possible 69 points according to LEED BD+C: New Construction (v2.2) in December 2011. Table 3-2 shows the LEED Scorecard of the WHO building, according to the U.S. Green Building Council of ‘energy and atmosphere’ and ‘indoor environmental quality’ sections. See Appendix I for the LEED Scorecard of all sections.

The surveys were conducted in the four main office floors. Figure 3-5 shows the floors where the surveys were conducted. The hatched areas related to the offices where measurements were taken, and the questionnaires were administered.

The building includes single, shared and open plan offices, meeting rooms, a conference area, a library and service areas. The modern design of the facades combines curtain walls, local stone ‘Ashlar’ and steel tubes, with aluminium cladding sheets serving as louvers for exterior shading devices.

Solar thermal technology and refrigerants were chosen with low ozone depleting potential (ODP) and global warming potential (GWP). Refrigeration and fire-fighting systems are CFC free.

Solar photovoltaic panels are used for exterior lighting. The renewable energy produced 2.5% out of the total energy consumption of both the building and site. Energy efficient lighting techniques were applied, through the use of energy efficient lamps and implementation of a lighting control system which used sensing devices to switch the lights in some spaces. The building design provides 90% of the spaces with daylight and views. Examples of water efficiency management are the rainwater harvesting systems which are used to capture roof and hardscape run-off, and also collect the water condensed from the AC Units. The collected water is stored in special tanks for use with high efficiency irrigation systems and toilet flushing. The project captures and treats 90% of the annual rainfall.

The HVAC design provides each space with a separate thermostat. It also has interior shading elements and double-glazed windows. The glazing characteristics are as follows: transmittance (34%), reflectance out (13%), reflectance in (28%), solar energy transmittance (17%), solar energy reflectance (8%), shading coefficient (0.32), U-Value Summer 1.66 W/m^2 K.

The detailed elevations and sections are shown in Appendix I. This building is referred to as Building 2 henceforth.

It should be noted that there were some changes from LEED-NC v2.2 (building 2) to LEED 2009 NC (building 1). The sustainable sites section was reweighted from 14 to 26 points, water efficiency from 5 to 10 points, energy & atmosphere from 17 to 35, materials & resources from 13 to 14, indoor environmental quality from 15 to 22, innovation & design 5 to 6 and a regional priority category was added with 4 points.

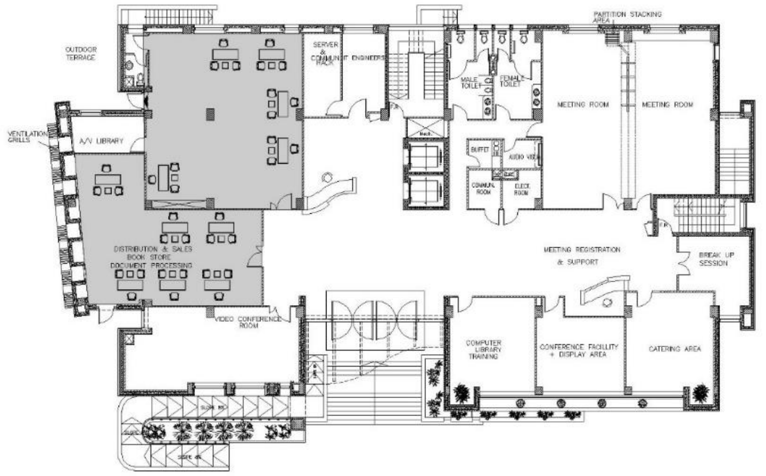
Table 3-2. The LEED Scorecard of building 2 according to the U.S. Green Building Council.

ENERGY & ATMOSPHERE		**AWARDED: 6 / 17**
EAc1	Optimize energy performance	4 / 10
EAc2	On-site renewable energy	0 / 3
EAc3	Enhanced commissioning	0 / 1
EAc4	Enhanced refrigerant Mgmt	1 / 1
EAc5	Measurement and verification	1 / 1
EAc6	Green power	0 / 1

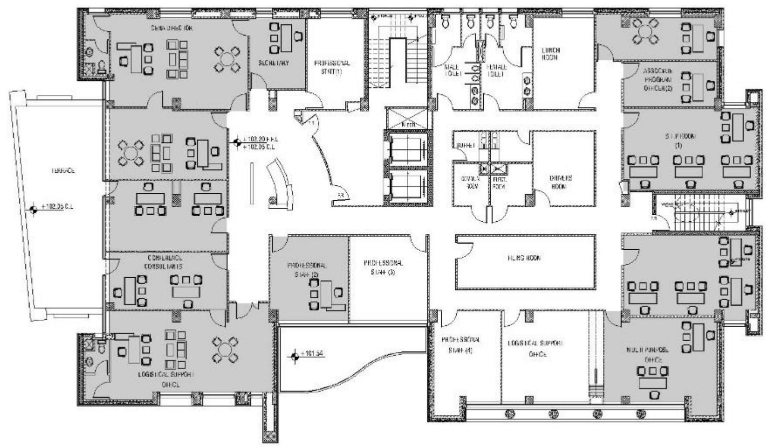
INDOOR ENVIRONMENTAL QUALITY		**AWARDED: 12 / 15**
EQc1	Outdoor air delivery monitoring	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - carpet systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	1 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight 75% of spaces	0 / 1
EQc8.2	Daylight and views - views for 90% of spaces	1 / 1

LEED BD+C: New Construction (v2.2).

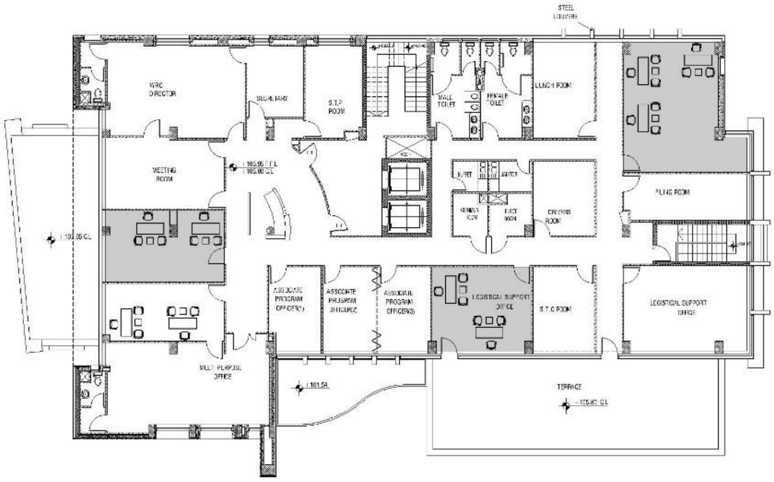
Figure 3-4. Photos of building 2. Source of the first photo is Engicon company: http://www.engicon.com/index.php/services/public-buildings



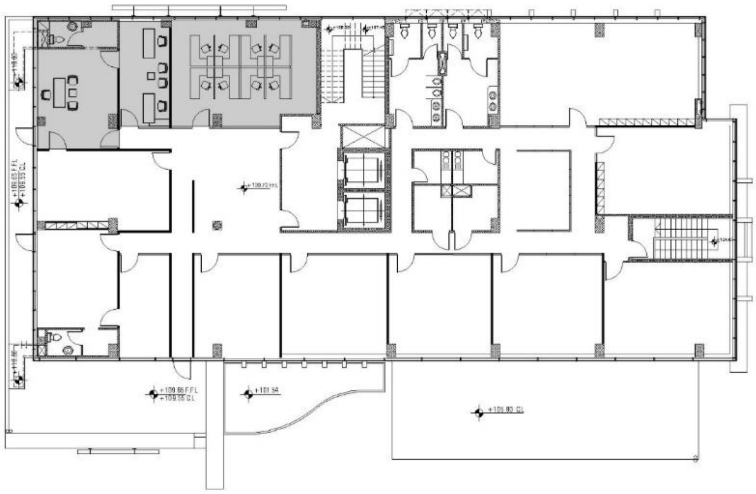
(a) Ground floor



(b) First floor



(C) Second floor



(D) Third floor

Figure 3-5. Floors where the surveys were conducted in building 2. Hatched areas related to the offices where measurements questionnaires took place.

3.1.3 Building 3

Yaghmour Architects office building represents a traditional old Ammani’ building, which was built in the 1940s as a residential house. It is located in, Jabal al-Weibdeh, one of Amman's older districts, at 14 Mohammad Iqbal Street. Yaghmour and his staff renovated the house in 2011, adding elegant contemporary touches. The building not only accommodates office and studio space, but also features a sizable area as a gallery dedicated to cultural events and exhibitions. The office building is a free-running building which has massive walls with stone cladding, with small openings provided with external and internal shading devices. The building offers many adaptive opportunities to its occupants, like adjustable windows, interior and exterior doors, blinds and personal fans and heaters. Moreover, the building has an interior environment that varies noticeably across seasons.

It occupies a land area of 500 m^2 with a total floor area of approximately 400 m^2 distributed between two floors. The ground floor serves as a gallery and the first floor is used for the main office activities. The first floor includes a reception office, two single offices, one open plan office, a meeting room and service areas. Figure 3-7 shows the floor plan where the surveys were conducted. The detailed elevations and sections are shown in Appendix I.

Despite the small size of this building and the small number of occupants working in it, it was important to consider it in the investigation as it is a successful example of the renovated buildings in Amman and one of the few remaining free-running buildings.

In the analysis related to this building in the forthcoming chapters, it is referred to as Building 3.

Figure 3-6. Photos of building 3. Source of the first photo is Yaghmour Architects.

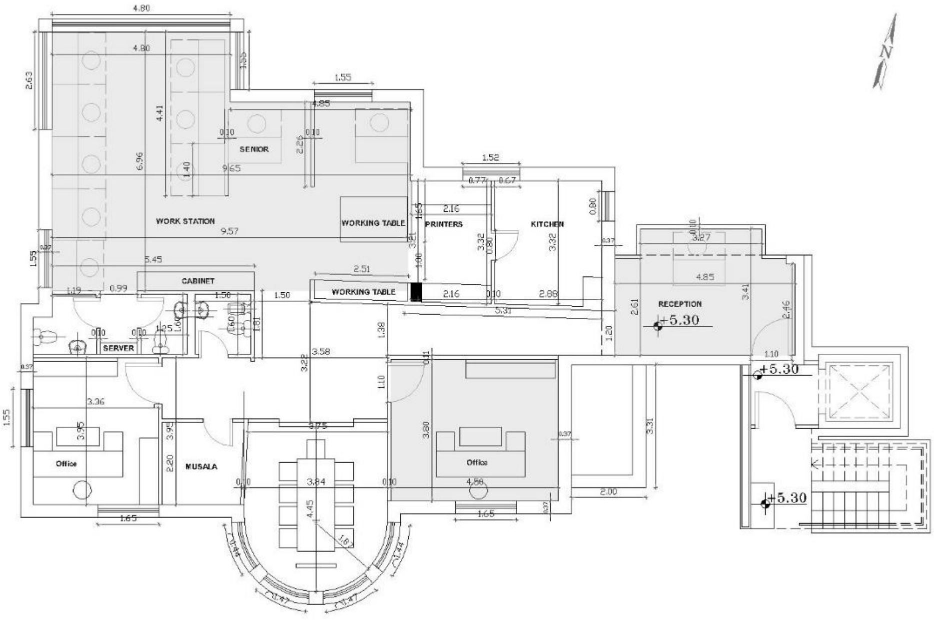


Figure 3-7. First floor plan where the surveys were conducted in building 3. Hatched areas related to the offices where measurements questionnaires took place.

3.2 External climatic conditions

The Longitudinal field surveys were conducted in three office buildings located in Amman, which is Jordan's economic, political and cultural centre, during four seasons. Amman’s position in the mountains near the Mediterranean climate zone, places it under the Mediterranean hot summer climate (Csa), according to Köppen-Geiger's climate classification (Rubel et al. 2017). The area's elevation ranges from 700 to 1,100 m. The city centre near the selected case studies has an altitude of about 800 m. Summer is hot, dry and breezy; however, one or two heat waves may occur during summer where highs reach 37°C and these are more likely in July and August. Winter usually starts around the end of November and continues from early to mid-March with an average temperature of 8 °C in January, with snow occasionally falling once or twice a year, with a total annual rainfall range of about 245 mm, of which 60 mm is in January and February. Spring usually starts between April and May with an average temperature of about 20 °C, Autumn lasts for a very short period between September and October with an average temperature of about 22 °C, and is characterized by low humidity and frequent breezes. Table 3-3 shows the historical climate data of Amman based on weather data from Amman airport weather station during 1985–2015 (Jordan Meteorological Department).

Table 3-3. The historical climate data of Amman during 1985–2015.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mean temperature °C	9	10	12	17	21	25	27	26	25	21	15	10
mean min. temperature °C	4	5	7	11	15	18	21	20	18	15	10	6
mean max. temperature °C	13	14	17	23	28	31	32	32	31	27	20	15
Humidity %	73	69	62	48	41	40	42	47	52	54	60	70
precipitation mm	17	15	8	1	0.2	0	0	0	0	0.6	3.1	9.3

The survey periods were selected according to the mean monthly outdoor temperatures in Amman: Spring 2016 (20 °C in April), Summer 2016 (28 °C in August), Autumn 2016 (22 °C in October) and Winter 2017 (8 °C in January and February).

3.3 Research design requirements

The main intention of this study is to investigate thermal comfort drivers and identify adaptive behavioural patterns related to personal control and thermal comfort during all four seasons. The context of this research is set in office settings, referred to as free-working environments in natural settings while the participant performs his/her everyday activities. The most influential parameters, as encompassed in the adaptive and predictive approaches, can be captured using measurements, questionnaires, observations and visual diaries to:

- measure the four thermal comfort physical environmental factors: air temperature, radiant temperature (using globe temperature measurement), air velocity and relative humidity;
- estimate the two personal factors: metabolic rate, and thermal insulation of clothing;
- calculate the running mean external temperature;
- gather information related to personal control: available control, perceived availability, perceived control, exercised control and desired control.

Table 3-4 shows the research design requirements for the data gathering phase.

Table 3-4. Research design requirements for the data gathering phase.

No.	requirement	priority	source
1	to collect information on the building, including: location, age, fabric, heating- cooling systems, etc.	must have	researcher
2	to collect information on the occupants, age, gender, working hours, working places and the duration of working at the building.	must have	questionnaire
3	to measure air temperature	must have	measurement
4	to measure Globe Temperature	must have	measurement
5	to measure relative humidity	must have	measurement
6	to measure relative air velocity	must have	measurement
7	to measure metabolic rate	must have	questionnaire
8	to measure thermal insulation of clothing	must have	researcher
9	to measure CO_2-concentration, ppm	could have	measurement
10	to measure Sound Pressure Level dB	could have	measurement
11	to collect information on the available adaptive control opportunities	must have	researcher
12	to collect information on the perceived adaptive control opportunities	must have	questionnaire
13	to collect information on the exercised adaptive control opportunities	must have	questionnaire
14	to collect information on the perceived availability of the adaptive control opportunities	must have	questionnaire
15	to collect information on the desired control of the adaptive control opportunities	must have	questionnaire
16	to measure external temperature	must have	Derived from Weather station

17	to measure external relative humidity	must have	derived from Weather station
18	to allow discrete observations and measurements	must have	researcher

Must have = High priority requirements that are fundamental to the research. Could have = Low priority requirements that would be nice to have, but can be omitted due to resource availability.

3.4 Sampling

Recruitment of participants

Having set the aims, objectives and research requirements, the researcher investigated different office buildings in Amman in terms of the ventilation systems and the adaptive opportunities available to the occupants, collecting architectural, mechanical and structural data. As mentioned above, three office buildings were selected as case studies, with respect to the research aims, depending on the availability of the instruments and the prior approval of buildings' managers to carry out the necessary investigations and long-term surveys.

The longitudinal survey involved 119 participants who volunteered from the three case study buildings. These comprised 61 occupants from Building 1, 50 occupants from Building 2 and 8 occupants from Building 3. The number of occupants differed slightly between the different seasons. During summer, 74 persons took part in the survey, while there were 67, 62 and 57 participants for spring, winter and autumn, respectively. Table 3-5 shows the distribution of participants among the three buildings.

Table 3-5. Number of participants in the three buildings in each season.

building	season			
	spring	summer	autumn	winter
building 1	37	39	31	28
building 2	23	29	21	28
building 3	7	6	5	6
total	67	74	57	62

The first step was to obtain approval to conduct the surveys in each of the buildings by contacting the managers through emails, phone calls and personal meetings. Information was provided about the project aims, timeline, the instruments and tools for collecting data, the required time and the frequencies of filling out the questionnaires. The researcher's role, her credentials, and the confidential nature of the research were also explained.

After obtaining the approvals for conducting the surveys, a call for participation was sent out to the employees, with general information providing clear explanations of the duration, aim and methods of the study. Once the initial agreement from the participant was received, the researcher provided more detailed information about the project and its non-judgmental role and the confidential sheet was distributed and signed by the volunteers before the beginning of the first survey. In addition, the researcher explained personally the nature of the project during the first visits to the buildings to encourage the employees to participate. No incentive was offered.

The study aimed to collect responses from each participant several times during each season, although it was difficult to maintain an equal number of responses for each participant within each season and during the different seasons. This was due to the nature of the surveys, which took place during the daily working activities. The researcher encouraged employees to participate and tried to collect maximum responses. However, it is acknowledged that this sample size is small, and is not intended to be statistically representative for Amman based on a case study, but it serves to support the emerging conclusions of the research.

3.5 Questionnaires

This study is a longitudinal survey with the aim to collect the required data and information from the involved participants over periods of time, in order to achieve the research aims. The surveys continued over a period of four seasons, starting from spring 2016, conducted in April, until winter 2017, conducted in January and February (Table 3-6).

Questionnaires were developed to gather the required data in order to achieve the aims, objectives and requirements of the research during the longitudinal surveys. There are two types of questionnaires in this study: the ‘background questionnaire’, which was distributed just once during the whole study and the ‘thermal comfort and personal control questionnaire’, which was distributed twice a week and over 2-3 weeks in each season.

Table 3-6. Monitoring period and dates of surveys for each season.

building	season	dates of surveys
building 1	spring	11.04.16
	spring	13.04.16
	spring	18.04.16
	spring	20.04.16

building 2	spring	12.04.16
	spring	17.04.16
	spring	19.04.16
building 3	spring	11.04.16
	spring	13.04.16
	spring	18.04.16
	spring	20.04.16
	spring	25.04.16
	spring	27.04.16
building 1	summer	22.08.16
	summer	24.08.16
	summer	29.08.16
	summer	31.08.16
building 2	summer	23.08.16
	summer	28.08.16
	summer	30.08.16
	summer	31.08.16
	summer	01.09.16
	summer	04.09.16
building 3	summer	23.08.16
	summer	24.08.16
	summer	29.08.16
	summer	30.08.16
	summer	04.09.16
building 1	autumn	09.10.16
	autumn	12.10.16
	autumn	13.10.16
	autumn	17.10.16
	autumn	18.10.16
building 2	autumn	04.10.16
	autumn	06.10.16

	autumn	10.10.16
	autumn	12.10.16
	autumn	16.10.16
	autumn	17.10.16
	autumn	19.10.16
	autumn	20.10.16
building 3	autumn	04.10.16
	autumn	06.10.16
	autumn	12.10.16
	autumn	16.10.16
building 1	winter	30.01.17
	winter	31.01.17
	winter	01.02.17
	winter	06.02.17
	winter	08.02.17
building 2	winter	31.01.17
	winter	02.02.17
	winter	07.02.17
	winter	09.02.17
building 3	winter	30.01.17
	winter	31.01.17
	winter	01.02.17
	winter	02.02.17
	winter	06.02.17
	winter	07.02.17
	winter	08.02.17

Both questionnaires were available as paper-based and online versions, according to participants' request. The online questionnaires were developed using 'LimeSurvey', which is a web server-based software. Using a web interface, it enables users to develop and publish on-line surveys, collect responses, and export the resulting data to other applications. The links to the questionnaires were sent to the email addresses of the participants, in order to access the surveys, or participants used the researcher's laptop to fill out the questionnaires, as in one of the case studies, the internet was available only for internal use, with restricted access to other websites.

It is important to use simple, clear and correct language for questions and the answer choices. Furthermore, the language used in the questionnaires should be appropriate for respondents and written with a suitable reading level for the sample, without the need of any previous knowledge related to the topic (Miller et al. 2010). Moreover, the phenomena associated with fundamental psychological principles differ between nationalities due to different languages and cultures. Because of that, it is necessary to avoid cultural threads which in turn may cause dissatisfaction from the subjects (Parsons 1993). The design of the questionnaires was based on the these considerations, as well as considering other questionnaires used in thermal comfort studies, such as the ASHRAE Standards 55 and questionnaires used by the Building Science Group at Karlsruhe Institute of Technology. New questions were also added in order to achieve the aims of the research. Furthermore, questionnaires were available in both Arabic and English, as participants could then choose their preferred language to complete the questionnaire.

The questionnaire was translated into the Arabic language. The translation was approved by experts in both languages for greater accuracy. The questionnaires were also tested with a small sample of 15 Jordanians in Amman before starting the field work.

The reasons behind conducting a pilot study or testing questionnaires are:

- to test peoples' understanding of each question;
- to revise and simplify the wordings of questions in accordance with the feedback, to avoid any uncertainty;
- to test the validity of the questions, which will contribute to the research objectives;
- to test the time needed to complete questionnaires.

After testing the questionnaire, modifications were made based on the feedback and comments which were collected and taken into consideration from the pilot sample, to improve both the layout and the language of the questionnaires.

3.5.1 Background questionnaire

As mentioned above, there were two types of questionnaires; the background questionnaire was distributed just once during the whole survey. The time required to answer this questionnaire was 10-15 minutes. It contained these sections:

Section I: Personal Data: this section was for collecting relevant personal information, including participants' gender, age, height, weight and smoking status.

Section II: General questions about work activity and workplace: this section aimed to investigate the participants' interaction history with the building and space they occupied. It included questions about the nature of the workplace and the activities carried out by the occupants, including duration of working in the case study building, duration of working at the same current office, office location in building, the weekly working hours at the workplace and type of office. It also included questions about the level of satisfaction with: the size of the office, opportunity to decorate workplace, partitions which separate the different workplaces, position of the workplace to the nearest window and door, sitting position in relation to another person, working without distraction, and the participant's overall satisfaction with the conditions of workplace. The last part of this section dealt with the importance of the following factors for working environment satisfaction: friendly atmosphere, comfortable room temperature, sufficient fresh air, pleasant humidity, good artificial light, view, adequate daylight.

Section III: This included questions about lighting conditions at the workplace/ daylight conditions/ artificial lighting conditions/ sun protection/ glare protection: this section includes questions addressing size/ location/ direction of the window, daylight and artificial lighting conditions, satisfaction with the daylight, artificial lighting and sun protection measures.

Section IV: Importance of and need for change concerning comfort zones: this section included questions covering the importance of the following conditions for well-being at work: lighting, temperature, air quality, acoustic conditions, privacy, furniture design and cleanliness.

Section V: Personal Control: this section collected information about the available adaptive opportunities at offices and the desired controls for the participants.

At the end of the questionnaire, a comments section was provided. The participants were asked to write their opinion about the workplace, building in general and the questionnaire, as well as any important comments they wished to mention.

3.5.2 The thermal comfort and personal control questionnaire

The second questionnaire 'The thermal comfort and personal control questionnaire' was distributed twice a week over a period of 2-3 weeks in each season. Occupants completed this questionnaire after they had been settled in their offices for more than 30 minutes. The surveys were conducted between 9:00 am and 4:00 pm. While they were completing the thermal comfort questionnaires, the physical environmental parameters were measured, while the clothing worn and the state of the given behavioural options, i.e. windows, doors, blinds, fans, heaters and thermostats were recorded by the researcher. The time needed to answer this questionnaire was approximately five minutes. This questionnaire was divided to two main sections:

Section I: Thermal comfort: This section asked about the occupant's perceptions regarding the environmental conditions and included questions about recent occupancy, thermal sensation, comfort level, and preference, as well as estimated temperature, comfort level of humidity, air movement perception, air movement preference, air movement comfort, air quality perception, metabolic rate and clothing. The questionnaire for the first field survey, which was conducted in April 2016, included questions related to clothing 'Garment Insulation'. This part was deleted from the questionnaires of the subsequent surveys, in order to reduce the time required to fill out the questionnaire. Instead, the researcher recorded the needed clothing information, 'Garment Insulation', while the questionnaires were being filled out, to calculate the clo values according to the ASHRAE 55-2013 standard.

Section II: Personal control: This part was designed to gather the data needed for the analysis required to answer the second aim of the research. It included questions related to recent behavioural opportunities and actions, such as exercised control, reasons behind not adjusting the available control options, perceived control, desired control and perceived availability.

Table 3-7 lists questions related to thermal comfort and personal control in the questionnaire with their corresponding coding. For more details, see Appendix II.

Table 3-7. Questions related to thermal comfort and personal control questionnaire.

question	response categories	code
Thermal sensation 'TSV' How do you perceive the Air Temperature at the moment in your office?	- cold - cool - slightly cool - neutral - slightly warm - warm - hot	-3 -2 -1 0 +1 +2 +3
Thermal preference 'TP' How would you prefer the Air Temperature at the moment in your office?	- much cooler - cooler - no change - warmer - much warmer	1 2 3 4 5
Thermal comfort 'TC' How do you rate the temperature in your office?	- very uncomfortable - 2 - 3	1 2 3

	- 4 - very comfortable	4 5
Humidity comfort 'HC' How do you rate the Humidity in your office	- very uncomfortable - 2 - 3 - 4 - very comfortable	1 2 3 4 5
Air movement perception Do you perceive at the moment any air movement?	- no movement - very slight - slight - strong - very strong	1 2 3 4 5
Air movement preference How would you prefer the Air movement at the moment in your office?	- much weaker - weaker - no change - stronger - much stronger	1 2 3 4 5
Air movement comfort How do you rate the air movement in your office?	- very uncomfortable - 2 - 3 - 4 - very comfortable	1 2 3 4 5
Air quality perception How do you perceive the air quality at this moment in your office?	- very bad - 2 - 3 - 4 - very good	1 2 3 4 5
Guessed temperature Please guess, how many degrees Celsius is the room temperature?		

Perceived availability Do you have these options in order to control the indoor climate? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	- yes - no	0 1
Desired control Do you prefer having the opportunity to adjust these options in order to control the indoor climate? (at the moment)? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	- yes - no	0 1
Exercised control What type of adjustment did you make to the given 'options to control indoor climate' during the last hours? Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	- opened without asking others - opened after asking others - closed without asking others - closed after asking others - no adjustment - not applicable	
Reasons for not exercising available controls What were the reasons you did not take the given 'options to control indoor climate'?[1)] Operable window, door to interior space, door to exterior space, blinds, personal fan, personal heater and thermostat.	- would not have helped - cannot adjust option any further - was not agreeable to others in the space - not sure if it would be OK with management - not worth asking others' permission - not worth disturbing my work - no need: co-worker did this - wanted to exhaust other control options first - I was comfortable enough	
Perceived control How much control do you have to change 'the thermal conditions' of your office (at the moment)?	- no control at all - 2 - 3 - 4 - a lot of control	1 2 3 4 5

[1)] Categories after Langevin (2014).

3.5.3 Ethical Considerations and data protection

Ethical implications of the research need to be considered, as the monitored subjects in this study are human participants. Generally, all research involving participants should conform within the standards set out by the research institution. Thus, this study considered KIT data protection guidelines and was approved by the KIT Research Ethics Committee before research commenced.

In connection to who will have access to the information, participants' identities were kept confidential, whereby only the research-team has access to the collected information. In order to relate the collected information with the measurements taken during the surveys, participants were identified by a code consisting of the first two letters of the father's first name, the first two letters of mother's first name and the two digits of day of birth. Codes were only accessible to the researcher, and supervisors upon request. Another coding method, which used numbers, was employed in case of dissemination of information when used for presentations and publications. The electronic files were password-protected and stored securely.

Two forms/ sheets were sent to the participants:

1- Information sheet - Prior to agreeing to take part in the study. The participant was informed about why the research was being done and what would it involve. The Information sheet provided a detailed description of the study, including its purpose, the data collection process, the benefit of taking part, insurance of confidentiality, and who would have access to the data and contact details.

2- Consent form - After agreeing to take part and before the start of the data collection, the participants signed the consent form. This agreement states the rules or boundary conditions of the research. This form included this information:

- the voluntary nature of the study, their right to withdraw their participation at any time;
- assurance of the confidentiality of study, who has access to the data, which will be treated as strictly confidential and handled in accordance with the provisions of the data protection policies at KIT;
- how data will be retained (security) and for how long;
- participant agrees they have understood the information sheet and what is involved in the study:
- confirming participation in the research;
- confidentiality - information provided will be held confidentially, such that only the researcher can be able to associate the responses with the identity.

The main aim of this approval process was to protect both the researcher and the participants.

3.6 Field measurements

Field surveys concentrate on gathering data about the thermal environment and the parallel thermal response of subjects in real conditions. Surveys obtain occupants' comfort perception directly whereas measurements of the environment predict those perceptions indirectly through models. In fact, conducting field surveys in real life is not an easy task to accomplish, especially when people are engaged with their daily tasks. Furthermore, surveys require engaging occupants and consuming some of their time. Based on these issues, it is necessary to have a well-planned communications approach to conduct a survey which is optimized for length and contents. The timing and frequency of repetition must also be considered.

There are two types of thermal comfort environment surveys:

1- Point in time 'thermal comfort and personal control questionnaire' surveys are used to evaluate thermal sensations of occupants at a single point in time. Researchers have used this type to correlate thermal comfort with environmental factors such as: air temperature, radiant temperature, air velocity, humidity, metabolic rate and clothing insulation. In order to use the results of 'point in time' surveys, the survey would have to be implemented under multiple thermal conditions. The difficulty of conducting/ arranging multiple surveys in office environments usually limits the possibility of using this type of survey for assessing comfort over time;

2- Satisfaction survey is used to evaluate occupants' thermal comfort responses over a certain span of time. This type of survey directly asks occupants to provide satisfaction responses. The basic assumption of a satisfaction survey is that occupants by nature can recall periods of thermal discomfort, identify patterns in building operation and provide 'average' comfort votes on their environment (ASHRAE Standard 55, 2017).

Drawing from the research design requirements section, a 'thermal comfort and personal control questionnaire' survey was chosen as the appropriate type of survey to collect the required data and information to achieve the aims of this study.

As listed in Table 3-4, measuring these six parameters is a high priority requirement fundamental to the research. The measurements and estimation of these six parameters as well as other required measurements for the research are explained below and were divided into two sections: 1- measured variables which were directly measured during the field surveys, and 2- calculated variables derived and calculated from other measured or collected indices.

Measurements were recorded at each office both continuously and also during the time occupants took to answer the questionnaires. Thus, during the ‘thermal comfort and personal control questionnaire’ surveys: air temperature, globe temperature, air velocity, relative humidity, CO_2 concentration and sound pressure level were measured. Furthermore, air temperature, globe temperature and relative humidity were measured continuously during the entire survey periods, at each office, using HOBO data loggers.

3.6.1 Measured variables

Air temperature

The air temperature is defined as the temperature of the surrounding air and is expressed in Kelvins (K) or degrees Celsius (°C). The physical measurement devices’ position within the building and timing of physical measurements, as well as instrumentation measurement ranges and accuracy characteristics of the instrument were chosen in compliance with the ASHRAE Standard 55 -2013 as follows:

- measurement’s location shall be in the middle of the place and 1.0 m inward from the center of each of the room’s walls and 1.0 m inward from the center of the largest window in the case of exterior walls;
- sensors shall be protected from direct radiation exchange with the surroundings;
- air temperature shall be measured at the 0.1, 0.6 and 1.1 m levels. Measurements in this study were taken only at one level due to the availability of the instruments;
- measurement intervals for air temperature shall be five minutes or less;
- instrumentation measuring range: 10 to 40 ˚C;
- instrumentation measuring accuracy: required ±0.5 ◦C; desirable ±0.2 ˚C.

Air temperature was measured continuously during each field survey using Onset HOBO U12- 012 and HOBO 08-003-02 data-loggers for thermal monitoring. The loggers recorded air temperature with an accuracy of ±0.35 ˚C at 2-minute intervals. They were located on the desks of the participants, approximately in the middle of the office, in a way that avoided any direct solar radiation. Furthermore, air temperature was measured at the same time while participants were answering the ‘thermal comfort and personal control’ questionnaires. ‘Testo 480 IAQ Pro’ was used for this purpose and the air temperature was measured for approximately 10 – 15 minutes in each office at a height of 1.1 m. The measurements’ position criteria mentioned above were also applied. The device has a measurement range of -20 to +70 °C and an accuracy of ±0.3 °C.

Globe Temperature

Globe temperature was necessary to be measured in order to calculate the mean radiant temperature. The globe temperature depends on changes in air temperature, radiant temperature and air velocity. The globe thermometer is an instrument used to determine the mean radiant temperature and is used to measure radiant heat. It basically consists of a thermometer with its sensor located at the center of a matt black sphere. Mean radiant temperature can be calculated from this result, if air temp and velocity are known (ISO 7726, 1998).

In order to calculate the globe temperature in each office in parallel to the air temperature measurements, a small globe thermometer for practical use was constructed by the researcher, using an NTC sensor which was placed in the middle of a 40 mm table-tennis ball, and was painted matt black. It was connected to the HOBO's data loggers so the measured data was recorded by using Onset HOBO U12- 012 or HOBO 08-003-02 data loggers. This method of using a small globe thermometer, about 40 mm in diameter has been recommended as more convenient and quicker than a standard globe for assessing the warmth of a room with slight air movement, due to the rapid response and convenient size of a table-tennis ball (Humphreys 1976).

Relative humidity

Humidity refers to the moisture content of the air. There are different thermodynamic variables that define it, including water vapor pressure, dew point temperature, wet bulb temperate, humidity ratio and relative humidity (ASHRAE Standard 55, 2013). The most commonly used measure to describe humidity is relative humidity (RH%). Relative humidity is defined as the ratio between the partial pressure of water and the saturated water vapor pressure at a given temperature and is expressed as a percentage (%). There are several ways to calculate relative humidity, either by applying equations derived from empirical correlations, or by measuring it using specific instruments.

According to ASHRAE Standard 55- 2013, the requirements of the physical measurement's position within the building and timing of physical measurements were in accordance with the air temperature requirements mentioned above. The required characteristics of instrumentation measurement ranges and accuracy are as follows:

- instrumentation measuring range: 25% to 95% rh;
- instrumentation measuring accuracy: required ± 5% rh.

Onset HOBO U12- 012 and HOBO 08-003-02 data-loggers were used for thermal monitoring in this study, capturing relative humidity levels with an accuracy of ± 2.5% at two-minute intervals. The measurement range is 5% to 95%.

Air Velocity

Air velocity is defined as the rate of air movement at a point without regard to direction in thermal comfort studies and is expressed in meters per second (m/s). Average air velocity is the average of the velocity surrounding a representative occupant with respect to location and time. The characteristics of the instrument measurement and timing should be as follows (ASHRAE standard 55, 2013):

- measuring range: 0.05 to 2 m/s;
- measuring accuracy: required ± 0.05 m/s;

Air velocity in this study was measured using the Testo 480 thermal flow velocity probe (robust hot bulb) Ø 3mm with telescope, (max. 860 mm) and fixed plug-in head cable, for direction-independent flow velocity measurement. It has a measurement range of 0 to +10 m/s and accuracy of ± 0.03 m/s. Measurements were taken at a height of 1.1 m while occupants were completing the questionnaires.

CO_2-concentration

Maintaining adequate indoor air quality in the workplace is becoming a priority for facility managers and building operating engineers. CO_2 concentration is one method to indicate the indoor air quality. Carbon dioxide (CO_2) is a by-product of combustion, as well as a product from the metabolic process in living organisms. The primary indoor source of CO_2 in office buildings is respiration. Exceeding a specific level of CO_2 concentration is an indicator when occupants tend to report headaches, fatigue, lethargy and a general sense that the air is stale (Seppanen et al. 1999). Furthermore, studies have also shown that there is an effect of high CO_2 levels on reducing occupants' productivity (Carpenter and Poitrast 1990).

ASHRAE Standard 62-2001 offers the following comment on CO_2: 'Comfort (odour) criteria with respect to human bio effluents are likely to be satisfied if the ventilation results in indoor CO_2 concentrations less than 700 ppm above the outdoor air concentration.' This means that acceptable indoor air quality can be assured by maintaining the space's CO_2 concentration at 700 ppm above the outdoor concentration.

For example, if 25.5 m^3/h per person of outdoor air (the CO_2 outdoor concentration is considered as 350 ppm) are delivered to a space, at equilibrium, the CO_2 concentration in that space will be about 1050 ppm. This equates to a 700 ppm difference between indoor and outdoor CO_2 concentrations. Table 3-8 shows the recommended CO_2 concentrations above the level of outdoor air concentration in ppm (EN 15251, 2012).

Table 3-8. Recommended CO_2 concentrations above the level of outdoor air concentration in ppm from EN 15251.

category	CO_2 concentrations above the level of outdoor air concentration; in ppm
I	350
II	500
III	800
IV	< 800

The Wöhler CDL 210-meter (PCE Instruments, UK) is an indoor non-dispersive infrared (NDIR) air quality meter, which was used to measure the CO_2 concentration in offices at the time of answering the questionnaires. The Wöhler CDL 210 CO_2 meter measures a range of 0 to 2000 ppm, has an accuracy ±50ppm or ±5% of the reading and a resolution of ±1ppm.

Sound Pressure Level dB

According to the International Electrotechnical Commission, sound pressure level (SPL) is defined as the ‘logarithm of the ratio of a given sound pressure to the reference sound pressure in decibels is 20 times the logarithm to the base ten of the ratio’ and expressed in dB.

EN ISO 11690 recommends sound quality levels for office workplaces, assuming that the persons in question are prepared to work and are not producing sound themselves with tasks or conversations. A quiet office with background sound pressure levels between 20 and 30 dB is the ideal work environment for highly demanding mental tasks. Table 3-9 shows the acoustic qualification of workstations.

These levels are valid for office workplaces in which information is compiled, collected, processed, stored and communicated, which can be found in many areas, for example administrative offices, typing pools, design offices, and purchasing and sales offices.

Sound pressure level was measured in parallel with answering the questionnaires, using PCE-322A, which has an accuracy of ±1.4 dB and resolution of 0.1 dB.

Table 3-9. The acoustic qualification of workstations.

< 30 dB	perfect
30–40 dB	very good
40–45 dB	good
45–50 dB	acceptable under normal circumstances
50–55 dB	not good
> 55 dB	too loud

3.6.2 Calculated variables

Mean radiant temperature

The mean radiant temperature is defined by ASHRAE Standard 55-2013 as ’the temperature of a uniform, black enclosure that exchanges the same amount of heat by radiation with the occupant as the actual surroundings’. It is expressed in Kelvins (K) or degrees Celsius (°C). There are different ways of estimating indoor mean radiant temperature, either by determining it from the plane radiant temperature in six opposite directions, weighted according to the projected area factors for a person or by measuring it directly using the black globe thermometer, usually 150 mm in diameter or by applying Equation 3-1 which depends on the measurements of the globe temperature, air temperature, and air velocity, which can be combined to calculate the value (ASHRAE Standard 55, 2013). Mean radiant temperature in this study was calculated using Equation 3-1.

$$t_r = \left[(t_g + 273)^4 + \frac{1.10 * 10^8 \, {V_a}^{0.6}}{\mathcal{E} D^{0.4}} \, (t_g - t_a) \right]^{1/4} - 273$$ *Equation 3-1*

Where t_r = mean radiant temperature (°C), t_g = globe temperature (°C), Va = air velocity m/s, t_a = air temperature (°C), D = globe diameter (m), ε = emissivity (0.95 for matt black globe).

Operative temperature

Operative temperature can be defined as the weighted value of both air temperature and mean radiant temperature, weighted respectively by the convective heat transfer coefficient and the linearized radiant heat transfer coefficient for the occupant (ASHRAE standard 55, 2013). Operative temperature can be calculated per the following equation:

T_{op}=A T_a + (1-A) T_r *Equation 3-2*

where T_{op} is operative temperature, T_a is air temperature and T_r is mean radiant temperature. The value of A can be found as a function of relative velocity (Va) as shown in Table 3-10.

Table 3-10. The value of A as a function of relative velocity.

V_a	<0.2 m/s (<40 fpm)	0.2 to 0.6 m/s (40 to 120 fpm)	0.6 to 1.0 m/s (120 to 200 fpm)
A	0.5	0.6	0.7

It is also acceptable to calculate the operative temperature as the average of air and mean radiant temperatures, if occupants are engaged in near sedentary physical activity with metabolic rates between 1.0 met and 1.3 met, not in direct sunlight, and not exposed to air velocities greater than 0.20 m/s as follows:

T_{op} = (T_a + T_r) / 2 *Equation 3-3*

In this study, operative temperature was calculated according toEquation 3-3 Equation 3-2 with respect to air velocity.

Running mean outdoor temperature

According to the adaptive comfort theory, days in the more remote past have less influence on the building occupants' comfort temperature than more recent days and this is can be reflected by attaching exponentially decaying weights to the sequence of mean daily outdoor temperatures. The equation for the exponentially weighted running mean outdoor temperature according to EN 15251 (2012) and ASHRAE 55 (2013) is:

$$T_{rm} = (1 - \alpha)T_{d-1} + \alpha\, T_{rm-1} \qquad \textit{Equation 3-4}$$

where T_{rm} is the running mean outdoor temperature (°C), T_{d-1} represents the mean daily outdoor temperature for the previous day of the survey, T_{rm-1} is the running mean temperature for the previous day of the survey and α=0.8.

The exponentially weighted running mean outdoor temperature was adopted in this research to reflect the significant role of the past and current thermal experiences with outdoor climate conditions. The running mean outdoor temperature was calculated for each day of the surveys considering the last 7 days prior to the day in question.

Outdoor data were derived from the closest weather station to the case studies which is located in 'Dahiyat AlHussain'. The source of outdoor data is 'Weather Underground' which provides local and long-range weather forecasts, weather reports, maps and tropical weather conditions for locations worldwide.

Predicted mean vote

Predicted mean vote (PMV) is defined as an index that predicts the mean value of the votes of a large group of subjects on the seven-point thermal sensation scale. It is a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate and clothing insulation. The thermal comfort tool provided from ASHRAE Standard 55 -2013 has been used to calculate the predicted mean votes in this study.

Metabolic rate

For estimating the metabolic rate of occupants during the field surveys, participants were asked in the 'thermal comfort and personal control' questionnaire to indicate the activities engaged in over the past half hour. The activities related to office activities were listed and an average of the corresponding metabolic rate of the engaged activities was calculated, referring to ASHRAE Standard 55 -2013. For more details, see Appendix III.

Clothing insulation (I_{cl})

Three methods for estimating clothing insulation are presented in ASHRAE Standard 55 -2013 as follows:

1- use the clothing insulation values provided for a variety of common typical clothing ensembles. If the case matches reasonably well with one of the ensembles, then the indicated value of I_{cl} can be used.

2- combine the clothing insulation values of typical clothing ensembles with the thermal insulation of a variety of individual garments. In this method, these garments may be added to or subtracted from the typical ensembles presented above.

3- define the complete clothing ensemble using a combination of individual garments. The insulation of the ensemble is estimated as the sum of the individual values listed in Appendix III.

This third method was used to calculate the clo values in this study, as the individual clothing garments were reported by the researcher during completing the questionnaires.

3.7 Instruments

The study employed multiple sensors to collect the required data. 49 HOBO instruments which were also connected to external NTC sensors placed in the middle of a table tennis balls were used during the longitudinal surveys. In addition, two Testo 480 sensors, which were mainly used to measure the air velocity at the time of answering the questionnaires, together with two CO_2- CDL 210 devices and two sound pressure level PCE-322 A devices.

Table 3-11 provides a summary of the instruments used during the surveys, with their corresponding measurement parameters, range and accuracy.

Table 3-11 Measurement parameters, devices, device range and accuracy.

parameter measured	instruments	range	accuracy	logging frequency
air temperature, T_a, °C	HOBO:H08-003-02	-20°C to +70°C	±0.35°C from 20° to 30°C, 30-50%	continuous (2 min.)
	HOBO U12	-20°C to +70°C	±0.35°C from 20° to 30°C, 30-50%	continuous (2 min.)
	CO_2- CDL 210	-10 to +60 °C	± 0,6 °C	at the time of the questionnaire
	Testo 480	-20 ... +70 °C	±0.3 °C	at the time of the questionnaire
globe temperature, T_g, °C	external NTC. 10K 3470 temperature sensor probe connected to HOBOs	-30 to 120 °C	the NTC sensor placed in the middle of a table tennis ball painted black	continuous (2 min.)

			(40mm diameter) ±0.35°C	
relative humidity, RH, %	HOBO:H08-003-02 HOBO U12 CO_2- CDL 210	0 - 95% RH 0 - 95% RH 5 to 95 %	±5% from 20° to 30°C, 30-50% ±2.5% from 20° to 30°C, 30-50% For 10 to 90 %, 25 °C ± 3% others ± 5%	continuous (2 min.) continuous (2 min.) at the time of the questionnaire
air velocity, Va, m/s	Testo 480, thermal flow velocity probe Ø 3 mm	0 to +10 m/s	± (0.03 m/s	at the time of the questionnaire at the time of the questionnaire
CO_2-concentration, ppm	CO_2- CDL 210	0 to 2000 ppm CO_2	50 ppm or ± 5 %	at the time of the questionnaire
sound pressure level dB	PCE-322 A	30 to 130 dB	± 1.4 dB	at the time of the questionnaire

3.7.1 Instruments calibration

The whole set of HOBO loggers and external NTC sensors were first calibrated by being exposed to constant thermal environmental conditions for 12-hours in the climate chamber (KS 320 / 75 from RS Simulatoren) of Karlsruhe Institute of Technology (KIT). Firstly, the temperatures were increased from 20°C to 40°C within the 30% RH. Then the relative humidity was increased to 50% and the temperature decreased from 40°C to 20°C. After that the relative humidity was set to 70% and the temperature increased from 20°C to 40°C as shown in Table 3-12.

Results from the calibration test showed that all loggers and sensors had accuracies within the range specified by the manufacturer. Instruments were tested against each other intending to establish linear regression and correction factors.

Table 3-12. Thermal environmental conditions which were applied in the climate chamber.

temperature	relative humidity		
	30%	50%	70%
20	●	●	●
25	●	●	●
30	●	●	●
35	●	●	●
40	●	●	●

During the field surveys, very few HOBOs showed strange fluctuations or stopped monitoring during the surveys. These data were excluded and replaced by the measurement of the nearest HOBOs at the same office as in some offices more than one HOBO was placed to overcome such problem.

3.8 Statistics

This section reviews the statistical methods involved in this study, including analysis, interpretation and reporting of the research findings. It provides a brief outline of the variables and tests used for data analysis.

3.8.1 Variables

Categorical or nominal variables are unordered. The data are classified into categories and cannot be arranged in any particular order. Examples of categorical variables are answers related to perceived availability, desired control, exercised control and reasons for not exercising available control in the 'thermal comfort and personal control questionnaire' (Table 3-7).

Ordinal variables have a clear ordering between the variables but may not have equal intervals. Examples answers related to thermal preference and thermal comfort questions (Table 3-7).

Interval variables is similar to an ordinal variable, except that the intervals between the values of the interval variables are equally spaced. An example of an interval scale is the Celsius temperature, where units of measurement are equal throughout the full range of the scale.

3.8.2 Descriptive statistics

Descriptive statistics provide a summary of data in the form of mean, median and mode.

Mean is the sum of all the scores divided by the number of scores. Median is the number that tells us where the middle of a ranked data set is, while mode is the most frequently occurring variable in a distribution. The measure of the central tendency for categorical variables is mode, for ordinal variables is median and it is mean or median for interval variables (Ali and Bhaskar, 2016).

Box-whisker-plot is a method of representing statistical data depicting the median, quartiles, and extreme values which has been used in this study using SPSS-Version 24 software as shown in Figure 3-8.

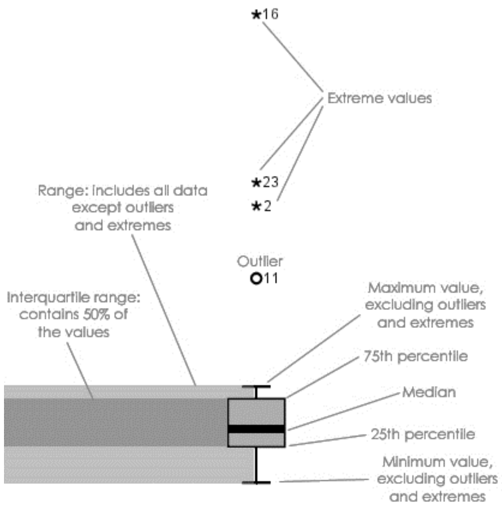


Figure 3-8. Box-whisker-plot explanation in SPSS software.

3.8.3 Non-parametric tests

When data are not normally distributed, parametric tests can lead to erroneous results. Non-parametric tests, or distribution-free tests, are appropriate in such a situation as they do not require a normality assumption. The data in this study were not normally distributed, thus the following non-parametric tests were applied.

Chi square test

The chi square test (X2) is a non-parametric test that is used to investigate whether distributions of categorical/ ordinal variables differ from one another. The contingency coefficient (C) is a coefficient of association that tells whether two variables or data sets are independent or dependent of each other and it is based on the chi square test. The obtained value will always fall along a range from 0 to 1, with 0 indicating no association between the row and column variables and values close to 1 indicating a high degree of association between the variables (Field 2013).

Kruskal-Wallis test

The Kruskal–Wallis test is a non-parametric test which analyses if there is any difference in the median values of three or more independent samples. This test is used when the dependent variable is continuous but not normally distributed or ordinal and the independent variable is nominal. The related descriptive statistics are median for each group and Box-whisker-plot (Field 2013). The Kruskal–Wallis test (α=0.05) was applied in this study to identify the differences of the median of perceived control in dependence on more than two different independent groups and the differences in the clothing median values between the buildings within the same season.

Friedmann test

The Friedmann test (α=0.05) is a non-parametric test for testing the difference between several related samples. It is used when the same parameter has been measured under different conditions on the same subjects. Dependent variable should be measured at the ordinal or continuous level (Altman & Bland 2009). It has been used to analyse the differences in seasonal clo-values for each building and the differences in perceived control between the seasons.

Mann Whitney-U-Test

The Mann Whitney-U-Test (α=0.05) is used to compare differences between two independent groups when the dependent variable is either ordinal or continuous but not normally distributed (Field 2013). The Mann Whitney-U-Test was used to compare differences between operative temperature of ‘comfortable’ and ‘not comfortable’ votes.

Dunn-Bonferroni post-hoc tests were carried out to compare pairwise tests. The effect size was evaluated using Kendall’s W interpreting it with Cohen: $0.1 < W \leq 0.3$ being a small, $0.3 < W \leq 0.5$ being a moderate and $W > 0.5$ being a strong effect (Dinno 2015).

Spearman’ correlation

The Spearman rank-order correlation coefficient (Spearman’s correlation, for short) is a nonparametric measure of the strength and direction of association that exists between two variables measured on at least an ordinal scale. It determines whether the variables are concordant or discordant and evaluates the strength of the possible association. Spearman’s rank correlation coefficient ranges between -1 and +1, in which -1 indicates a perfect negative correlation while +1 indicates a perfect positive correlation (Grzegorzewski et al, 2011). The Spearman’s rank correlation (2-tailed $p<0.01$) was used to investigate the correlations between perceived control and both thermal comfort perception and air quality perception.

3.8.4 Panel analysis regression

Longitudinal data (cross-sectional time-series data) were collected. Longitudinal data are more informative and allow individual dynamics to be studied (Kopp & Lois, 2009). Because values of entities across time were observed, repeated measurements of variables on each person were carried out. The analysis used the panel data regression procedure of Stata 14 software with a level of significance of 0.05 and an explanation of variance of $R^2 \geq 0.10$ required. Panel data regression was used to determine the neutral temperature. The reciprocal of the gradient of the regression models is interpreted as thermal sensitivity (Fanger 1972, de Dear et al. 2018).

3.8.5 Loess

The Loess (locally weighted regression) procedure was used for fitting smooth curves to the nonparametric seasonal data (Cleveland 1979, Jacoby 2000). It was used to identify the form of the regression line suitably describing the dependency of the comfortable temperature on the mean running outdoor temperature. Two parameters were specified:

a) The smoothing parameter which determines the proportion of the total data that is included within each subset for local regression and is specified as a value between 0 and 1. If this value is too small then there will be insufficient data near x for an accurate fit, resulting in a large variance. If it is too large then the regression will be over-smoothed, resulting in a loss of information, hence a large bias. Typically, smoothing parameter values fall between 0.40 and 0.80 (Jacoby 2000).

b) The degree of the loess polynomial which reflects the functional form of the local regressions being either linear or quadratic (Jacoby 2000). A linear functional form was applied. MATLAB R2018a software was used to generate the loess regressions in this study.

4 Thermal Comfort Results

In this chapter the results related to thermal comfort are presented, explained and analysed. The results cover analyses related to descriptive statistics, guessed temperature vs. operative temperature thermal comfort, determine neutral temperatures from the relation between thermal sensation votes and operative temperatures using panel analysis regression, comfort votes and models as well as the variation of clothing insulation.

4.1 Descriptive statistics

This section covers the following analysis: local weather during the survey, participating occupants, indoor and outdoor environmental parameters, air-conditioning state in the mixed mode buildings and subjective perception of the indoor thermal environment.

4.1.1 Local weather during survey

During the time of the surveys, the highest mean monthly temperature was 34°C in August while the lowest mean minimum temperature was 3°C in February. Monthly mean outdoor temperatures in April 20°C and October 22°C presenting the spring and autumn surveys respectively were quite similar. The mean outdoor relative humidity varies between 30 and 70%. Figure 4-1 shows the outdoor maximum/ mean/ minimum temperatures (monthly mean) and mean humidity of Amman during the field surveys. Outdoor environmental data consisting of temperature and relative humidity for the entire period of study was recorded from the nearest weather station. The source of outdoor data was (Weather Underground, 2018).

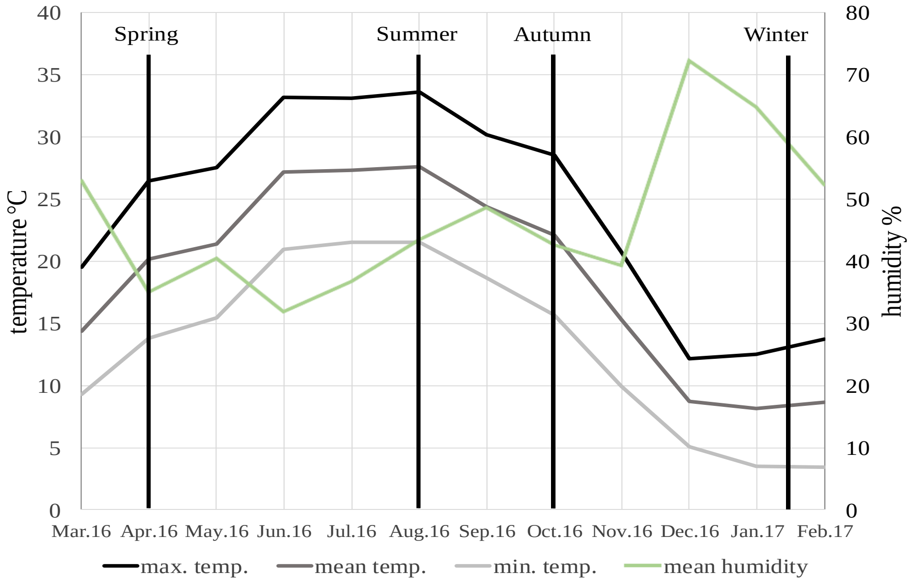


Figure 4-1. Outdoor maximum/ mean/ minimum temperatures (monthly mean) and mean humidity of Amman during the field surveys (Weather Underground, 2018).

4.1.2 Participating occupants

In total, the sample comprised of 119 occupants who were willing to participate in the in the thermal comfort surveys. They completed 659 questionnaires during the four seasons. Of these, 34% (N=227) questionnaires were collected in spring 2016, 26% (N=174) in summer 2016, 18% (N=116) in Autumn 2016 and 22% (N=142) in Winter 2017. The ratio of males (56%) participated in the study was a bit higher than of females (44%). It is worth mentioning that the gender distribution of employees in the buildings is quite equal. Table 4-1 shows the gender distribution, number and percentage of questionnaires within the three buildings during the four seasons. All the occupants were acclimatized to the local climate of Amman, as they had been living in the city for a minimum of one year.

Table 4-1. The number of females/ males in each building and number of questionnaires returns within the three buildings during the four seasons.

	gender			season			
buildings	female	male	total	spring	summer	autumn	winter
building 1	24	37	61	109	101	52	69
building 2	23	27	50	50	61	47	59
building 3	5	3	8	68	12	17	14
total	52	67	119	227	174	116	142
percentage	44%	56%	100%	34.4%	26.4%	17.6%	21.6%

4.1.3 Indoor and outdoor environmental parameters

The seven-day running mean outdoor temperature was 20°C in spring, 28°C in summer, slightly above 23°C in autumn and slightly above 6°C in winter. For the two mixed mode buildings the difference between the indoor air temperature and the running mean outdoor temperature was 4 to 6 K in spring, -5 K in summer, around zero in autumn and 17 K in winter. The free running building 3 showed differences of 2 K in spring, -2 K in summer, 2 K in autumn and 11 K in winter.

The range of operative temperatures was 20.0°C - 26.7°C in building 1, 19.1°C - 27.3°C in building 2, and 13.3°C - 28.4°C in building 3. The highest and lowest operative temperatures were recorded in the free running building, while the ranges related to the mixed mode buildings were very similar. The free running building experienced a variation in the mean and median operative temperature during the four seasons, while the mean and median temperatures were around 23 to 24°C during all seasons in the mixed mode buildings. Relative humidity varied between 20 and 65% in all buildings and the ranges were quite similar in all buildings. The median air velocity in both mixed mode buildings was 0.1 m/s during all seasons or lower; and in the free running building 0.1 m/s but 0.2 m/s in autumn. The maximum air velocity was measured in building 1 of 0.8 m/s in summer while it was 0.32 m/s in building 2. Table 4-2 shows minimum, mean, median and maximum values of indoor and outdoor environmental parameters determined during the field surveys.

Concerning CO_2 concentration, the medians of CO_2 concentration in mixed mode buildings were always below 1000 ppm, which is a concentration typical of occupied spaces with good air exchange. In the case of the free running building, medians were under 1000 ppm during all seasons, except winter, when it was 1800 ppm, which indicates insufficient ventilation and poor air. This is due to the use of portable gas heaters, which increased the amount of CO_2 in indoor air. It could also be due to lack of ventilation as it was cold outside.

The sound pressure levels (SPL) were within the acceptable ranges of SPL < 55 dB in the offices most of the time except, some values which were recorded in offices that face the main streets. Sound pressure level (SPL) instruments were not available during the first survey in April, therefore these measurements are missing in Table 4-2.

Table 4-2. Minimum, mean, median and maximum values of indoor and outdoor environmental parameters observed during the field surveys.

Spring and summer

	season/ building																							
	spring												summer											
	building 1				building 2				building 3				building 1				building 2				building 3			
parameter	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.
T_{mm}, °C	12.0	18.7	19.0	24.0	13.0	17.9	21.0	23.0	12.0	19.8	20.0	24.0	27.0	27.8	27.0	30.0	24.0	27.7	27.0	29.0	24.0	27.7	28.0	29.0
T_{rm}, °C	16.6	19.7	19.3	22.2	16.6	19.3	18.3	21.4	19.3	21.5	22.2	24.1	27.3	27.8	27.9	28.5	25.6	27.9	28.0	28.3	25.6	28.0	28.0	28.5
T_a, °C	22.1	23.3	23.3	26.0	21.1	23.6	23.9	25.5	16.5	24.2	24.3	27.9	20.1	23.0	22.9	26.0	20.1	23.7	23.3	27.2	25.6	26.3	26.4	26.7
ΔT, K	5.5	3.6	4.0	3.8	4.5	4.3	5.6	4.1	-2.9	2.6	2.1	3.8	-7.2	-4.8	-5.0	-2.5	-5.5	-4.2	-4.7	-1.1	-0.1	-1.7	-1.6	-1.8
Tg, °C	21.9	23.9	23.6	26.2	20.6	23.9	24.1	25.7	16.2	24.4	24.6	28.4	20.3	23.0	23.0	26.0	19.9	23.7	23.5	27.3	25.5	26.1	26.3	26.7
T_r, °C	21.3	24.2	23.7	28.5	19.9	24.0	24.1	26.2	16.1	24.6	25.0	29.0	20.4	23.0	23.1	26.0	19.5	23.7	23.6	27.3	24.9	25.9	26.1	26.9
T_{op}, °C	21.8	23.8	23.7	26.0	20.5	23.8	24.1	25.8	16.3	24.4	24.6	28.4	20.3	23.0	23.0	26.0	19.8	23.7	23.5	27.3	25.4	26.1	26.2	26.7
RH %	24	37	38	52	23	38	38	48	20	29	27	61	30	49	51	60	40	49	46	64	43	56	55	66
va, m/s	0.01	0.06	0.04	0.19	0.01	0.06	0.04	0.32	0.02	0.15	0.10	0.60	0.01	0.12	0.11	0.79	0.01	0.11	0.12	0.27	0.08	0.13	0.12	0.24
I_{cl}	0.6	0.9	1.0	1.2	0.5	0.7	0.6	1.0	0.5	0.8	0.6	1.3	0.6	0.7	0.6	1.1	0.5	0.6	0.6	1.0	0.5	0.6	0.6	0.8
M	1.0	1.2	1.2	1.4	1.0	1.2	1.2	1.5	1.0	1.2	1.3	1.4	1.0	1.2	1.2	1.4	1.0	1.2	1.2	1.6	1.0	1.3	1.3	1.5
CO_2	468	695	644	1033	300	530	523	883	372	467	451	609	420	663	683	876	434	520	522	665	451	463	458	502
SPL													30	53	55	76	38	51	51	68	47	58	60	70

Autumn and winter

	season/ building																							
	autumn												winter											
	building 1				building 2				building 3				building 1				building 2				building 3			
	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.	Min.	Mean	Median	Max.
T_{mm}, °C	22.0	22.7	22.0	24.0	18.0	23.7	24.0	26.0	22.0	23.6	23.0	26.0	4.0	7.0	6.0	9.0	4.0	7.8	6.0	11.0	4.0	7.4	7.5	11.0
T_{rm}, °C	22.1	23.1	23.3	23.7	21.9	23.4	23.5	24.1	22.2	23.3	23.3	24.1	5.9	6.7	6.4	8.3	5.1	6.9	6.2	9.8	5.1	6.7	6.5	8.3
T_a, °C	21.0	23.1	23.0	24.9	22.0	24.1	23.7	26.8	24.3	25.6	25.2	27.6	19.6	23.4	23.5	26.7	19.5	23.1	23.5	26.2	13.8	17.5	17.8	19.7
ΔT, K	-1.1	0.1	-0.3	1.2	0.1	0.7	0.2	2.7	2.1	2.3	1.9	3.5	13.7	16.8	17.1	18.4	14.4	16.2	17.3	16.4	8.7	10.8	11.4	11.4
Tg, °C	21.3	23.2	23.3	24.9	21.6	24.1	24.1	27.1	24.3	25.6	25.4	27.6	20.1	23.6	23.4	26.7	18.9	23.3	23.6	26.3	13.3	17.2	17.6	19.1
T_r, °C	20.7	23.3	23.4	25.0	21.1	24.2	24.5	28.0	24.4	25.7	25.4	27.9	20.4	23.7	23.5	26.7	18.8	23.3	23.6	26.3	12.3	16.8	17.5	19.0
T_{op}, °C	21.3	23.2	23.3	24.9	21.6	24.1	24.2	26.9	24.3	25.6	25.5	27.6	20.0	23.6	23.4	26.7	19.1	23.2	23.5	26.3	13.3	17.2	17.6	19.0
RH %	26	42	45	56	24	37	37	50	27	34	35	40	23	35	36	54	23	37	37	50	37	54	55	66
va, m/s	0.01	0.10	0.11	0.31	0.01	0.08	0.05	0.28	0.10	0.15	0.17	0.27	0.01	0.04	0.03	0.26	0.01	0.03	0.03	0.15	0.03	0.08	0.08	0.13
I_{cl}	0.6	0.6	0.6	1.1	0.5	0.6	0.6	1.0	0.6	0.7	0.7	0.8	0.6	1.0	1.0	1.1	0.6	1.0	1.1	1.3	0.8	1.1	1.2	1.3
M	1.0	1.2	1.2	1.4	1.0	1.2	1.2	1.5	1.2	1.3	1.3	1.4	1.0	1.2	1.2	1.6	1.0	1.2	1.2	1.4	1.2	1.3	1.3	1.4
CO_2	455	759	735	1061	442	544	546	767	438	502	511	546	506	821	809	1117	412	769	734	1683	1400	1779	1800	1901
SPL	50	60	59	69	40	55	54	75	48	64	62	77	22	52	53	66	36	50	50	62	22	51	58	65

T_{mm}: mean monthly outdoor temperature, T_{rm}: running mean outdoor temperature (7 days, α=0.8) in °C, T_a: indoor air temperature, °C; ΔT: temperature difference of T_a and Trm , K; T_g: globe temperature in °C, T_r: mean radiant temperature in °C (calculated), T_{op}: indoor operative temperature in °C (calculated), RH: relative humidity in %, v_a: air velocity in m/s, , I_{cl}: total clothing insulation (excluding chair) in clo, M: metabolic rate in met, CO_2 concentration in ppm, SPL sound pressure level in dB.

Figure 4-2 shows the distribution of outdoor running mean temperatures and indoor operative temperature for the three buildings during the four seasons.

In spring the median running mean temperature was 20.0°C while the corresponding operative temperature in the three buildings was around 24.0°C. During summer the median running mean temperature was 28°C. The free running building 3 showed a median operative temperature of 26°C, 3 K higher than those in the mixed mode buildings (23°C). The Autumn's median running mean outdoor temperature was 23°C, while the operative temperatures were 23.5°C, 24°C and 25.5°C in buildings 1, 2 and 3 respectively. In winter the median running mean outdoor temperature was around 6.5°C. The operative temperature in the mixed mode buildings 1 and 2 were similar to that in other seasons, at around 23.5°C, but comparatively low at 18°C in the free running building.

The exponentially weighted running mean outdoor temperature was adopted in this study to reflect the significant role of the occupants' past and current thermal experiences with outdoor climate conditions. It was calculated for each day of the surveys considering the last 7 days prior to the day in question.

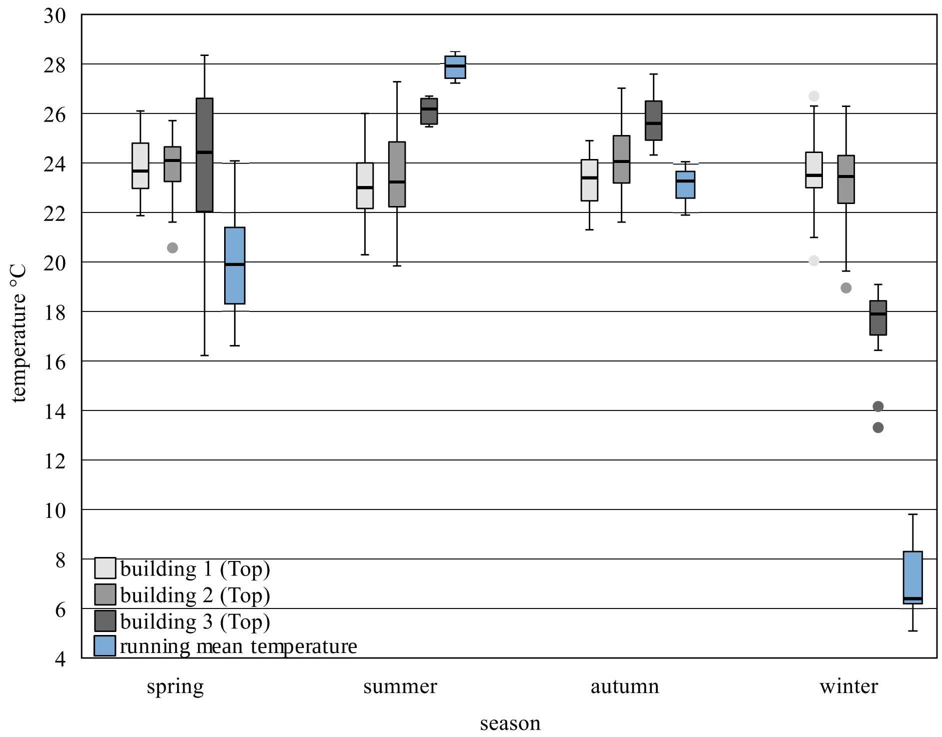


Figure 4-2. Distribution of the running mean outdoor temperature and indoor operative temperature for the three buildings during the four seasons.

The median clothing insulation of females was found to be slightly higher in spring than that of the males, despite the similar minimum 0.5 and maximum 1.3. On the other hand, median clothing insulation was found to be the same during the other seasons for both females and males. Median metabolic rate was 1.2 met which relates to seated office activities. That was also observed while conducting the surveys as they were mostly seated or doing light office work. Table 4-3 shows the descriptive data of the clothing insulation and metabolic rate in relation to gender and season.

Table 4-3. Minimum, median and maximum values of clothing insulation Icl (excluding chair) in clo and metabolic rate M in met for female and male occupants during the four seasons.

		season											
		spring			summer			autumn			winter		
		min	med.	max	min	med.	max	min	med.	max	min	med.	max
I_{cl}	female	0.5	0.9	1.3	0.5	0.6	1.1	0.5	0.6	1.1	0.7	1.0	1.3
	male	0.5	0.6	1.3	0.5	0.6	1.0	0.5	0.6	1.0	0.6	1.0	1.3
M	female	1.0	1.2	1.5	1.0	1.2	1.6	1.0	1.3	1.4	1.0	1.3	1.6
	male	1.0	1.2	1.4	1.0	1.2	1.5	1.0	1.2	1.5	1.0	1.2	1.6

4.1.4 Air conditioning state in the mixed mode buildings

Table 4-4 shows the state of the thermostats in the mixed mode buildings during filling in the set of questions. Given that the thermostats' state were registered only while the occupants filled in the questionnaires, the frequency of ON and OFF states are quite similar in both buildings. In spring, occupants did not make use of the air-conditioning in 78 to 85% of the observed time, indicating both buildings were mostly used in a free running mode. In both summer and winter, air-conditioning was in use 67 to 75% of the time. In autumn, the percentages are equally divided between ON and OFF. This indicates that it might be differences in the frequency of the usage.

Table 4-4. Proportion of thermostat state ON or OFF in the mixed mode buildings 1 and 2 while filling in questionnaires.

Thermostat state	season/ building							
	spring		summer		autumn		winter	
	b 1	b 2	b 1	b 2	b 1	b 2	b 1	b 2
ON, %	15	22	67	75	50	51	71	75
OFF, %	85	78	33	25	50	49	29	25

4.1.5 Thermal sensation

During the 'thermal comfort and personal control questionnaire', the thermal sensation of subjects was assessed using the question 'How do you perceive the air temperature at the moment in your office?' the occupants voted on the ASHRAE seven-point thermal sensation scale which has the range of -3 cold to +3 hot. The following observations were made:

- More than 80% of the responses on the seven-point thermal sensation scale were related to the central votes (slightly cool, neutral, slightly warm) except for the winter votes in the free running building. The proportion of occupants' responses in the three central votes was 78, 84 and 91% in spring, 74, 87 and 100% in summer, 81, 83 and 88% in autumn and 86, 83, and 43% in winter season for building 1, building 2, and building 3 respectively (Figure 4-3).
- During spring season, median thermal sensations were 'neutral' in all buildings (Table 4-5).
- During summer and autumn seasons, median sensations were found to be slightly warm in the free running building, neutral in building 2 while slightly cool in building 1 which is one of the mixed mode buildings (Table 4-5).
- During winter season, median thermal sensations were found to be neutral in the mixed mode buildings but cool in the free running building, as the median operative temperature as mentioned before was relatively low 18°C in this building (Table 4-5).

Only a few occupants felt cool or cold in winter in the case of the mixed mode buildings, whereas more than half of the occupants did in the free running building. In summer few respondents reported feeling warm or hot among all buildings (Figure 4-3).

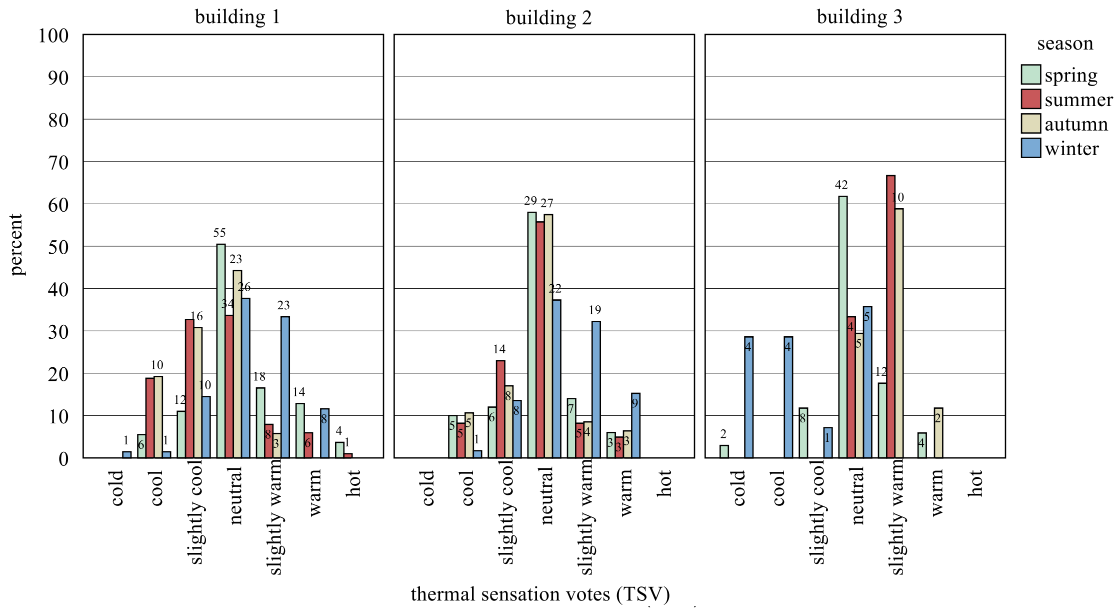


Figure 4-3. Thermal sensation votes during the different seasons. Numbers refer to the number of votes.

Table 4-5. Median values of thermal sensation, thermal preference, thermal comfort, air velocity perception, preference and comfort and PMV.

	season											
	spring			summer			autumn			winter		
	b 1	b 2	b 3	b 1	b 2	b 3	b 1	b 2	b 3	b 1	b 2	b 3
thermal sensation	0	0	0	-1	0	1	-1	0	1	0	0	-2
thermal preference	3	3	3	3	3	3	3	3	2	3	3	4
thermal comfort	4	4	4	3	4	4	3	4	4	3	4	2
air movement perception	2	1	3	3	2	3	3	1	2	1	2	2
air movement preference	3	3	3	3	3	3	3	3	4	3	3	3
air movement comfort	3	4	4	3	4	3	3	4	4	3	4	3
PMV	0.4	0.2	0.3	0.0	0.0	0.7	0.0	0.2	0.6	0.5	0.5	-0.4

Key: thermal sensation (7-point scale, 0 = neutral), thermal preference (5-point scale, 3 = no change), thermal comfort (5-point scale, 1 = very uncomfortable, 5= very comfortable), air movement perception (5-point scale, 3 = slight), air movement preference (5-point scale, 3 = no change), air movement comfort (5-point scale, 1 = very uncomfortable, 5 = very comfortable). b1: building 1, b2: building 2, b3: building 3.

4.1.6 Thermal preference

Thermal preferences were captured with the question ‘How would you prefer the air temperature at the moment in your office?’ the occupants voted on five-point scale which has the range of 1 for much cooler and 5 for much warmer. Figure 4-4 shows thermal preference during the different seasons. Following observations were made:

- The highest percentages of votes in building 1 were related to ‘no change’ during the spring, autumn and winter seasons, while the occupants preferred a cooler temperature in summer. Percentages for the ‘no change’ vote were 50%, 39%, 52% and 42% in spring, summer, autumn and winter, respectively.
- The majority of occupants in building 2 preferred not to change the thermal conditions among all seasons, as the corresponding percentages of the ‘no change’ vote were 60%, 65%, 68% and 70% in spring, summer, autumn and winter respectively.
- Occupants in the free running building preferred ‘no change’ in spring. In summer the votes were distributed between ‘no change’ and preferring a cooler air temperature. They preferred having cooler temperatures in autumn and warmer temperature in winter. Percentages for ‘no change’ vote were 51%, 50%, 35% and 29%, in spring, summer, autumn and winter, respectively (Figure 4-4).
- The median thermal preferences were found to be ‘no change’ in the mixed mode buildings among all seasons. On the other hand, occupants in the free running building preferred no change in their thermal environment in spring and summer, but cooler in autumn and warmer in winter as shown in (Table 4-5).

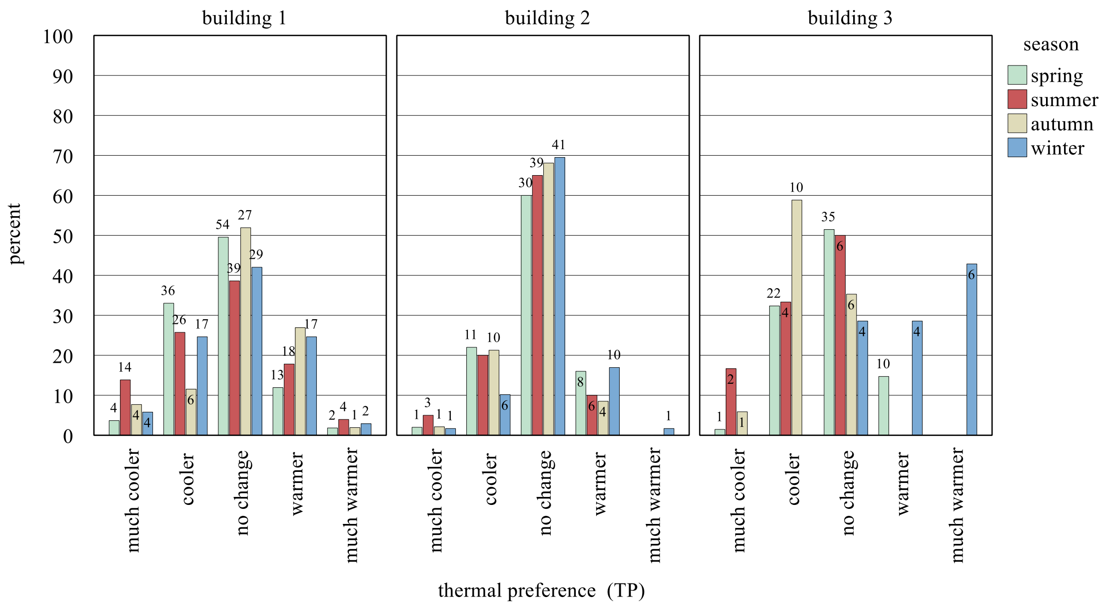


Figure 4-4. Thermal preference during the different seasons. Numbers refer to the number of votes.

4.1.7 Thermal sensation and preference

Figure 4-5 shows the relation between thermal sensations and thermal preferences among the four seasons. Occupants preferred no change or cooler air temperatures when they indicated answers towards the warm part ,1, 2 and 3, on the thermal sensation scale while they preferred no change or warmer air temperatures if their thermal sensation votes were related to the cool part, -1, -2 and -3. The preference answer for the neutral thermal sensation was 'no change'.

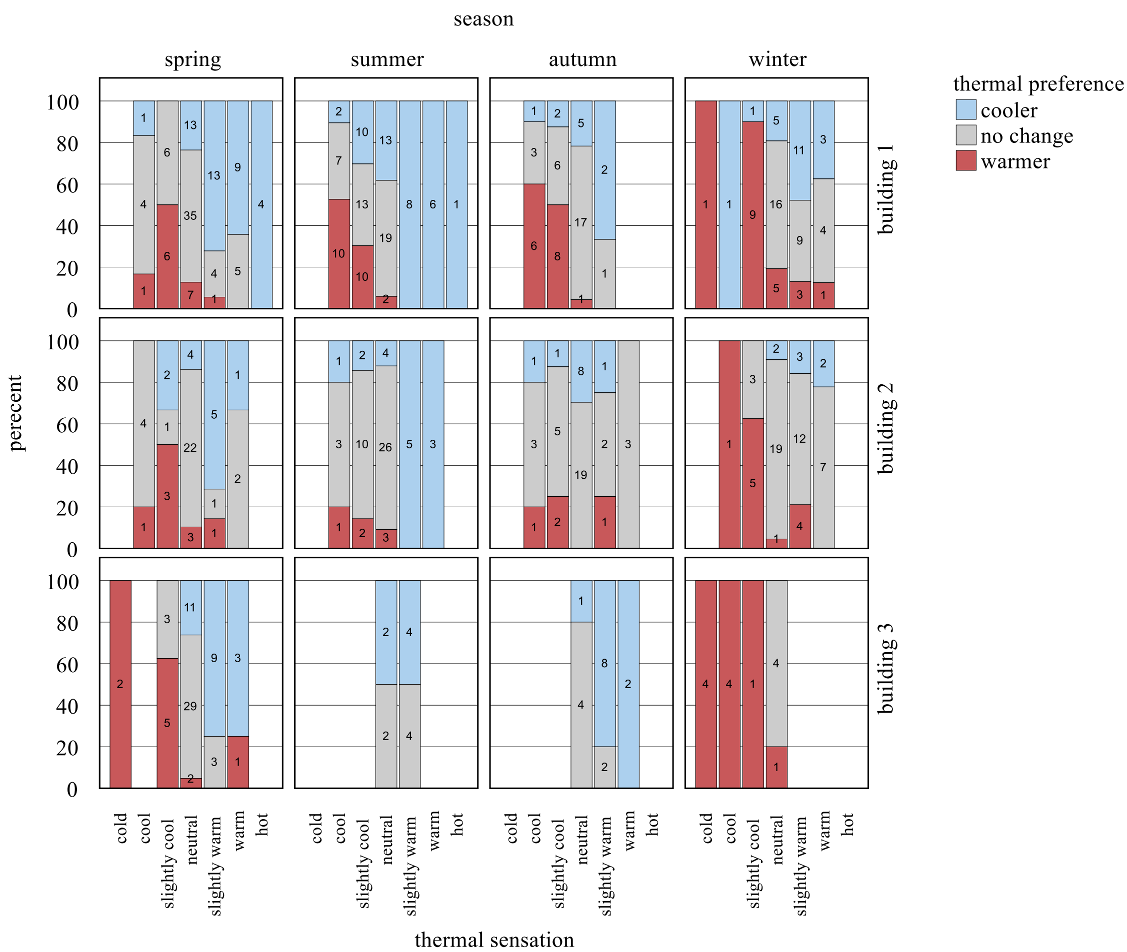


Figure 4-5. The relation between thermal sensations and thermal preferences during the four seasons. Numbers refer to the number of votes.

4.1.8 Thermal comfort perception

The question related to thermal comfort perception in the 'thermal comfort and personal control questionnaire' was 'How do you rate the temperature in your office?'. The occupants voted on a five-point scale: 'very uncomfortable' (1)…'very comfortable' (5). Most of the votes were distributed from 3 to 5 on the comfort scale, with high percentages in the three buildings during all seasons except in case of the winter season in the free running building. The following responses were observed on the 3 to 5 comfort scale, as shown in Figure 4-6:

- Building 1: 83% in spring, 70% in summer, 89% in autumn and 77% in winter. The median values of the comfort perception votes were either 3 or 4 on the scale.
- Building 2: 90% in spring, 96% in summer, and 92% in autumn and winter. The median value of the comfort perception votes was 4 during all seasons.
- Building 3, 82% in spring, 92% in summer, 82% in autumn, and 43% in winter. The median values of the comfort perception votes were 4 in all seasons and 2 in winter.

These values indicate high levels of thermal comfort in all seasons, in both mixed mode buildings and also the free running building, except in winter.

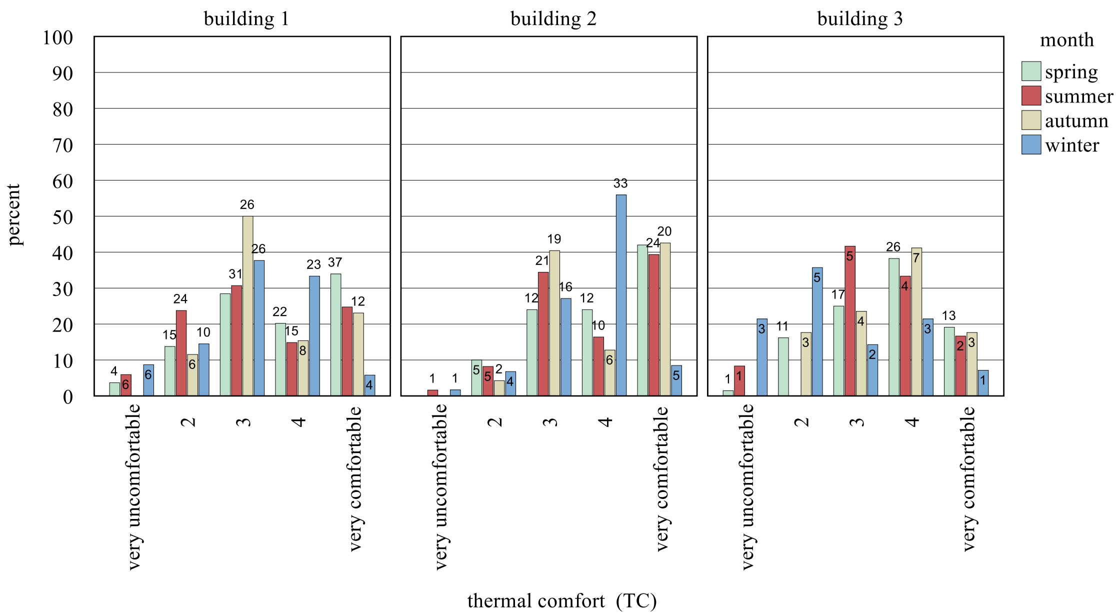


Figure 4-6. Thermal comfort during the different seasons. Numbers refer to the number of votes.

As the thermal comfort scale used in this study was a five-point scale, statistical analysis was applied to determine if the votes on the middle part of the scale '3' could be considered as 'comfortable' or 'uncomfortable' (Table 4-6).

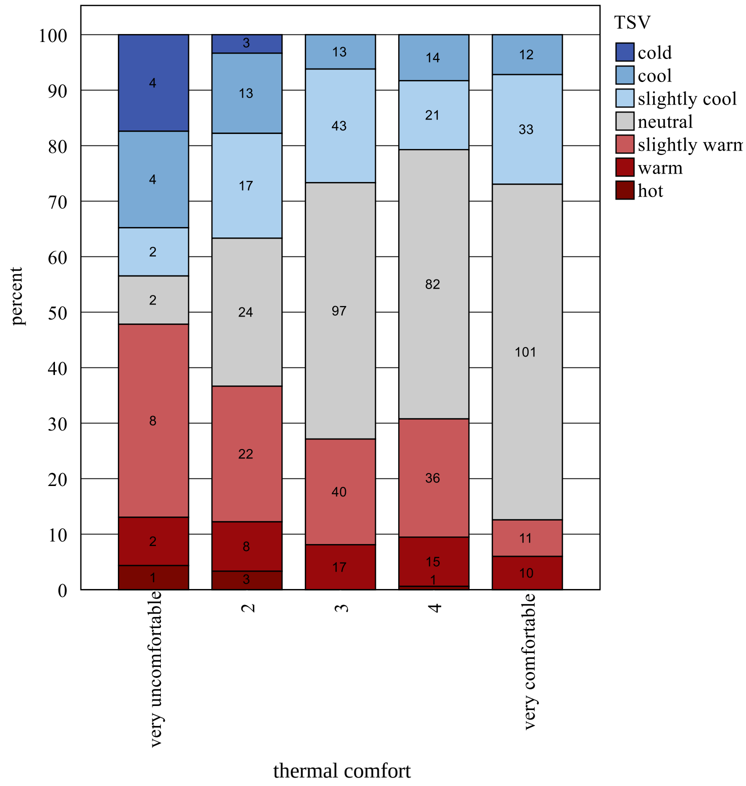


Figure 4-7. The relation between thermal sensation votes and thermal comfort. Numbers refer to the number of votes.

As shown in Figure 4-7 the distribution of the thermal sensation votes on vote ‘3’ of the thermal comfort scale (TC) is similar to that on ‘4’ and ‘5: very comfortable’.

Chi square and contingency coefficient tests were applied between the thermal sensation votes and thermal preference votes for three cases (Table 4-6):

1-Thermal sensation votes (7-point scale) and thermal comfort votes on a 5-point scale.

2-Thermal sensation votes and thermal comfort votes when the votes of the middle part on the thermal comfort scale (TC) were related to ‘comfortable’ votes.

3-Thermal sensation votes and thermal comfort votes when the votes of the middle part on the TC scale were related to ‘uncomfortable’ votes.

The tests showed that adding the votes of the middle part of the scale to the ‘comfortable’ votes was significant and had a moderate relation with C_{cor} = 0.27, while it was not significant when adding these votes to the ‘uncomfortable’ votes and the relation was weak C_{cor} = 0.12. Furthermore, the distribution trend of ‘case 2’ when adding the middle votes to the comfortable votes was very similar to the original case on the 5-point scale.

Based on these results, the votes of the middle part of the scale can be considered as ‘comfortable’ in this study.

Table 4-6. Chi square and contingency coefficient tests between thermal sensation votes and thermal comfort votes.

case	description	Pearson Chi-Square	df	Sig. (2-sided)	contingency coefficient	corrected contingency coefficient
case 1	TC 5-point scale	33.7	2	0.00 *	0.22	0.27
case 2	uncomfortable 1-2, comfortable 3-5 on the TC scale	25.6	8	0.00 *	0.19	0.27
case 3	uncomfortable 1-3, comfortable 4-5 on the TC scale	3.7	2	0.16	0.074	0.12

* correlation is significant at the 0.05 level (2-tailed).

4.1.9 Air movement

Air movement was mostly imperceptible; therefore, the highest percentages of air velocity perception were related to the responses of ‘no movement, very slight and slight’. The corresponding percentages of these three votes were 95% in spring, 96% in summer, 94% in autumn and 98% in winter as shown in Figure 4-8. The median values of the air velocity perception votes were also ‘no movement 1, very slight 2 and slight 3’ (Table 4-5).

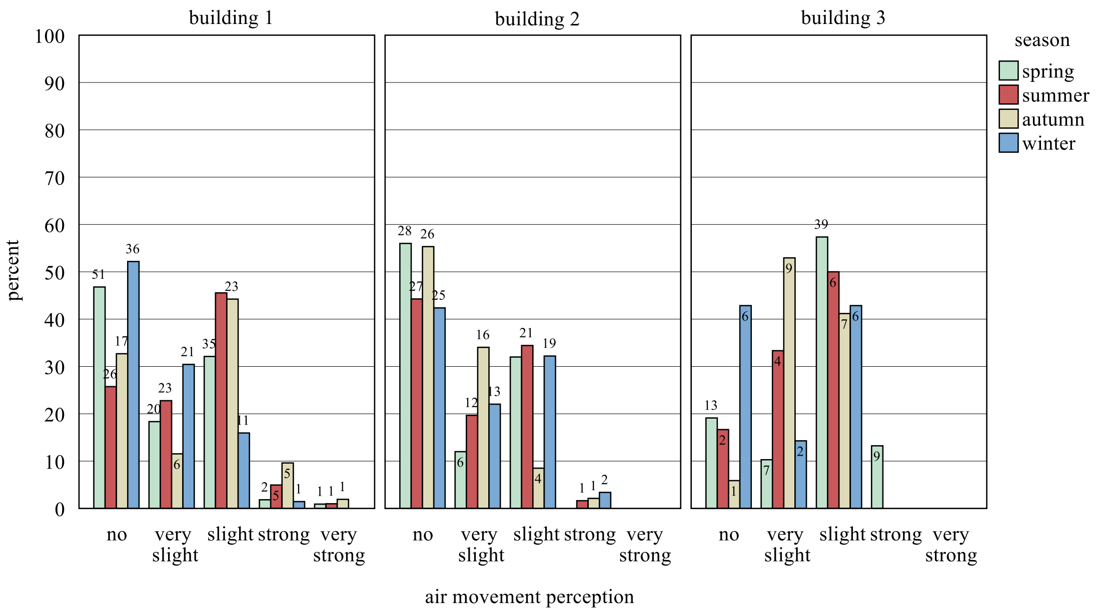


Figure 4-8. Air movement perception during the four seasons. Numbers refer to the number of votes.

Although the highest air velocity preference was for ‘no change’ among all seasons, some occupants preferred stronger air velocity in summer (40%, 25%, 42%) and weaker air velocity in winter (40%, 25%, 50%) in buildings 1, 2 and 3 respectively (Figure 4-9).

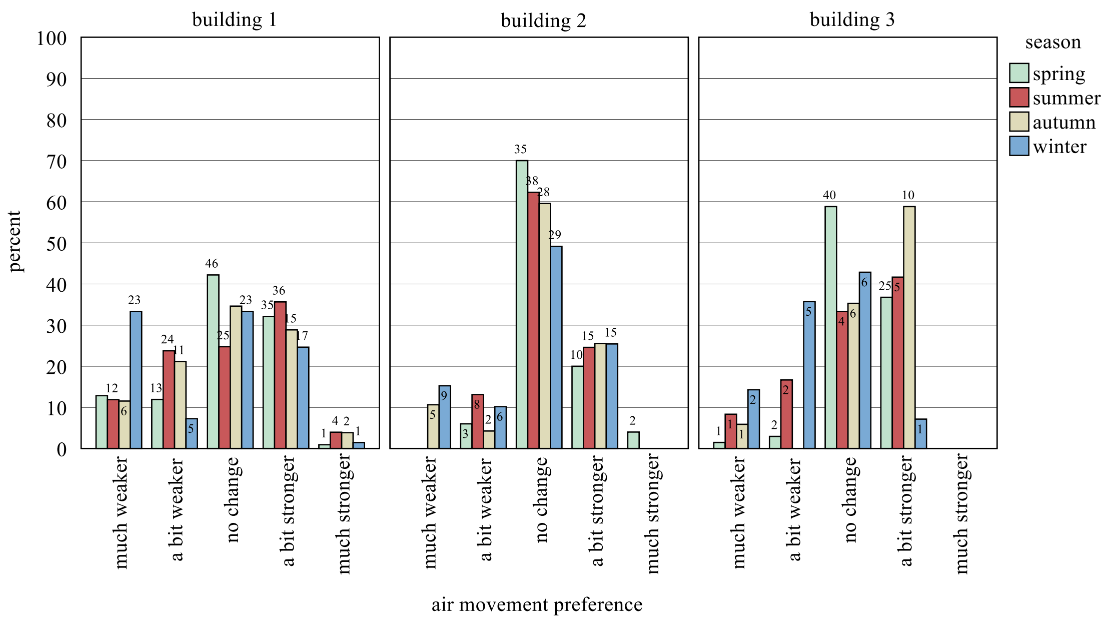


Figure 4-9. Air movement preference during the four seasons. Numbers refer to the number of votes.

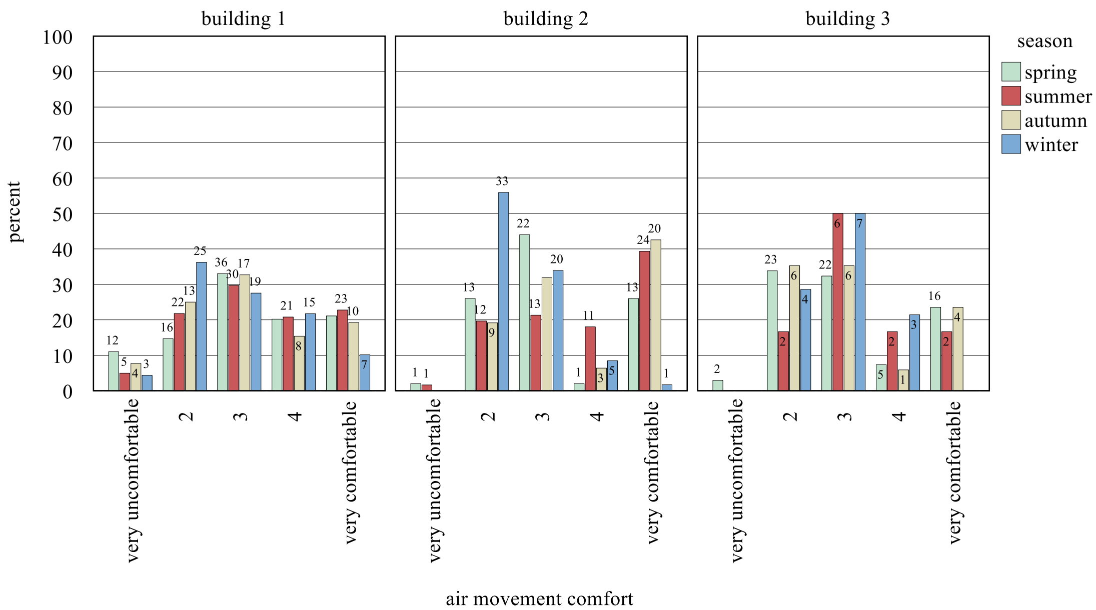


Figure 4-10. Air movement comfort during the four seasons. Numbers refer to the number of votes.

The results showed that occupants felt comfortable with the air movement in their offices, as the following percentages were reported considering the votes 3 to 5 on the air movement comfort scale: 69%, 74%, 77% and 74% in building 1, 96%, 80%, 94%, and 92% in building 2 and 90%, 84%, 94% and 79% in building 3, during the spring, summer, autumn and winter seasons respectively (Figure 4-10).

4.1.10 Humidity

The medians of relative humidity measurements during the surveys varied between 27% and 56%. Gonzalez & Gagge, 1973 concluded, if the air temperatures are within or around the comfort zone, relative humidity from 20% to 60% do not have any impact on thermal sensation. In this study, only one subjective question was related to RH which was 'How do you rate the Humidity in your office?'. The occupants voted on a five-point scale from very 'uncomfortable (1)' to 'very comfortable (5)'. The votes were distributed on the 3 to 5 comfort scale with high percentages 83% in building 1, 95% in building 2 and 92% in building 3 (Figure 4-11). These percentages indicated a high level of humidity comfort.

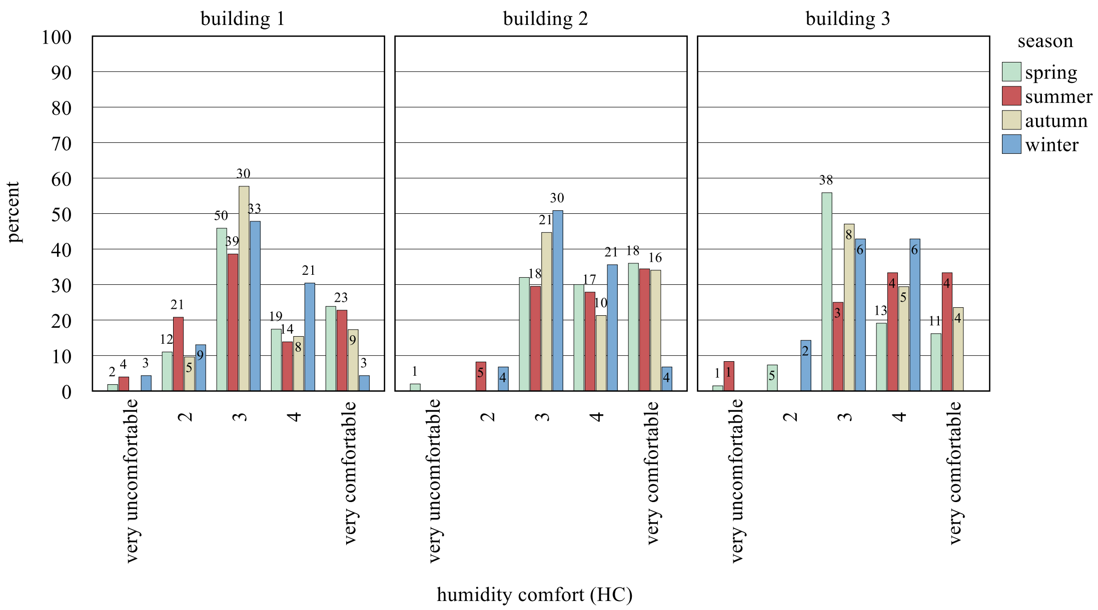


Figure 4-11. Humidity comfort during the four seasons. Numbers refer to the number of votes.

4.2 Guessed temperature vs. operative temperature

Thermal sensation votes are a result of the occupants' perception in regard to the indoor temperature. One of the addressed questions during the survey was to let the subjects guess the indoor temperature. In some cases, the relation between the TSV and operative temperature was negative, as occupants reported negative perception for relatively high temperatures. When these responses were compared with the guessed temperatures, a positive relation was found as, the occupants' perception of the indoor temperature was lower than the real measured values. In spring, summer and autumn, the guessed temperatures on the warm part of the TSV scale were higher than the measured ones. On the other hand, the guessed temperatures on the cool part tended to be lower than that measured. In winter, guessed temperatures tended to be higher than that measured. Guessed and measured indoor temperatures related to the 'neutral' vote were approximately in the same range (Figure 4-12).

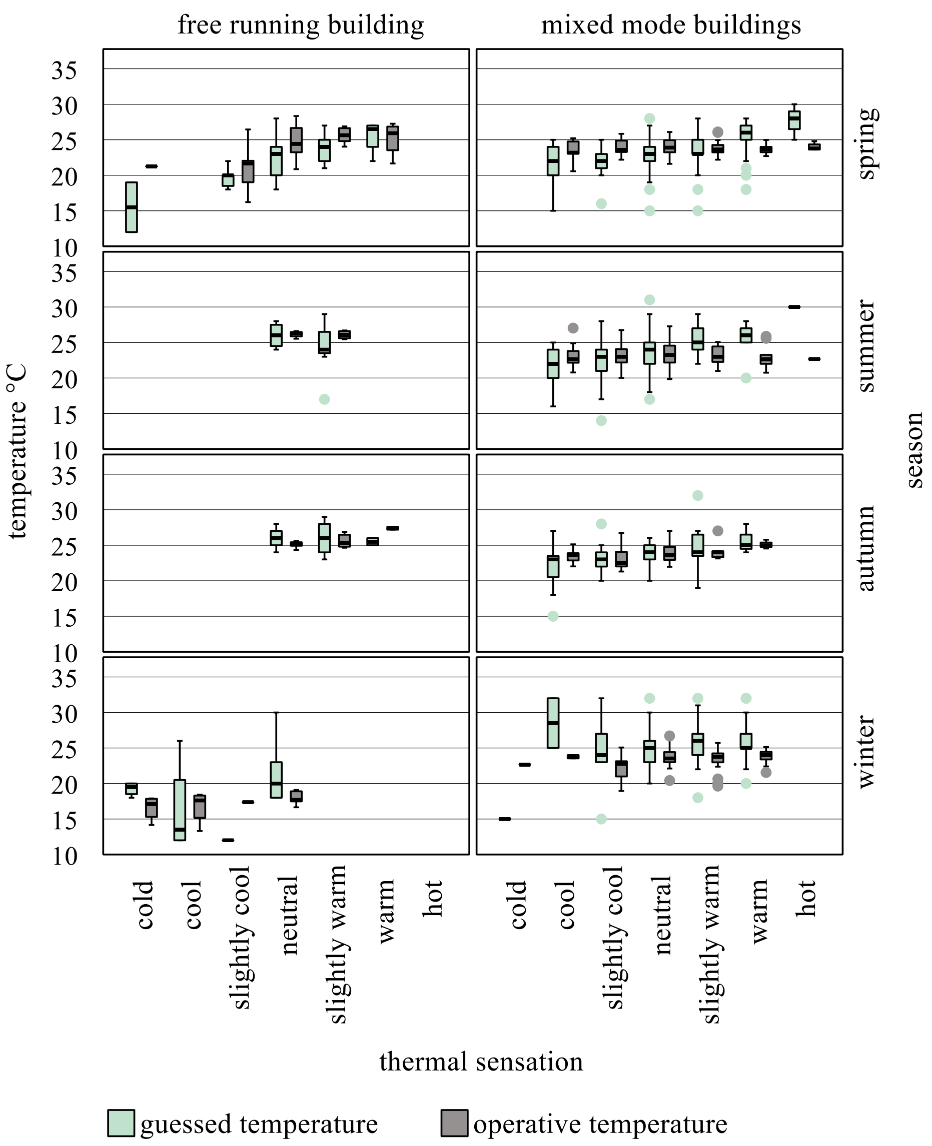


Figure 4-12. The relation of TSVs for both indoor operative temperature and temperature guessed by the occupants.

4.3 Determine neutral temperatures from thermal sensation votes and operative temperatures

In order to determine the neutral temperature, thermal sensation votes were plotted against the operative temperatures as shown in Figure 4-13. The models are based on the panel analysis regression (Table 4-7).

In building 1, the regression lines of both spring and winter are around the 'neutral' thermal sensation vote and towards 'slightly warm' while in autumn occupants felt 'slightly cool' and towards 'neutral'. The regression models failed to determine the neutral temperatures as the values on the x axis (operative temperature) were observed to be the same observations as those on the y axis, in addition to the nature of the data, which are not normally distributed (Figure 4-13a). In summer, the thermostat set point temperatures during the AC mode were low in some offices, at around 16 -18 °C, as observed during the surveys. In these offices which were shared or open plan offices, thermal sensation votes were 'slightly cool' and 'cool' as the occupants answered based on a knowledge that indoor temperature was lower than the real measured values, resulting in a negative slope of decreasing the TSV when the operative temperature increased as shown in Figure 4-12.

In building 2, the occupants felt neutral to the different temperature variations in spring, summer and autumn, as the responded regression lines were around 'neutral'. In winter, a linear relation was found between the 2 variables with a significant regression model (Figure 4-13b & Table 4-7).

In both mixed mode buildings, there was a wide range of indoor temperatures as occupants adjusted the available opportunities in particular thermostats to create their own thermal preference. The wide distribution of the indoor temperatures according to the individual adjustments reflected on low R-squared values. The slopes of the regression lines were very small (almost straight), thus the neutral temperatures could not be determined.

Building 3 tends to show distinct temperature ranges in each season. The results of the regression models represent the concept of adaptive thermal comfort, with a positive linear relation between thermal sensation votes and operative temperatures. In this case, the panel analysis failed to determine the neutral temperature for summer and winter, very likely because the number of responses during these seasons was relatively small (Figure 4-13c & Table 4-7).

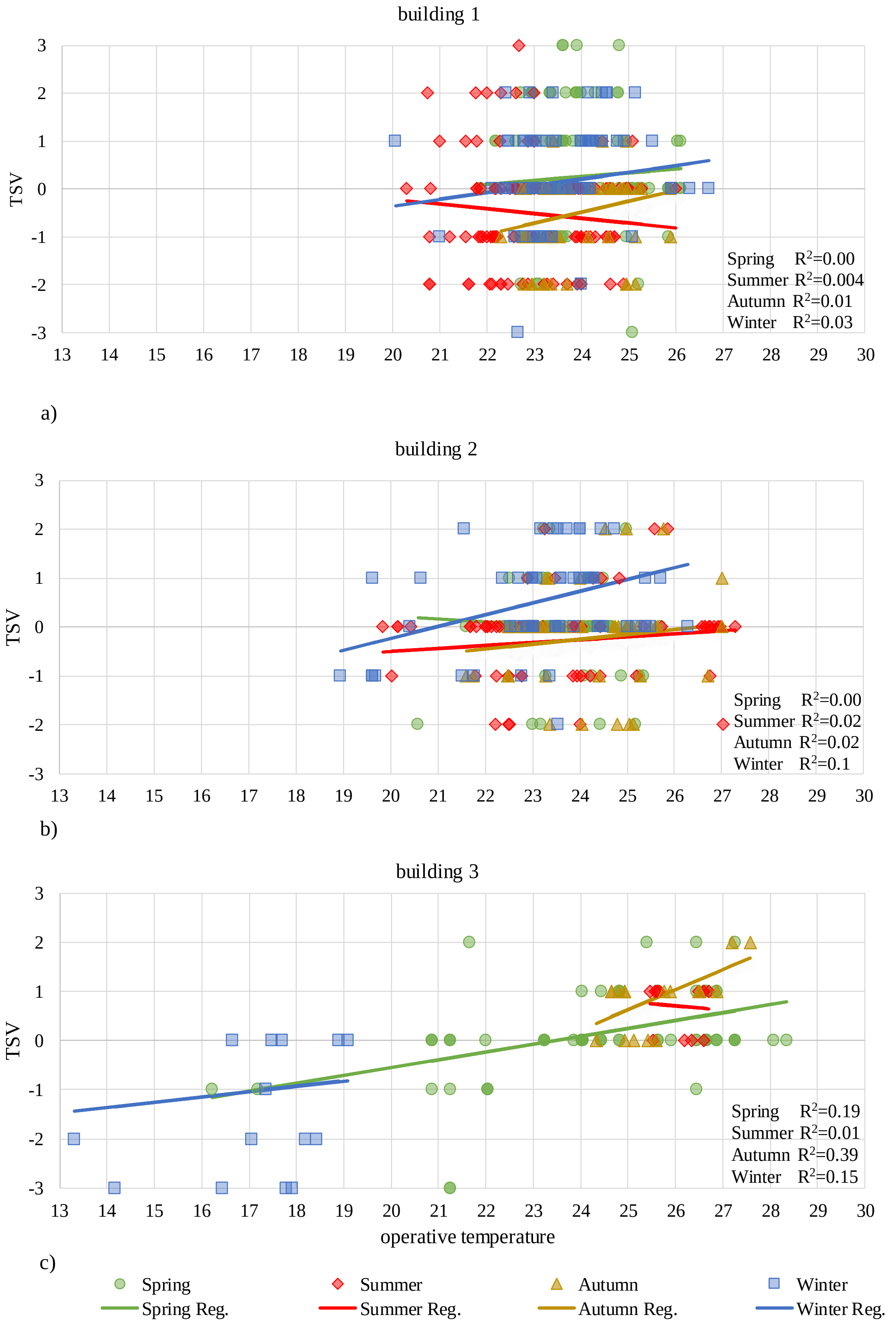


Figure 4-13. Thermal sensation votes TSV plotted over the operative temperature. Colours indicate the season. Regression lines derived from the panel analysis. a) building 1, b) building 2, c) building 3.

Figure 4-14 shows the regression models of all buildings' data considering the four seasons. The regression models for the mixed mode buildings 1 and 2 failed to determine the neutral temperatures while a significant regression model was found in the case of the free running building (Table 4-7). Significant regression models are shown in Figure 4-15. Neutral temperatures were determined from models which reached statistical significance at the $p < 0.05$. The R-squared values related to the significant regression models were between 0.1 and 0.44.

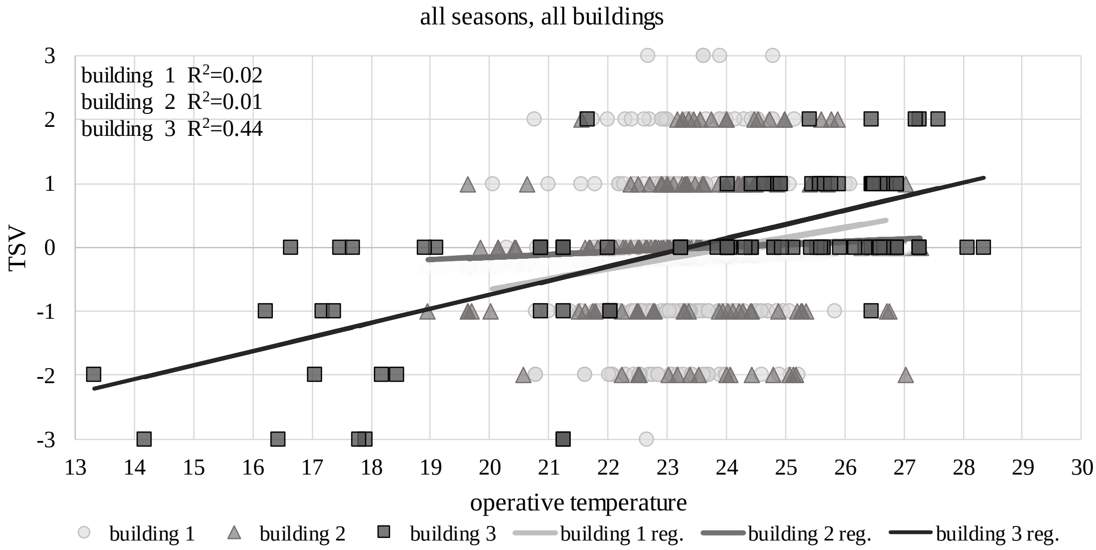


Figure 4-14. Thermal sensation votes TSV plotted over the operative temperature of the three buildings considering the four seasons. Colours indicate the building. Regression lines derived from the panel analysis.

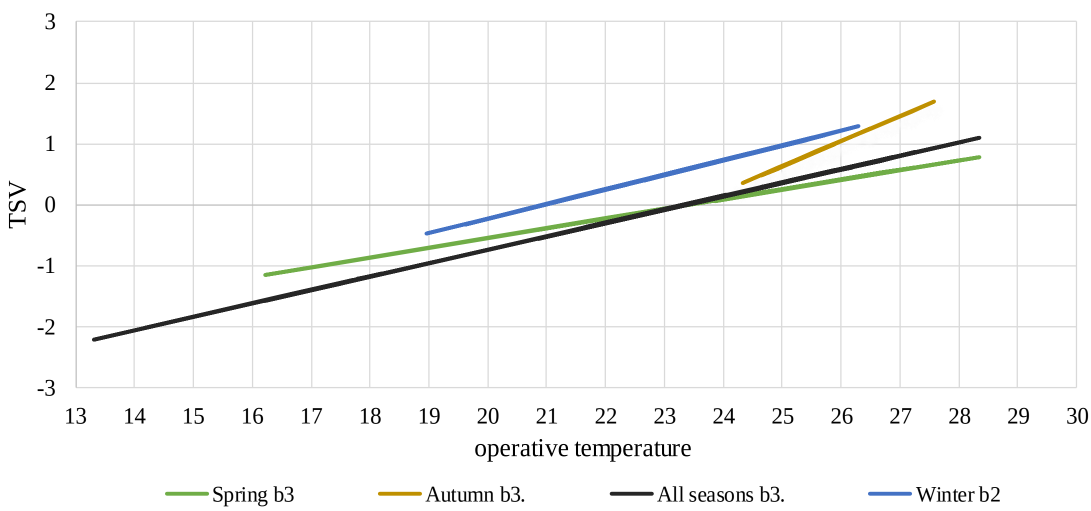


Figure 4-15. Significant linear regression models for thermal sensation votes depending on operative temperature: building 2: winter; building 3: spring, autumn, all seasons. For regression equations, p-values and R^2 see Table 4-7.

Table 4-7. Linear regression models for thermal sensation votes depending on operative temperature, predicted neutral temperature and thermal sensitivities for significant models.

building	N	median T_{rm}, °C	regression model TSV = a T_{op} + b	R^2	p	$T_{neutral}$*, °C	Thermal sensitivity K/TS-unit
spring							
b 1	109	19.3	TSV= 0.08* Top – 1.66	0.00	0.48	-	-
b 2	50	18.3	TSV= - 0.06* Top + 1.43	0.00	0.67	-	-
b 3	**68**	**22.2**	**TSV= 0.16 * Top – 3.75**	**0.19**	**<0.05**	**23.4**	**6.3**
summer							
b 1	101	27.9	TSV= -0.1 * Top +1.79	0.00	0.29	-	-
b 2	61	28.0	TSV = 0.06 * Top – 1.7	0.02	0.30	-	-
b 3	12	28.0	TSV= - 0.08 * Top + 2.79	0.01	0.80	-	-
autumn							
b 1	52	23.3	TSV= 0.23 * Top – 6.0	0.01	0.05	-	-
b 2	47	23.5	TSV= 0.10 * Top – 2.65	0.02	0.33	-	-
b 3	**17**	**23.3**	**TSV= 0.41 * Top – 9.62**	**0.39**	**<0.05**	**23.5**	**2.4**
winter							
b 1	69	6.4	TSV= 0.14* Top – 3.15	0.03	0.17	-	-
b 2	**59**	**6.2**	**TSV= 0.24 * Top – 5.03**	**0.1**	**<0.05**	**21.0**	**4.5**
b 3	14	6.5	TSV= 0.11 * Top – 2.91	0.15	0.4	-	-
all seasons							
b 1	331	22.1	TSV= 0.16* Top – 3.85	0.02	0.004	-	-
b 2	217	21.4	TSV = 0.04* Top – 0.95	0.01	0.37	-	-
b 3	**111**	**22.2**	**TSV= 0.22* Top – 5.14**	**0.44**	**<0.05**	**23.4**	**4.2**

Key: T_{rm}: running mean outdoor temperature (7 days, α=0.8) in °C ; TSV: thermal sensation vote; T_{op}: operative temperature, °C; a, b,: regression coefficients; T_{neural}: neutral temperature, °C; *only shown for significant regression models with $p < 0.05$ and explanation of variance $R^2 \geq 0.1$; thermal sensitivity: given in Kelvin per unit on the 7-point thermal sensation scale.

4.4 Comfort votes and models

4.4.1 Comfort votes

Because finding the neutral temperatures from the relation of thermal sensation vote and indoor operative temperature failed for both mixed mode buildings, the temperatures at which the occupants felt comfortable were analysed. As mentioned above, a high proportion of the occupants rated the temperature in their offices as comfortable: 79%, 92% and 78% in buildings 1, 2 and 3 respectively. Moreover, as seen in Table 4-8, occupants felt comfortable on different votes on the thermal sensation scale, not only in the case of a 'neutral' vote. They felt comfortable with regard to cool, slightly cool, slightly warm and warm, with high percentages. Furthermore, the perception of feeling comfortable on the same thermal sensation vote differed between the different seasons. In spring and autumn, feeling comfortable was related to votes ranging from cool to warm on the thermal sensation scale. In summer, the highest proportion of comfortable votes was related to slightly cool and neutral votes, while in winter, occupants felt more comfortable from the neutral vote towards the warm side of the scale. Votes related to hot or cold were considered as uncomfortable in all seasons and were also rarely voted.

Based on these results, temperatures at which occupants felt comfortable were derived from the observed operative temperatures related to the comfort votes. These temperatures are associated with adaptation during the different seasons. For each season, comfort temperatures were derived from the median values, while ranges were from the interquartile (Table 4-9).

Table 4-8 The proportion of comfortable and uncomfortable votes in each category of the thermal sensation scale, all buildings' data.

	Spring							summer						
TSV	-3	-2	-1	0	1	2	3	-3	-2	-1	0	1	2	3
not comfortable %	100	18	12	8	30	24	75	0	38	17	11	38	33	100
comfortable %	0	82	88	92	70	76	25	0	63	83	89	62	67	0
	autumn							winter						
TSV	-3	-2	-1	0	1	2	3	-3	-2	-1	0	1	2	3
not comfortable %	0	13	8	9	12	0	0	100	67	32	6	21	12	0
comfortable %	0	87	92	91	88	100	0	0	33	68	94	79	88	0

The observed median of the operative temperature of the 'comfortable' group varies in a narrow range over the seasons in both mixed mode buildings: from 23.2 to 23.6°C in building 1 and from 23.2 to 24.1°C in building 2. Building 3 medians cover a wider range from 17.6 to 26.3°C. The interquartile ranges vary between 1.2 to 2 K in building 1 and 2, but for building 3 they are between 1 and 3.3 K (Table 4-9).

Table 4-9. Observed median temperatures at which occupants felt comfortable and the interquartile ranges during the four seasons in each building.

	season							
	spring		summer		autumn		winter	
	med.	interquartile range	med.	interquartile range	med.	interquartile range	med.	interquartile range
b 1	23.6	23.0 – 25.0	23.2	22.4 – 24.2	23.4	22.4 - 24.0	23.6	23.0 - 24.2
b 2	24.1	23.3 – 24.5	23.2	22.2 – 24.9	24.1	23.1 – 25.1	23.5	22.9 – 24.3
b 3	24.6	23.2 – 26.5	26.3	25.6 – 26.6	25.7	24.9 – 26.5	17.6	17.4 – 18.9

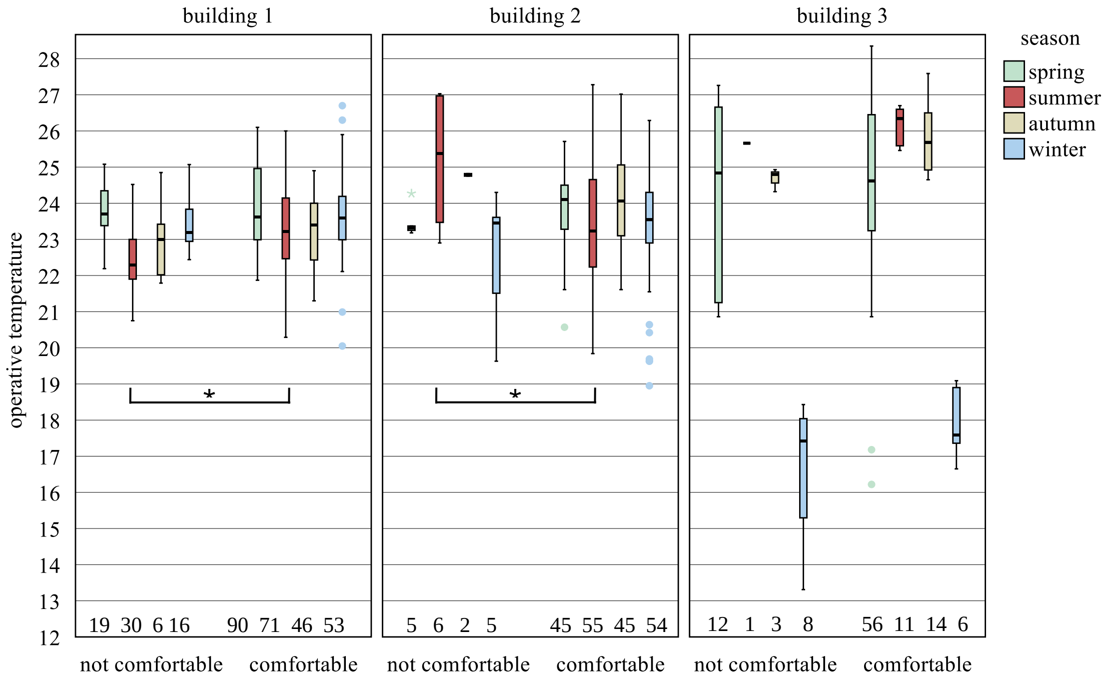


Figure 4-16 Distribution of operative temperatures of those occupants voted not comfortable and those voted comfortable. Numbers refer to the number of responses. Lines marked with a star indicate pairwise significant difference.

The operative temperature distribution of ‘comfortable’ and ‘not comfortable’ votes was compared (Figure 4-16). The operative temperature distributions of the ‘comfortable’ group look rather similar to those of the ‘not comfortable’ group in most seasons or only few occupants responded ‘not comfortable’. Significant differences (Mann Whitney-U-Test) between the operative temperatures of both groups were only found in the summer season in buildings 1 and 2 (Table 4-10). The median value of the uncomfortable group was 1 Kelvin lower than of the comfortable group in building 1 but 2 Kelvin higher for building 2. The low number of responses on the ‘not comfortable’ category could be a reason for the non-significant results.

Table 4-10 Mann-Whitney-u-test between the operative temperatures and thermal comfortable categories for each season in the three buildings.

	building/ season											
	building 1				building 2				building 3			
	spr.	sum.	aut.	win.	spr.	sum.	aut.	win.	spr.	sum.	aut.	win.
mann whitney U	837.5	663.0	115.0	355.5	71.5	84.0	33.0	103.5	331.5	4.0	6.0	17.0
Sig. (2 tailed)	0.89	**0.003**	0.51	0.33	0.19	**0.05**	0.53	0.40	0.94	0.66	0.06	0.34
N	101	109	52	69	50	61	47	59	68	12	17	14

The significance level is 0.05 (2-tailed)

In order to find an explanation for the different comfort voting at similar temperatures, the Mann Whitney-U-Test (α=0.05) was used to identify whether the differences of the median of perceived control were in dependence on the ‘not comfortable’ and ‘comfortable’ categories. A significant difference in the median of perceived control of about one unit on the five-point scale for those who voted ‘not comfortable’ (median = 3) and those voted ‘comfortable’ (median = 4) was identified in buildings 1 and 3. The analysis also shows significant differences of both categories’ median of perceived control on the building level (p= 0.003, p= 0.022, p= 0.001 for buildings 1,2 and 3 respectively). Despite the similar median of both categories in building 2, there is a significant difference between the two categories, although the votes on the ‘not comfortable’ category were very small (Figure 4-17).

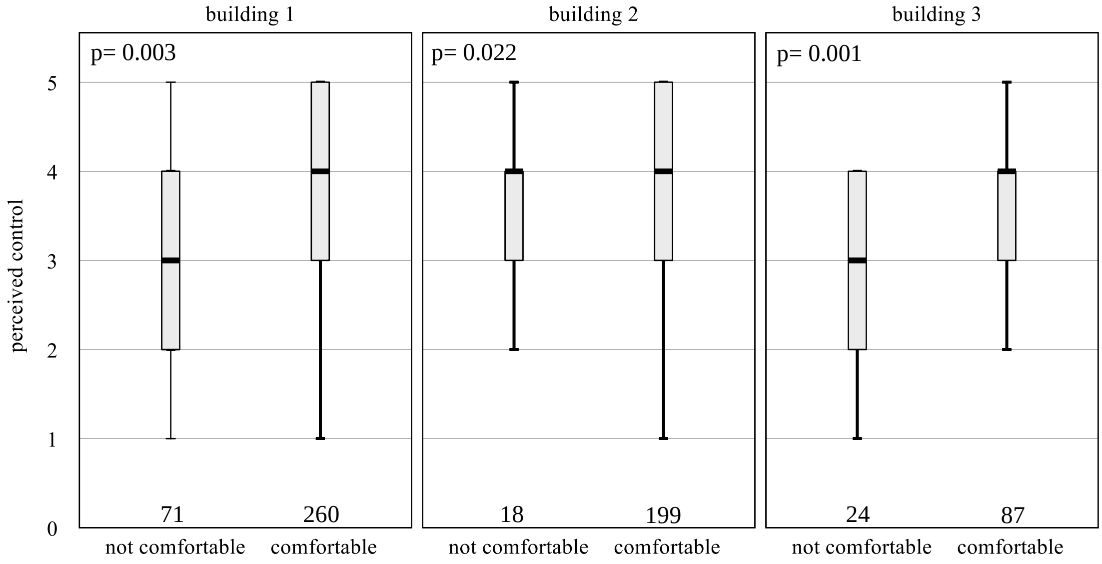


Figure 4-17 Distribution of the occupants' votes on perceived control for both 'not comfortable' and 'comfortable' categories. 0: no control at all, 5: a lot of control. Numbers refer to the number of responses.

4.4.2 Comfort models for the investigated office environments

The observed operative temperatures of those occupants who voted comfortable were plotted against the running mean outdoor temperature for each building. Linear Loess regressions with smoothing factors ranging from 0.1 to 0.9 were performed. For building 1 the application of smoothing factors in the range of 0.5 to 0.7 did not change the results. Smoothing factors between 0.4 and 0.6 ended up in a similar course of the regression for building 2. But a smoothing factor of 0.7 produced a regression line which was comparable to that of building 1. For building 3 the basic character of the regression lines did not change substantially with smoothing factors between 0.6 and 0.8. 0.7 was chosen for all buildings (see Appendix IV).

Figure 4-18 shows the scatter plots, the Loess regression, including the confidence intervals. The fitted Loess curves related to the mixed mode buildings are almost flat, which indicates no relation between the comfort temperature and the running mean outdoor temperature. The curves of the two mixed mode buildings evolve towards lower comfort temperature values in summer at appr. 22°C running mean outdoor temperature. The free running building curve has a linear relation between comfort and running mean outdoor temperature, with two discontinuities at about 19°C and 24 °C. The gradient of the graph is slightly higher between 19 and 24°C compared to the gradient < 19°C. At 24°C the curve changes into a flat line, indicating that the comfort temperature will not further increase with an increase in the running mean outdoor temperature. Because of the few responses between 6 °C and 19 °C, one regression was fitted for data related to running mean outdoor temperatures between 6 °C and 24°C. Table 4-11 shows the equations generated based on Loess regression.

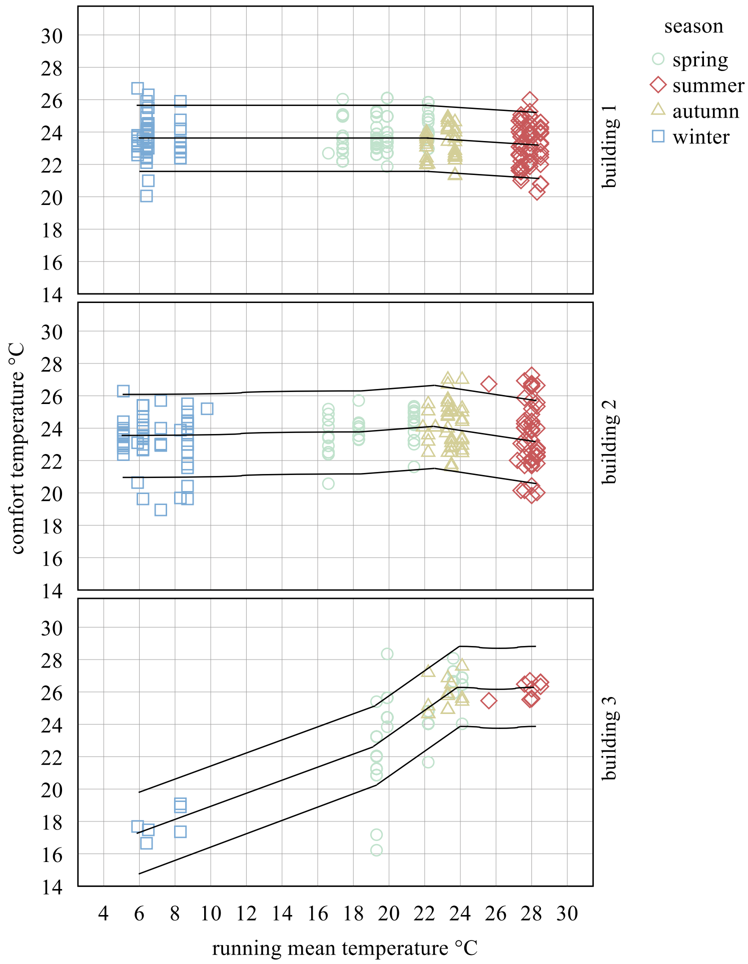


Figure 4-18. Scatterplots comfortable temperatures over running mean outdoor temperature and Loess regression models with smoothing factor =0.7, linear local regression and robustness iterations, showing also the confidence intervals.

Table 4-11. Equations generated based on Loess regression with coefficients (with 95% confidence bounds) and a smoothing factor of 0.7.

	T_{rm} range	model	P1	P2	coefficient P1 bound	Coefficient P2 bound
building 1	6°C ≤ T_{rm} ≤ 22°C	$T_c = 0.00 * T_{rm} + 23.66$	-0.00	23.66	(-0.00, -0.00)	(23.65, 23.67)
	22°C < T_{rm} ≤ 28.5°C	$T_c = -0.07 * T_{rm} + 25.19$	-0.07	25.19	(-0.08, -0.06)	(24.98, 25.39)
building 2	5°C ≤ T_{rm} ≤ 22°C	$T_c = 0.03 * T_{rm} + 23.46$	0.03	23.46	(0.02, 0.03)	(23.43, 23.49)

building 2	22°C < T_{rm} ≤ 28.3°C	T_c = -0.149 * T_{rm} + 27.57	-0.149	27.57	(-0.15, -0.14)	(27.42, 27.72)
building 3	6°C ≤ T_{rm} ≤ 24°C	Tc = 0.524 * T_{rm} + 13.3	0.524	13.3	(0.4853, 0.5618)	(12.52, 14.08)
	24°C < T_{rm} ≤ 28.5°C	T_c = -0.07 * T_{rm} + 28.32	-0.07	28.32	(-0.11, -0.037)	(27.35, 29.28)

As for the case of the free running building, occupants continued to adapt in winter, as shown in Figure 4-19 until the regression line becomes horizontal when reaching approximately 24.0°C running mean outdoor temperature. This reflects a comfort temperature of approximately 26.0°C (Table 4-11). The findings related to the free running building are based on a relatively small size sample as a larger sample was not available, but still was able to reflect the adaptive thermal comfort concept.

In the case of mixed mode buildings, the comfort temperatures were plotted against the 80% acceptability comfort ranges of ASHRAE Standard 55 and EN 15251. As shown in Figure 4-20, the data related to spring fall most of the time within the ASHRAE Standard 55 and EN 15251 limits, while most of the summer and autumn data values are lower than the lower limit of EN 15251-II. In the case of the winter, many data values are above the EN 15251- II upper limit. Models of both mixed mode buildings are steady, at around 24°C comfort temperature, when T_{rm} ≤ 22°C and evolve towards lower comfort temperature values for T_{rm} > 22°C.

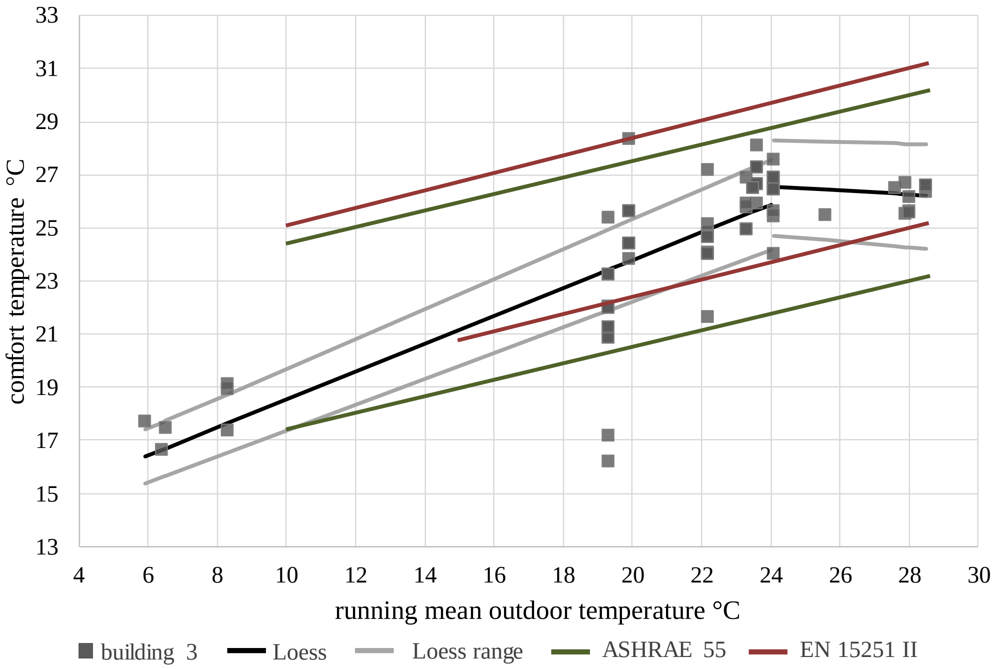


Figure 4-19. Free running building adaptive model vs ASHRAE 55- 80% acceptability and EN 15251-II adaptive models.

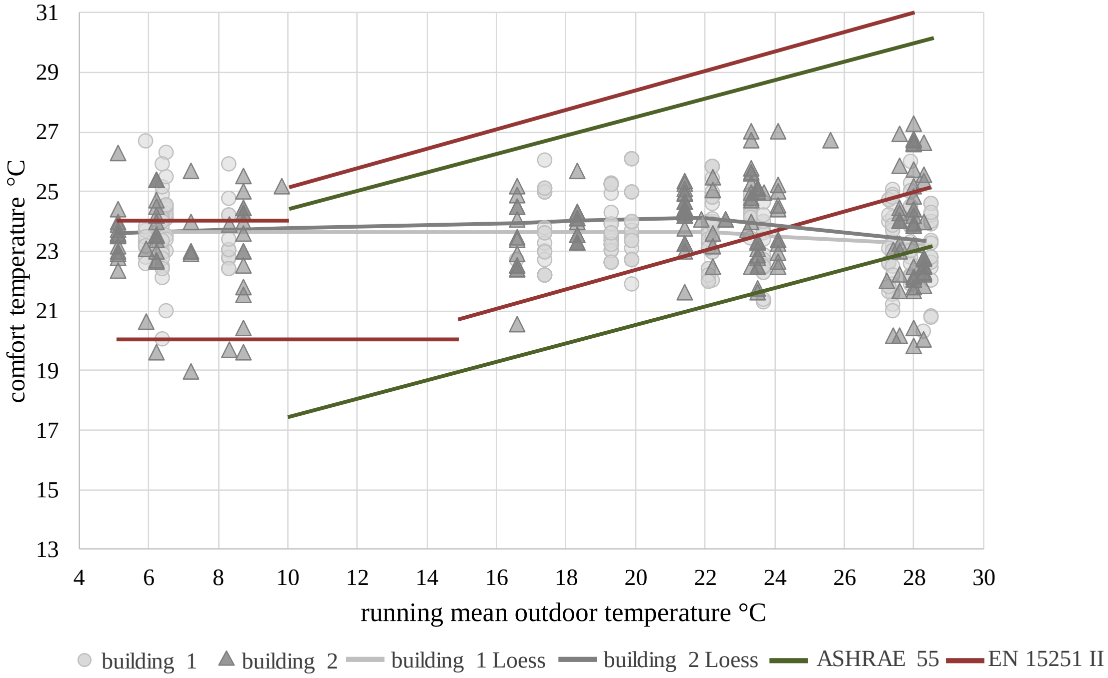


Figure 4-20. Mixed mode comfort temperatures vs ASHRAE 55- 80% acceptability and EN 15251-II adaptive models.

4.5 Variation of clothing insulation

Clothing insulation values varied between the four seasons. The highest median I_{cl} value was found to be 1.03, in winter, and the lowest value of 0.59 was found in both summer and autumn. Spring has a median I_{cl} value of 0.66 (see Table 4-12).

Table 4-12. Minimum, median and maximum values of clothing insulation in clo during the four seasons.

	season											
	spring			summer			autumn			winter		
	min.	med.	max.	min.	med.	max.	min.	med.	max.	min.	med.	max.
I_{cl}	0.53	0.66	1.34	0.53	0.59	1.11	0.53	0.59	1.08	0.58	1.03	1.32

Clothing insulation values were recorded for each occupant during the ‘The thermal comfort and personal control questionnaire’ questionnaire in all four seasons. They were plotted against the outdoor running mean temperatures in each building, as shown in Figure 4-21. Clothing insulation values decrease from winter to summer. In order to analyse the dependence of clothing on the running mean temperature, panel regression linear analysis was carried out for each building.

Table 4-13 shows the equations of the panel analysis linear regression for building 1, 2 and 3. A strong correlation was found between running mean outdoor temperatures and the clothing insulation in building 2 followed by a moderate correlation in the free running building. Building 1 had a weak correlation.

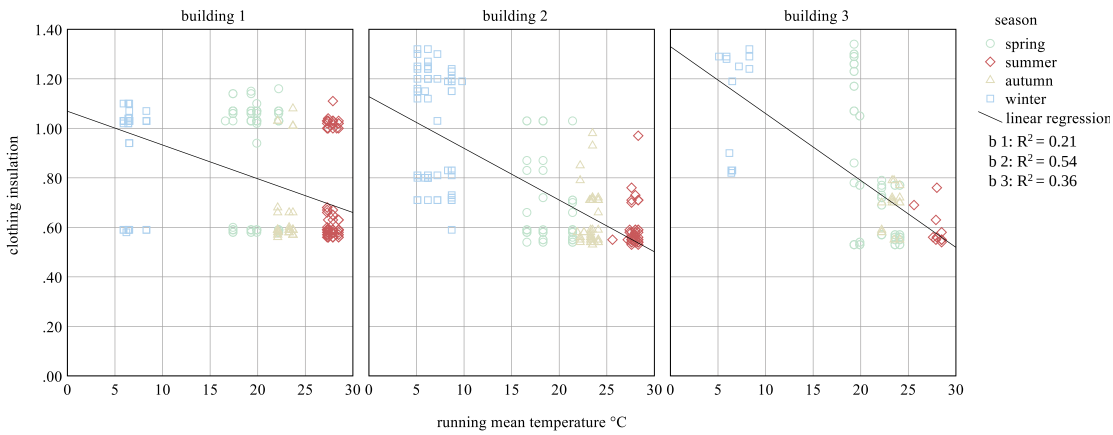


Figure 4-21. Variation of clothing insulation within the running mean temperature.

Table 4-13. Equations of the panel analysis linear regression for building 1, 2 and 3.

building	regression model $I_{cl} = a\ T_{rm} + b$	R^2
building 1	$I_{cl} = -0.014 * T_{rm} + 1.1$	0.21
building 2	$I_{cl} = -0.02 * T_{rm} + 1.12$	0.54
building 3	$I_{cl} = -0.027 * T_{rm} + 1.33$	0.36

R^2: < 0.3 weak, 0.3 to 0.5 moderate, > 0.5 strong (Field 2013).

Differences between buildings in each season

A Kruskal-Wallis (α=0.05) test was carried out to compare the variation of clothing values in the three buildings over the four seasons. The differences in the clothing values between the buildings were significant for all seasons (Figure 4-22).

Pairwise tests were applied for the three pairs of groups and the results were as follows (Table 4-14):

- In spring and summer: differences between the clo values occurred between the mixed mode building 1 on one hand and both buildings 2 and 3 on the other hand.
- In autumn: there was just one instance of evidence ($p < 0.05$, adjusted using the Bonferroni correction) of a difference between the clo value of occupants in building 2 and building 3.

- In winter: the only evidence ($p < 0.05$, adjusted using the Bonferroni correction) of a difference between the clo value of occupants was between building 1 and building 3.
- The effect size was small in spring, autumn and winter, as Cohen's d values were 0.140, 0.049 and 0.038 respectively, while the effect size was moderate, 0.310, in summer.

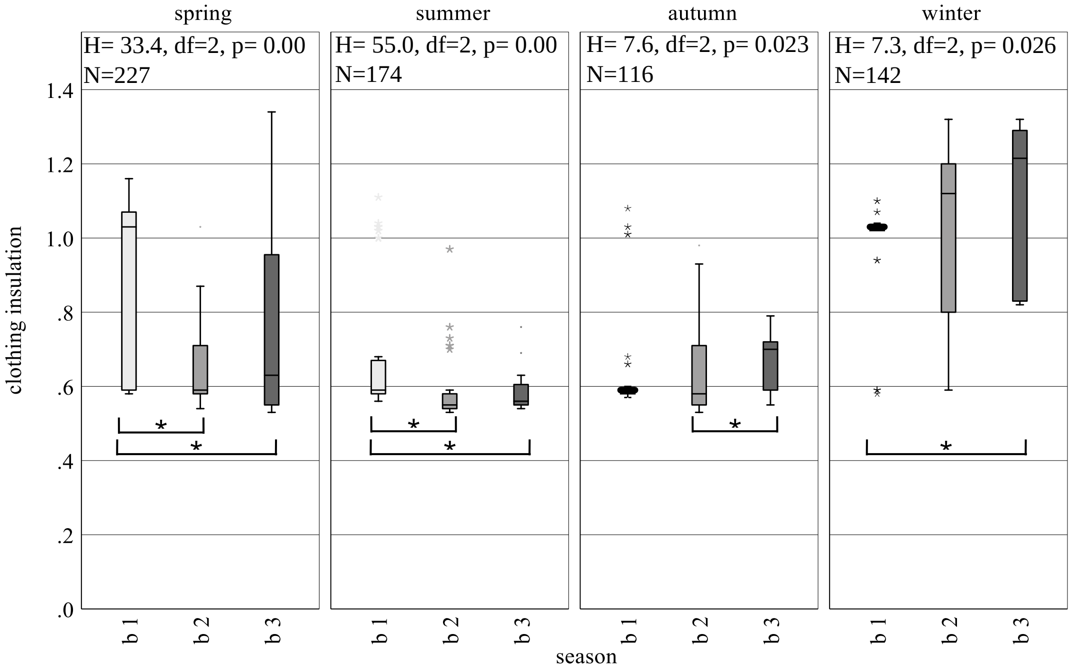


Figure 4-22. Distribution of clothing insulation values in the three buildings during the four seasons; lines marked with a star indicate pairwise significant difference. Numbers refer to the number of responses. b1: building 1, b2: building 2, b3: building 3.

Table 4-14. Significance values adjusted after Dunn-Bonferroni pairwise post hoc tests for buildings during the four seasons .

	adj.Sig./ season			
Pairwise groups	spring	summer	autumn	winter
building 1-building 2	**0.000**	**0.000**	0.433	0.207
building 1-building 3	**0.000**	**0.012**	0.273	**0.045**
building 2-building 3	0.868	1.000	**0.020**	0.567

Asympotic significances (2 sided tests) are displayed. The significance level is 0.05. Significance values have been adjusted by Bonferroni correction for multiple tests.

Differences between seasons in each building

Considering building variations in clothing insulation of those occupants who responded in all four seasons (N=30), there was found to be a significant difference between the seasons in the three buildings, based on the Friedman test ($\alpha=0.05$) (Figure 4-23). Dunn-Bonferroni pairwise post hoc tests were carried out to compare the clo values between each of the two seasons in each building. The results are as follows (Table 4-15):

- Building 1 pairwise analysis: there were significant differences between autumn and spring, autumn and winter, summer and spring and summer and winter ($p < 0.05$) after Bonferroni adjustments. There were no significant differences between autumn and summer or, spring and winter.
- Building 2 pairwise analysis: there were significant differences between autumn and winter and, summer and winter ($p < 0.05$) after Bonferroni adjustments. There were no significant differences between any other seasons
- Building 3 pairwise analysis: there was a significant difference between summer and winter ($p < 0.05$) after Bonferroni adjustments. There were no significant differences between any other seasons.

Kendall's W (coefficient of concordance) was carried out, which looks at agreement between the different categories. The Kendall's W was 0.58 for building 1, 0.69 for building 2 and 0.89 for building 3, which indicates a large effect size.

For this analysis, the median of the clothing insulation values for each person in each season was calculated in order to apply the Friedman test as the measurements were repeated for each occupant within the same building.

Table 4-15. Significance values adjusted after Dunn-Bonferroni pairwise post hoc tests among the different seasons in each building.

	Adj.Sig./ building		
Pairwise groups	building 1	building 2	building 3
autumn-summer	1.000	1.000	0.450
autumn-spring	**0.003**	1.000	1.000
autumn-winter	**0.001**	**0.011**	1.000
summer-spring	**0.026**	1.000	1.000
summer-winter	**0.005**	**0.003**	**0.010**
spring-winter	1.000	0.171	0.240

Asymptotic significances (2 sided tests) are displayed. The significance level is 0.05. Significance values have been adjusted by Bonferroni correction for multiple tests.

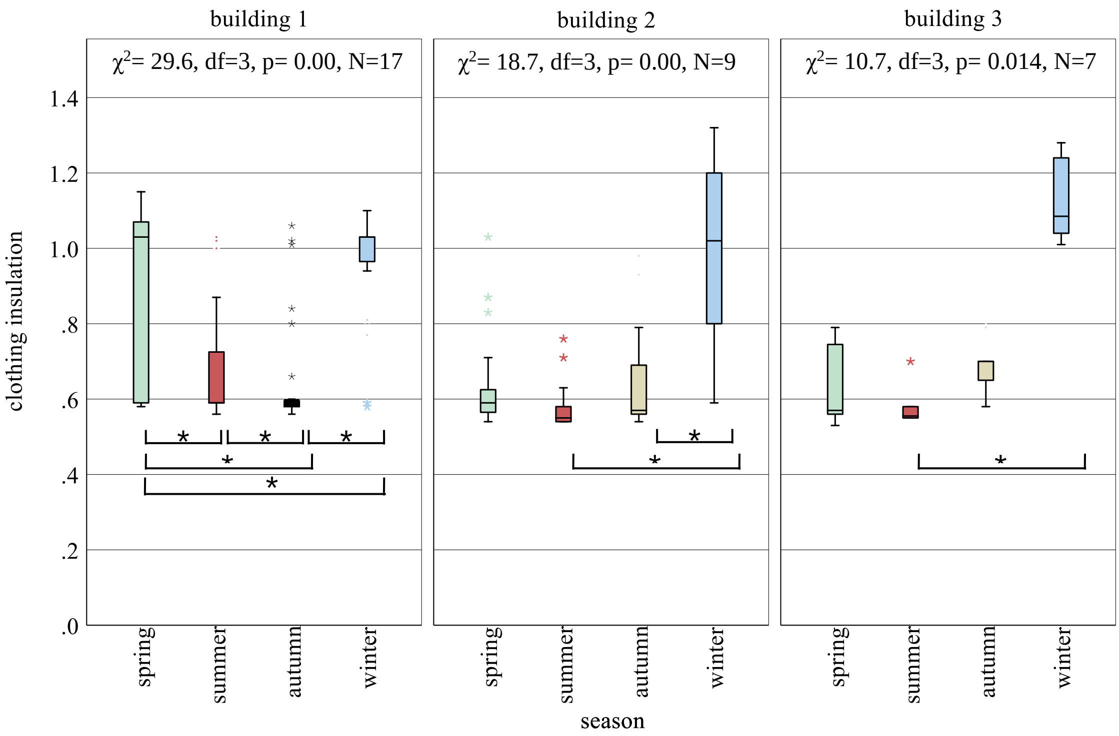


Figure 4-23. Distribution of clothing insulation values in the three buildings during the four seasons among the different seasons in each building; lines marked with a star indicate pairwise significant difference. Numbers refer to the number of persons.

Figure 4-24 shows the change of clothing insulation for participants who responded in all seasons. In building 2 (MM) and building 3 (NV) almost all occupants chose a thinner garment ensemble from spring onwards, staying the same in summer and autumn; 60% of the occupants in building 1 (MM) changed their garment ensemble towards a lower clo-value only after spring. This effect was found in males as well as in females.

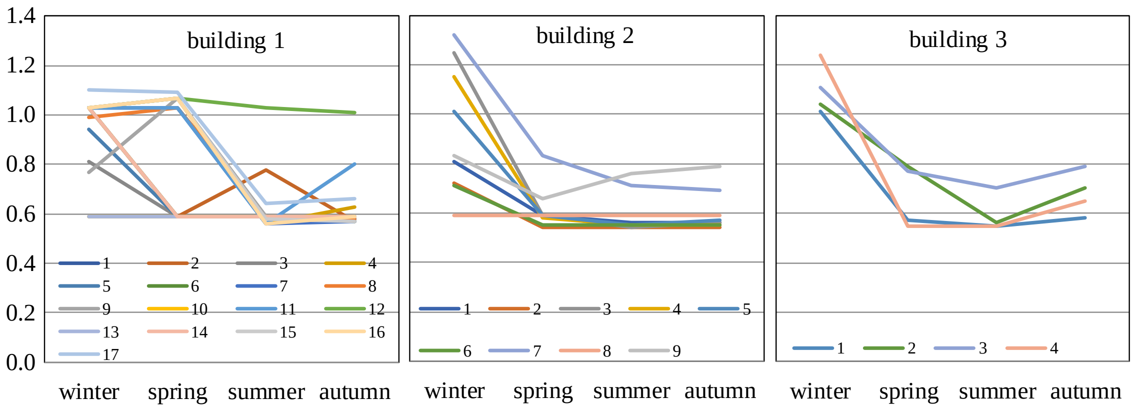


Figure 4-24. Change of clothing insulation for participants who responded in all seasons.

5 Personal Control Results

In this chapter the results related to personal control over the indoor environment are presented, explained and analysed. The following aspects are analysed: objective availability, perceived availability, desired control, consistency of perceived availability and objective availability, conformity between perceived availability and desired control, exercised control, reasons for not having exercised available adaptive control, impact of office type and season on perceived control, and the impact of perceived control on thermal comfort and air quality perception.

As mentioned in the methodology chapter, occupants answered the set of questions twice a week for a period of two to three weeks per season. Therefore, the mode of responses for each person per each question has been calculated for each season for the nominal scales, while the median was calculated for ordinal scales.

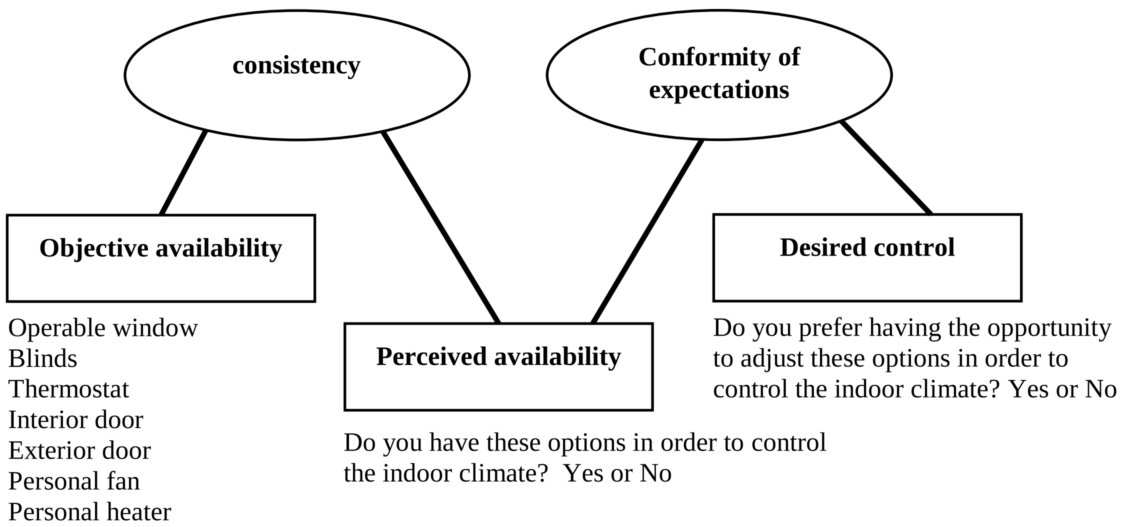


Figure 5-1. Simplified conceptual framework of the main analysis in this chapter after Al-Atrash, F. ,Hellwig, R.T and Wagner, A. (2018).

5.1 Objective availability

As mentioned in the research design requirements, collecting information on the available adaptive control opportunities is a high priority for this research. The availability of the control opportunities in offices was assessed by the researcher.

The analysis of objectively available controls has been related to the office type. Only offices occupied by participants in the survey were considered. Both, building 1 and building 2 contain three office types as follows: single offices, shared offices inhabited by two to five persons in building 2 and two to three persons in the case of building 1. The third type is an open plan office shared by up to ten persons. The third building which is the free running office building has single offices and one open plan office shared by around six persons. Figure 5-2 shows the distribution of office types within the three buildings.

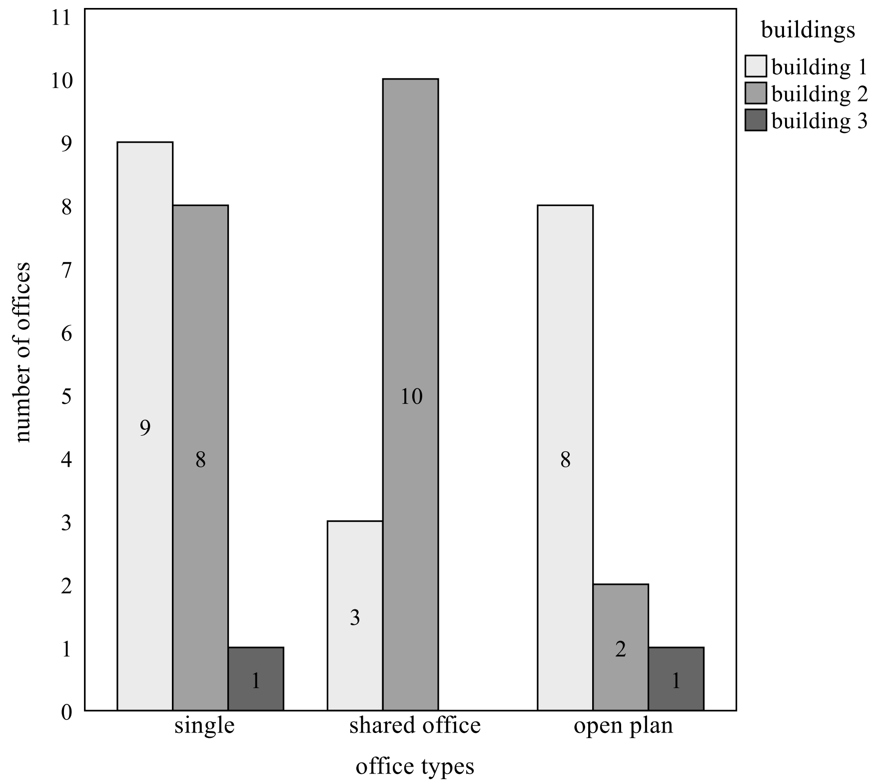


Figure 5-2. Distribution of office types within the three buildings.

Figure 5-3 shows the available controls in the offices of building 1. Building 1 has nine single offices. All offices have operable windows, interior doors, blinds and adjustable thermostats. Just one of them has an exterior door to access a terrace. The only available controls in shared offices are interior doors and adjustable thermostats. These offices were occupied by six persons. Occupants in these offices rely on mechanical ventilation to provide fresh air. In all open plan offices, adjustable thermostats are available, while two offices lack the availability of operable windows and blinds. One office does not have an interior door. The exterior door to a terrace was available in one office. The open plan offices were occupied by 46 persons. It is worth mentioning that in both shared and open plan offices one or two thermostats were available per office to be shared by the occupants.

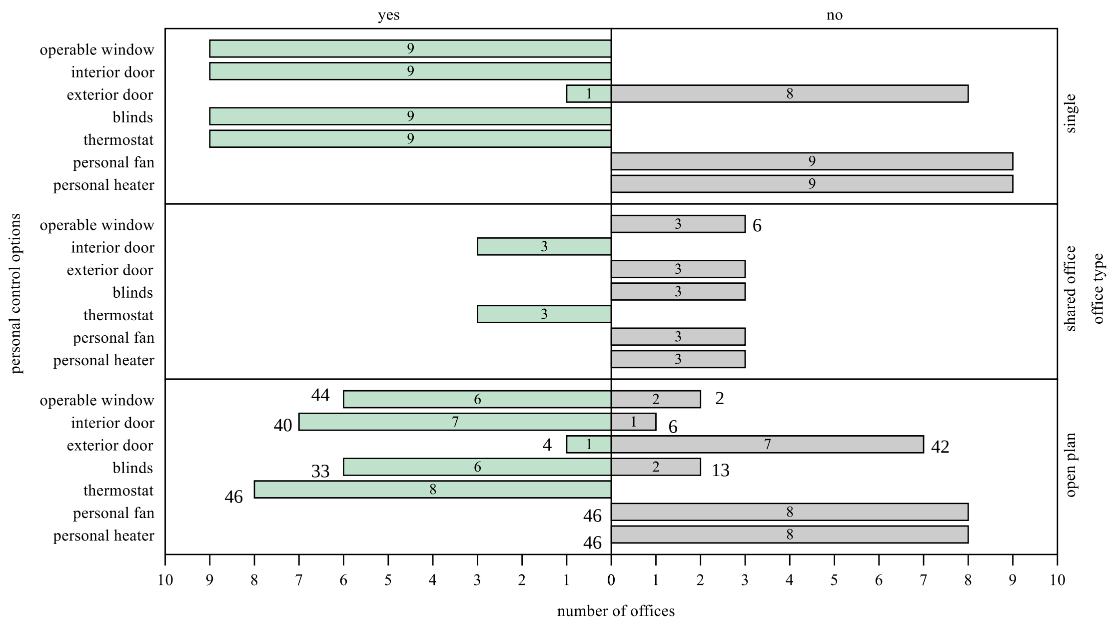


Figure 5-3. Available controls in offices of building 1. Numbers outside the boxes refer to the number of persons.

Figure 5-4 shows the available controls in offices of building 2. Building 2 has eight single offices. All of them have interior doors and adjustable thermostats. One office lacks operable windows, two offices do not have blinds. None of the single offices has access to a terrace. Personal fans and heaters were not found in any of the offices. The single offices were occupied by nine different persons (instead of eight) because the occupancy of one office changed during the longitudinal survey. All the shared offices have interior doors and thermostats. Three of these offices lack operable windows as well as blinds. Two offices have access to a terrace. A personal fan was found in one of these offices. Personal heaters were not available. There were 32 people in these offices. The open plan offices have operable windows, interior and exterior doors in addition to thermostats (one or two per office to be shared by the occupants). They lack blinds, personal fans and heaters. The open plan offices were shared between nine persons. In both shared and open plan offices one or two thermostats were available per office to be shared by the occupants.

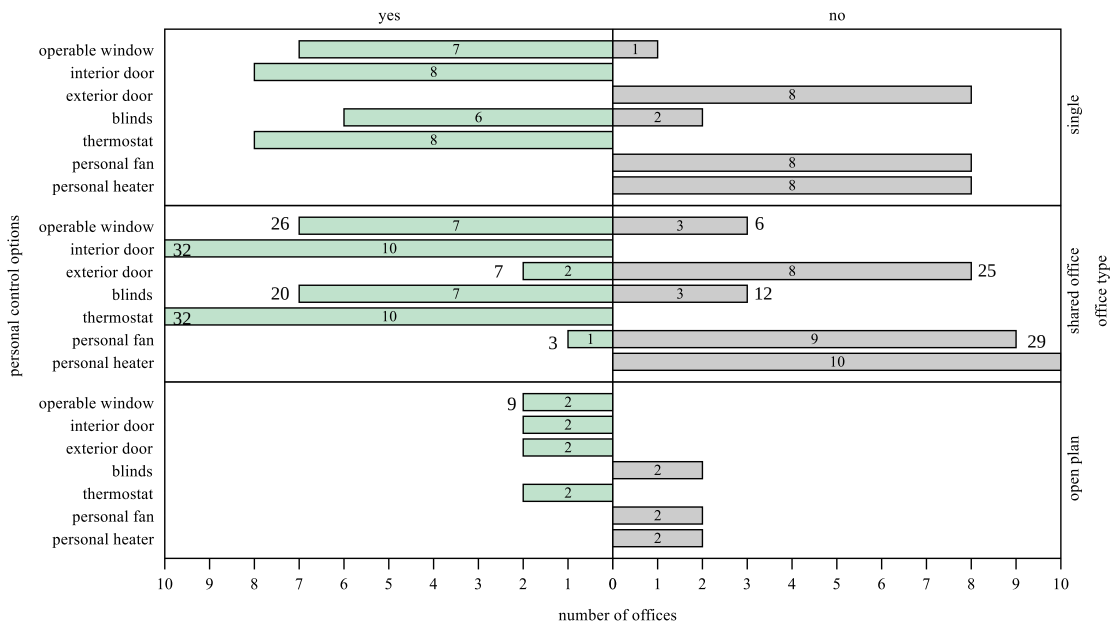


Figure 5-4. Available controls in offices of building 2. Numbers outside the boxes refer to the number of persons.

Figure 5-5 shows the available controls in offices of the third building. The single office in building 3 has operable windows, an exterior door, blinds, a personal fan and a personal heater. The open plan office, which was shared by six persons, has operable windows, interior door, blinds and personal heaters.

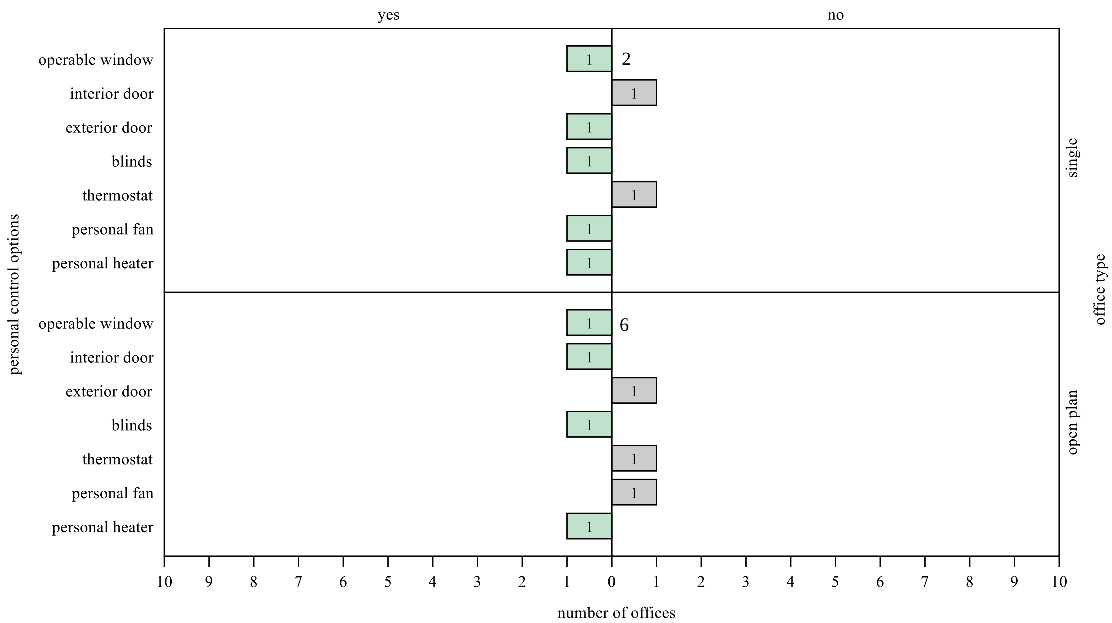


Figure 5-5. Available controls in offices of building 3. Numbers outside the boxes refer to the number of persons.

5.2 Perceived availability

Perceived availability in this study is defined as the subjective perception of availability of certain controls. It relates to the subjective opinion or belief of having or not having adaptive control options available.

Figure 5-6 shows the perceived availability of controls in building 1. All nine occupants of the single offices believed that they had access to operable windows, interior doors, blinds and adjustable thermostats. Three occupants reported perceived availability to control exterior doors. All six occupants of the shared offices stated that they could control interior doors and adjustable thermostats. Two of them declared the absence of operable windows and blinds. One occupant believed he/she was able to control exterior doors. The occupants of the open plan offices reported differing perceptions on access operable windows, interior doors, blinds and adjustable thermostats. Only twelve persons out of 46 reported that they perceived exterior doors to be available. In none of the offices did occupants believe that they had control over personal fans and heaters.

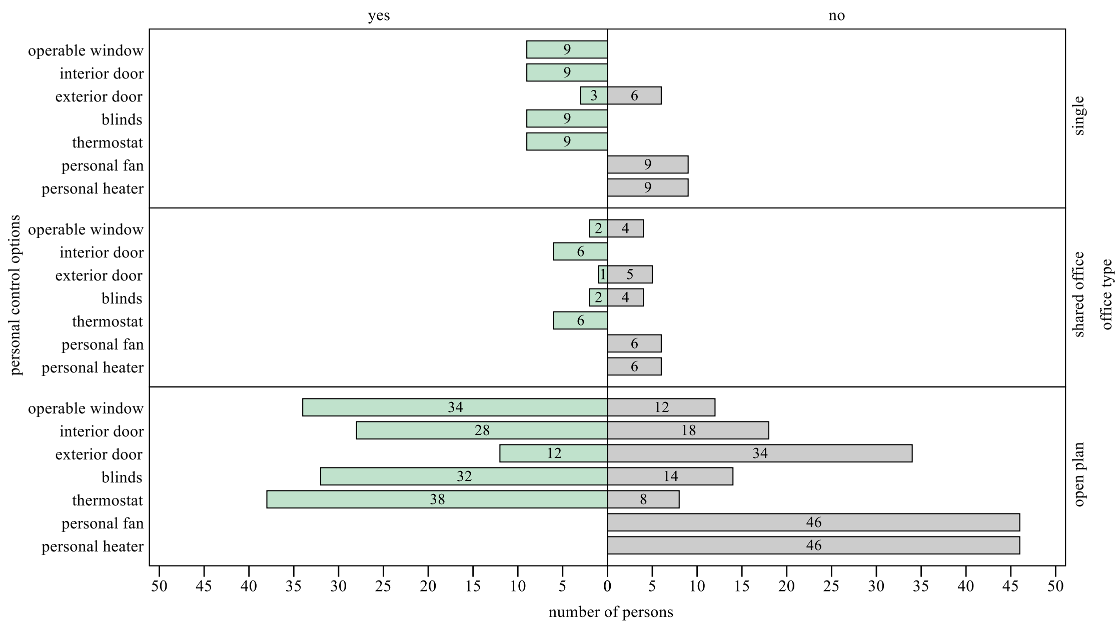


Figure 5-6. Occupants’ perceived availability of controls in building 1.

Figure 5-7 shows the perceived availability of different controls by each person in building 2. Almost all occupants in all three office types reported having control over windows and interior doors. Occupants in open plan offices perceived the availability to control exterior doors. However, approximately half of the occupants of other office types perceived this control as available. Five persons in single offices stated having control over blinds, compared to only two in open plan offices. However, only five occupants stated that they did not have control over blinds in shared offices. Thermostats were perceived to be available by all the respondents except for one in the shared offices.

Concerning personal fans and heaters, no occupants of the single and open plan offices reported having these control options. In the shared office, less than 5% reported having these options.

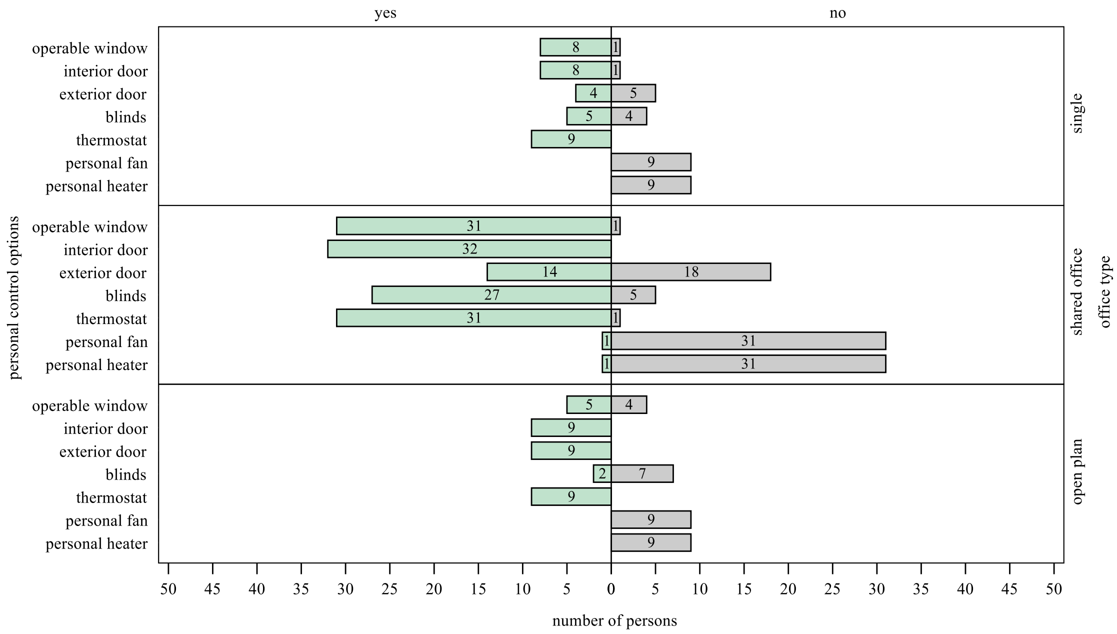


Figure 5-7. Occupants’ perceived availability of controls in building 2.

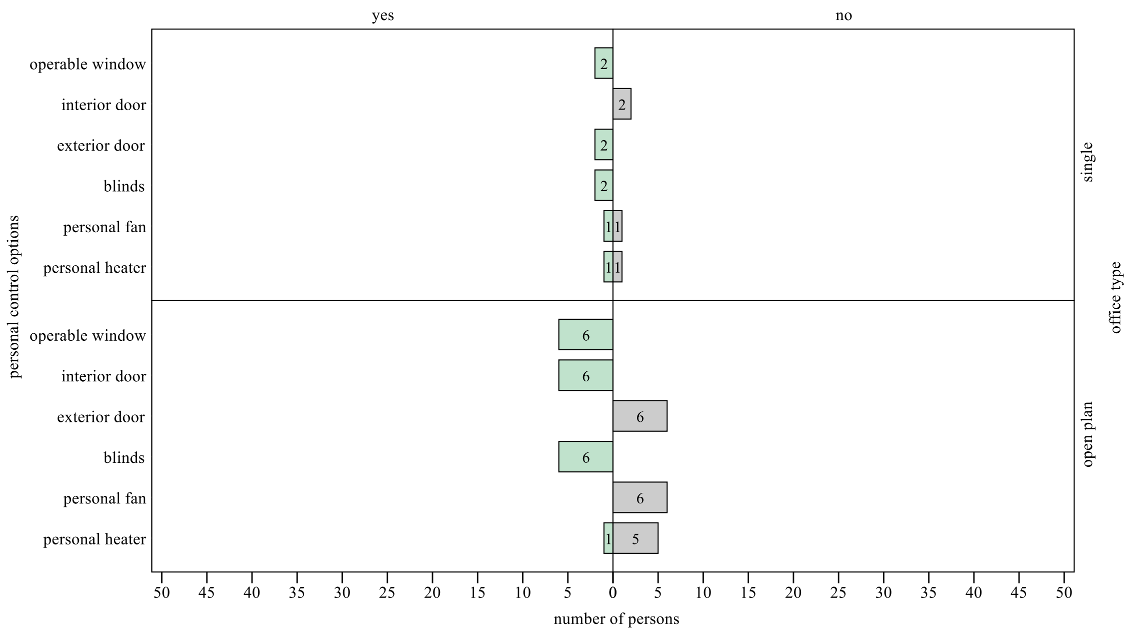


Figure 5-8. Occupants’ perceived availability of controls in building 3.

Figure 5-8 shows the perceived availability of controls for each person in building 3. All occupants in single and open plan offices stated they had control over operable windows and blinds. Six occupants of the open plan offices reported having control over the interior doors, while the two in the single offices did not. This can be explained by the fact that the single office only had access to an exterior door. None of the occupants in the open plan office perceived availability to control exterior doors. Only one person in each of the single and open plan offices, reported having control over a personal heater. Concerning the personal fan control option, one person in the single office answered yes, but no one had such control in the open plan office.

5.3 Desired controls

This study defines desired controls as the occupant's wish for control options to adjust the indoor climate. The question referred to in this part is: Do you prefer having the opportunity to adjust these options in order to control the indoor climate?

Figure 5-9 shows the responses regarding desired controls in building 1. None of the occupants in shared offices wished to have control over personal fans and heaters, whereas some of the single and open plan occupants did. Operable windows and adjustable thermostats were the most desired control options in all office types.

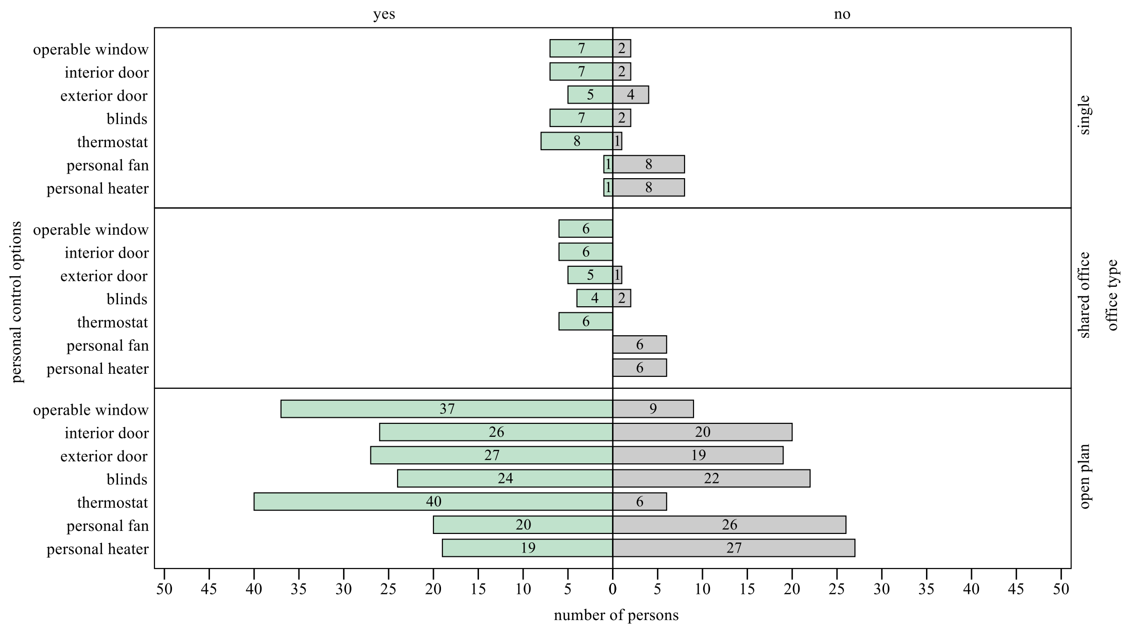


Figure 5-9. Occupants' desired controls in building 1.

Figure 5-10 shows the controls desired in building 2. Most of the occupants in both single and shared offices wished to have control over operable windows, interior doors, blinds and adjustable thermostats. Some of them wished to have control over personal fans and heaters. Interior doors and thermostats were the most desired control options in the open plan offices. The wish to have personal fans and heaters also appeared in this type of office.

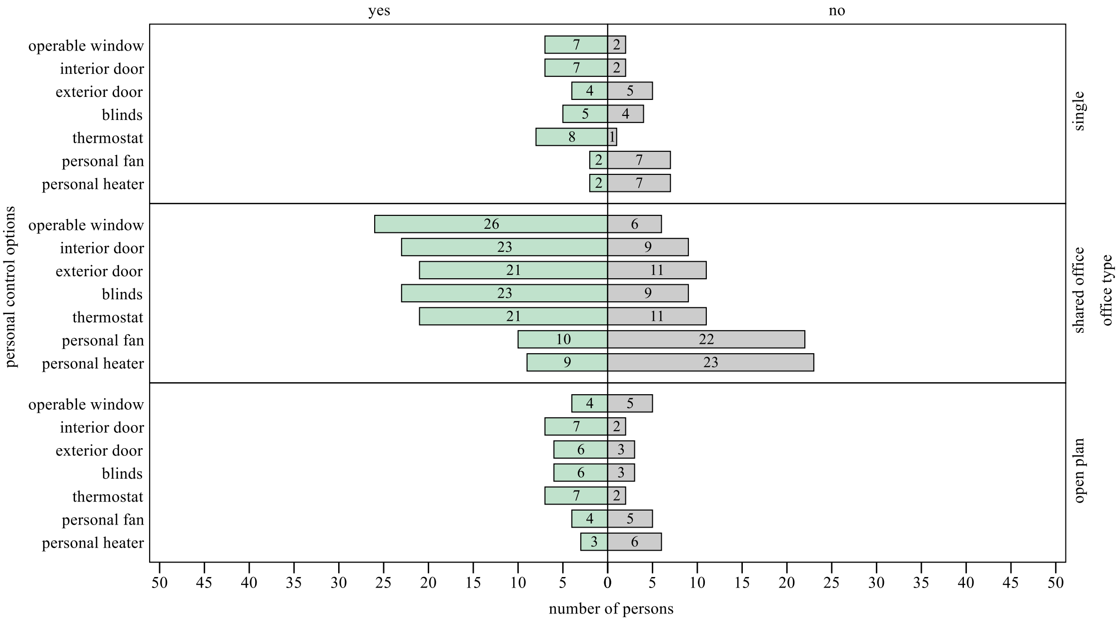


Figure 5-10. Occupants’ desired controls in building 2.

Figure 5-11 shows the occupants’ desired controls in building 3. In the single office, the most desired control options were an interior door, an exterior door, blinds, an adjustable thermostat, personal fan and personal heater, followed by operable windows, while the most desired control option at the open plan office was adjustable thermostat.

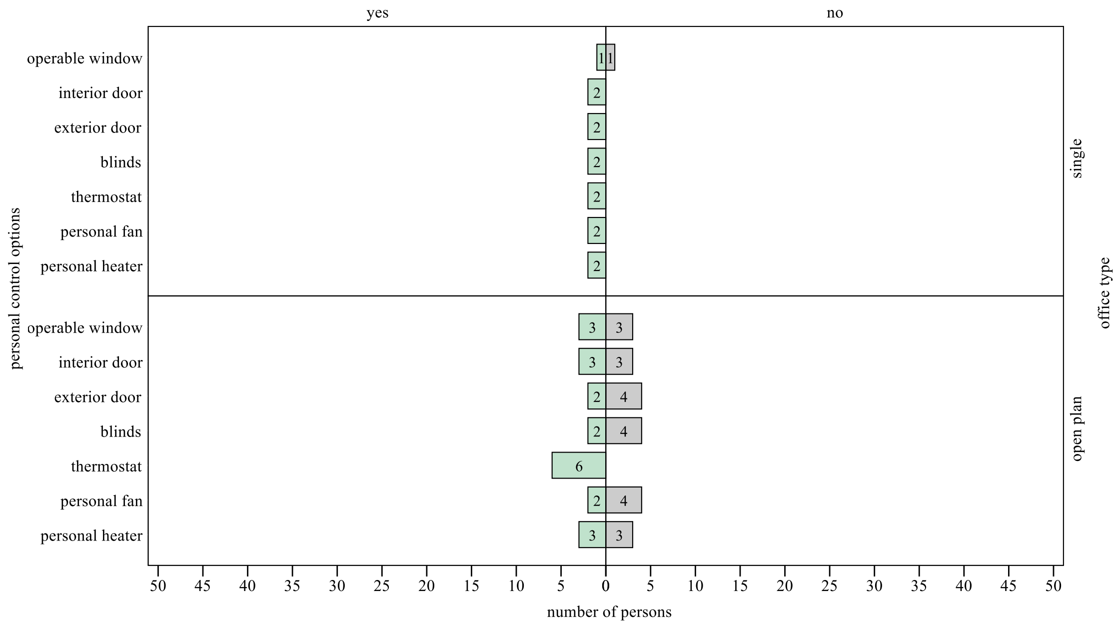


Figure 5-11. Occupants’ desired controls in building 3.

5.4 Consistency of perceived availability and objective availability

In order to compare the perceived availability with the objective availability, in other words to provide proof of consistency between perception and reality, objective availability was subtracted from perceived availability. The answers to the related questions are binary, where +1 stands for ‘having the control option’ and ‘0’ for ‘not having the control option’. A difference of ‘0’ means that the occupants’ perception was consistent with the real conditions. An outcome of ‘-1’, means the occupants may perceive some restrictions in accessing the respective control option. A difference of ‘+1’ indicates that they assume this control option is available, although it is not objectively available in their working environment. In this case, the occupants have never even tried to change the thermal environment with this control option or this control option is not important from their point of view.

Table 5-1. Categories of consistency between perceived availability and objective availability.

perceived availability	0	0	1	1
objective availability	1	0	1	0
difference	-1	0		+1
category	restriction	consistency		false positive assumption

Figure 5-12 shows the prevalence of categories of consistency between perceived availability and objective availability in the three buildings. In the case of the single offices, two persons believed they had access to outdoor space in building 1, while four persons believed this in building 2. The perceived availability of the other control options was consistent with the objective availability in building 1. One person believed there was access to blinds in building 2. There was the perception that access to interior doors and blinds was restricted in building 2.

The perceived availability of controls in shared offices in building 1 was consistent with the objective availability for adjustable thermostats and interior doors, but not for operable windows and blinds, which two persons believed they had access to, nor for an exterior door, which one person believed there was access to. In building 2, perceived availability was in accordance with the objective availability only for interior doors. There was the perception of restricted access to exterior doors, blinds and the thermostat.

In building 1, the perception of restrictions for all control options appeared in the open-plan office type, with the smallest proportion for access to exterior doors and the largest share for interior doors. In the case of building 2, restrictions were perceived in the open plan office type just as in the case of operable windows. In building 3, the perceived availability of most of the control options was in accordance with the objective availability. Restrictions were perceived for personal fans and personal heaters in the single office and for personal heaters in the open plan office.

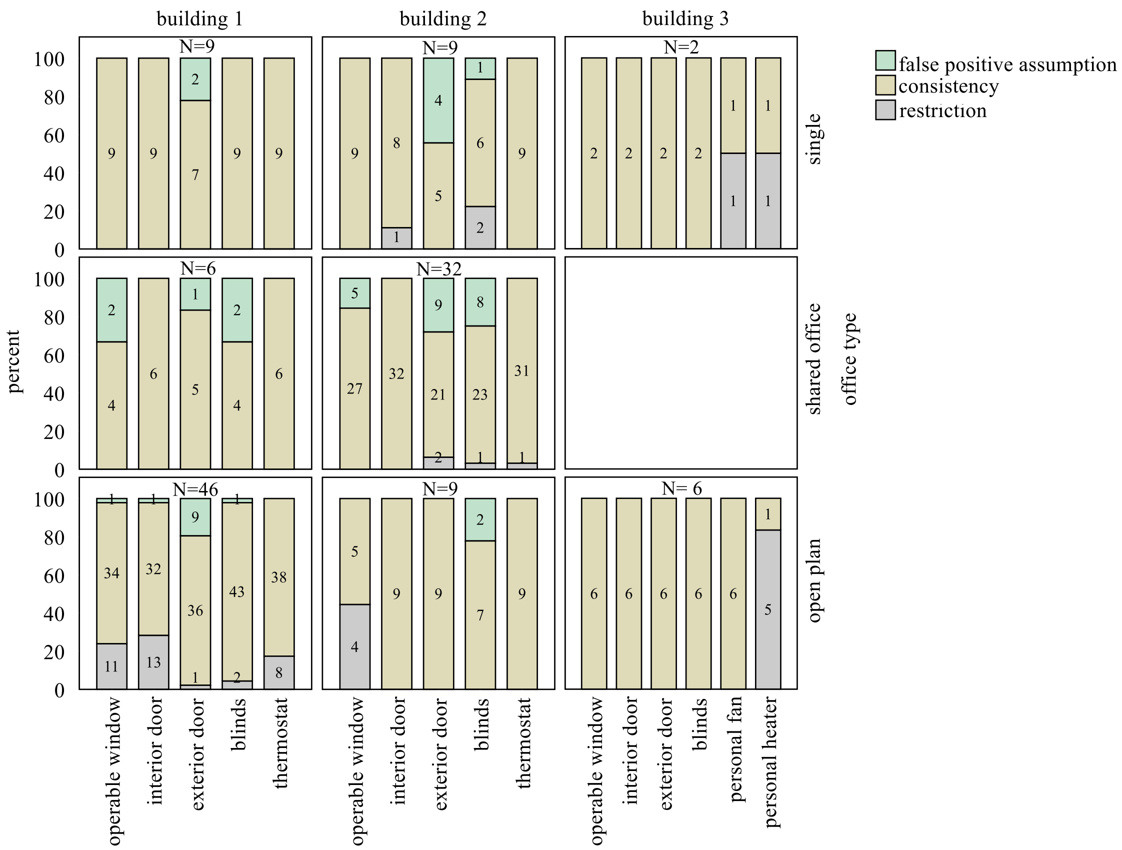


Figure 5-12. Categories of consistency between perceived availability and objective availability in the three buildings. Numbers in the columns represent the absolute number of occupants.

For each category of consistency between perceived availability and objective availability, the distribution of the occupants' votes on perceived control for each control opportunity in each season was displayed and analysed (Figure 5-13). Personal fans and heaters were excluded from this analysis as they were rarely available. The analysis shows no significant differences in the three categories' median of perceived control ($p > 0.05$) of the different adaptive opportunities during the different seasons, except the analysis related to interior door adaptive opportunity in spring ($p= 0.04$). For adaptive opportunities for operable windows, blinds, interior doors and thermostats, the median perceived control scores for the categories 'consistency' and 'false positive assumption' lie, in most cases, one unit above the median score for the category 'restriction'.

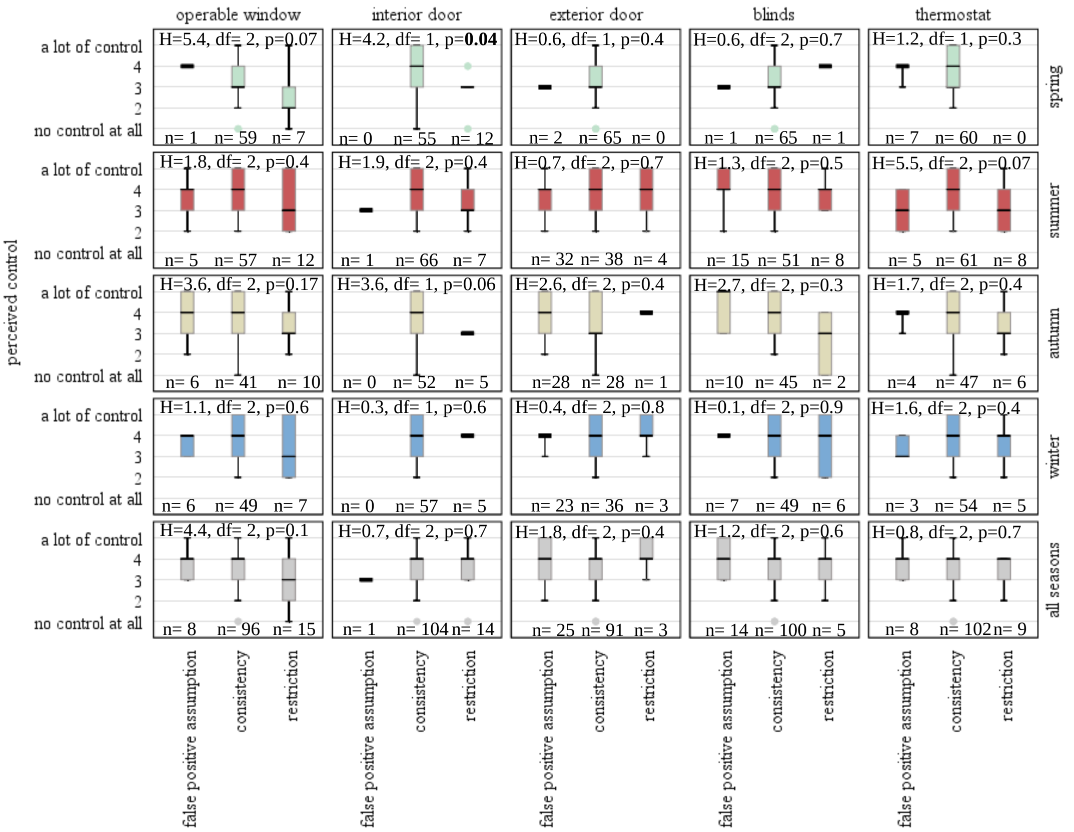


Figure 5-13. Perceived control for the three categories of consistency between perceived and objective availability. Analysis based on Kruskal-Wallis test (α=0.05). Numbers refer to the number of occupants. H is the test statistic for the Kruskal-Wallis test, df: the degree of freedom equals the number of groups in your data minus 1, p-value determines whether any of the differences between the medians are statistically significant.

5.5 Conformity between perceived availability and desired controls

The same principle as in section 5.4 was applied when investigating the level of conformity between perceived availability and desired controls. The desired controls responses were subtracted from perceived availability replies. A result of '0' means that the office control options match exactly the occupant's expectation. An outcome of '-1' can be interpreted as a perception of a lack of control, hence a negative non-conformity to expectation. A value of '+1' means that more control options are perceived to be available than the occupant desired, leading to a positive non-conformity to expectation.

Table 5-2. Categories of conformity between perceived availability and desired controls.

perceived availability	0	0	1	1
desired controls	1	0	1	0
difference	-1	0		1
category	negative non-conformity	conformity		positive non-conformity

Figure 5-14 shows the frequency of the categories of conformity between perceived availability and desired controls in the three buildings. Building 1: In the case of single offices, the perceived availability of operable windows, interior doors, blinds and adjustable thermostats is in conformity with the desired controls or shows positive non-conformity. Four persons desired exterior doors but did not perceive their availability. Some occupants in shared offices lacked the opportunity to control operable windows, exterior doors and blinds while few occupants in open-plan offices missed the opportunity to control operable windows, interior and exterior doors blinds, and thermostats. Building 2: In single offices, the results were similar to those in building 1, but the category negative non-conformity also appeared for operable windows and blinds. Occupants in shared offices lacked the opportunity to control operable windows, exterior doors and blinds, while in open plan offices, occupants only lacked the operable windows and blinds control options. Occupants in building 3 lacked the opportunity to control interior doors, in the case of the single office, and the exterior door in the open plan office, as well as personal fans and personal heaters in both offices.

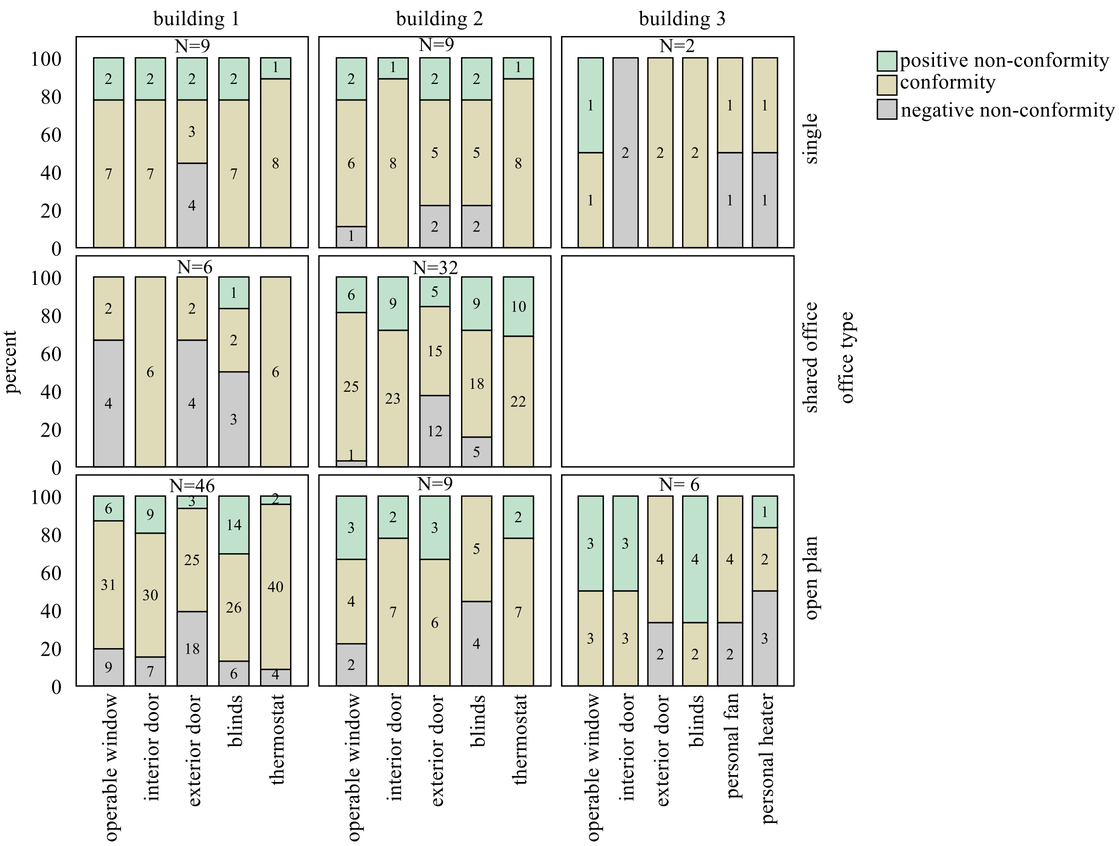


Figure 5-14. Categories of conformity between perceived availability and desired controls in the three buildings. Numbers in the columns represent the total number of occupants.

For each category of conformity between perceived availability and desired controls the distribution of the occupants' votes on perceived control for each control opportunity in each season was displayed and analysed (Figure 5-15). Personal fans and heaters were also excluded from this analysis, as mentioned before.

The analysis shows significant differences in the three categories' median of perceived control ($p < 0.05$) of operable windows in spring, summer and all seasons, blinds in spring and interior doors in spring. The analysis regarding the other adaptive opportunities shows no significant differences in the three categories' median of perceived control ($p > 0.05$). For all adaptive opportunities, the median of perceived control score for the category 'negative non-conformity' lies in most cases one unit lower than the median scores for the categories 'conformity' and 'positive non-conformity'.

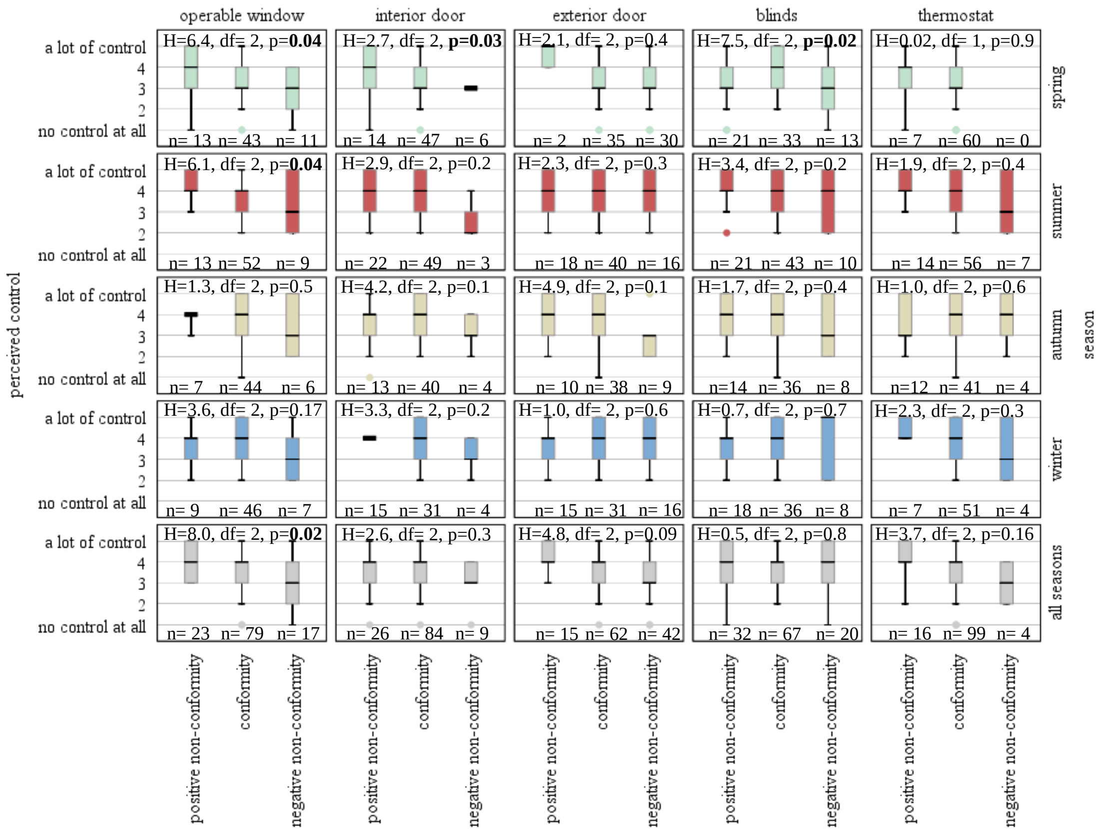


Figure 5-15. Frequencies of perceived control votes for the three categories of conformity between perceived availability and desired controls. Analysis based on Kruskal-Wallis test (α=0.05). Numbers refer to the number of occupants.

For the significant cases above, pairwise tests were applied to analyse the relation between the three categories of conformity between perceived availability and desired controls (Table 5-3). Significant differences appeared between positive non-conformity and both conformity and negative non-conformity.

Table 5-3. Significance values adjusted after Dunn-Bonferroni pairwise post hoc tests. Conformity between perceived availability and desired controls.

	Adj.Sig./ adaptive opportunity, season			
Pairwise groups	window_spring	window_ summer	window_ all seasons	blinds- spring
positive non-conformity-conformity	1.000	**0.049**	0.461	**0.032**
positive non-conformity-negative non-conformity	**0.049**	0.204	**0.014**	1.000
negative non-conformity-conformity	0.93	1.000	0.105	0.214

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05. Significance values have been adjusted by Bonferroni correction for multiple tests.

5.6 Exercised control

Exercised control was investigated as a function of the office type in all four seasons. Exercised control was calculated by percentage and with reference to the number of occupants who perceived available control. Figure 5-16 displays the result for exercised control in spring. In single offices, the frequencies of responses are distributed equally between ‘opened without asking others’ and ‘no adjustment’ (44%). In both, the shared offices and the open plan offices the highest prevalence is in ‘no adjustment’ (62%). The other responses are distributed evenly between the other control options. In single offices, the highest prevalence found was ‘no adjustment’, followed by ‘opened without asking others’ and ‘closed without asking others’. In shared offices and open plan offices, ‘no adjustment’ shows the highest frequency, followed either by opening the control options ‘after asking others’ or ‘without asking others’. The lowest prevalence relates to closing the control options ‘after asking others’ or ‘without asking others’. A similar trend as for spring was found among summer, autumn and winter (Figure 5-17, Figure 5-18, and Figure 5-19).

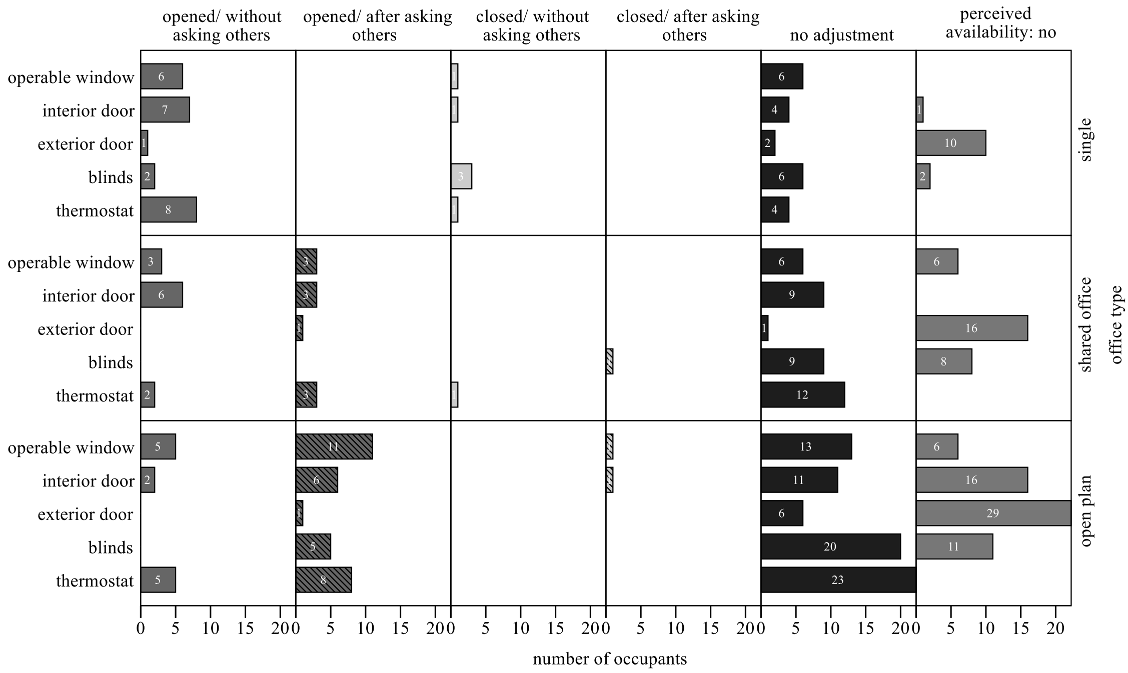


Figure 5-16. Exercised control in spring in all buildings. Numbers refer to the number of answers.

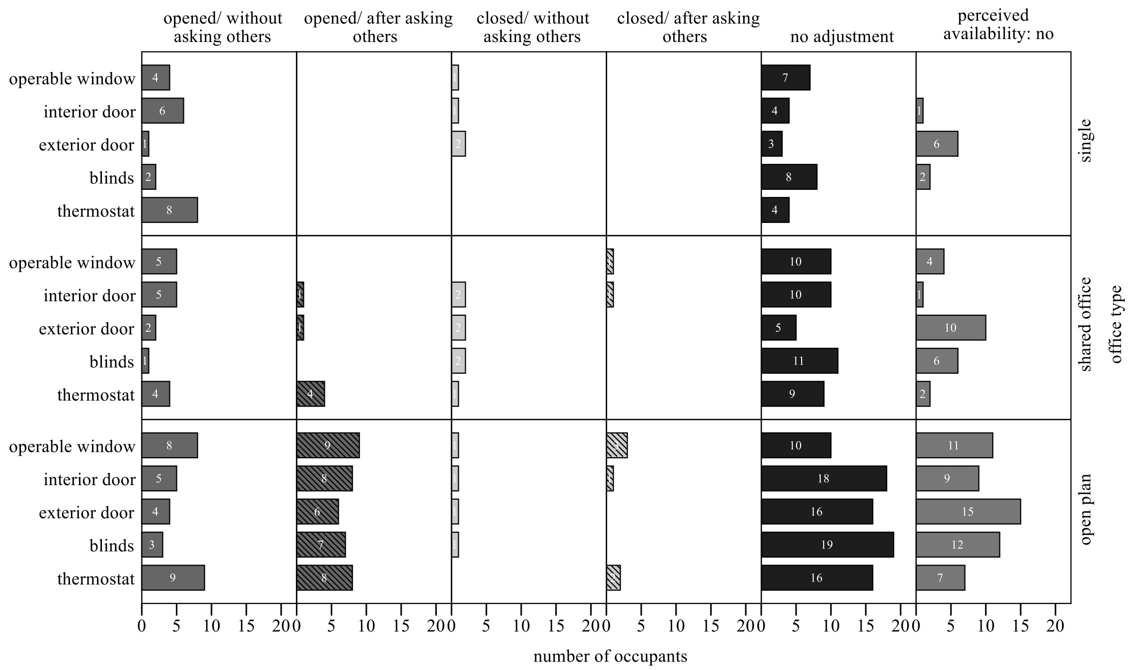


Figure 5-17 Exercised control in summer in all buildings. Numbers refer to the number of answers.

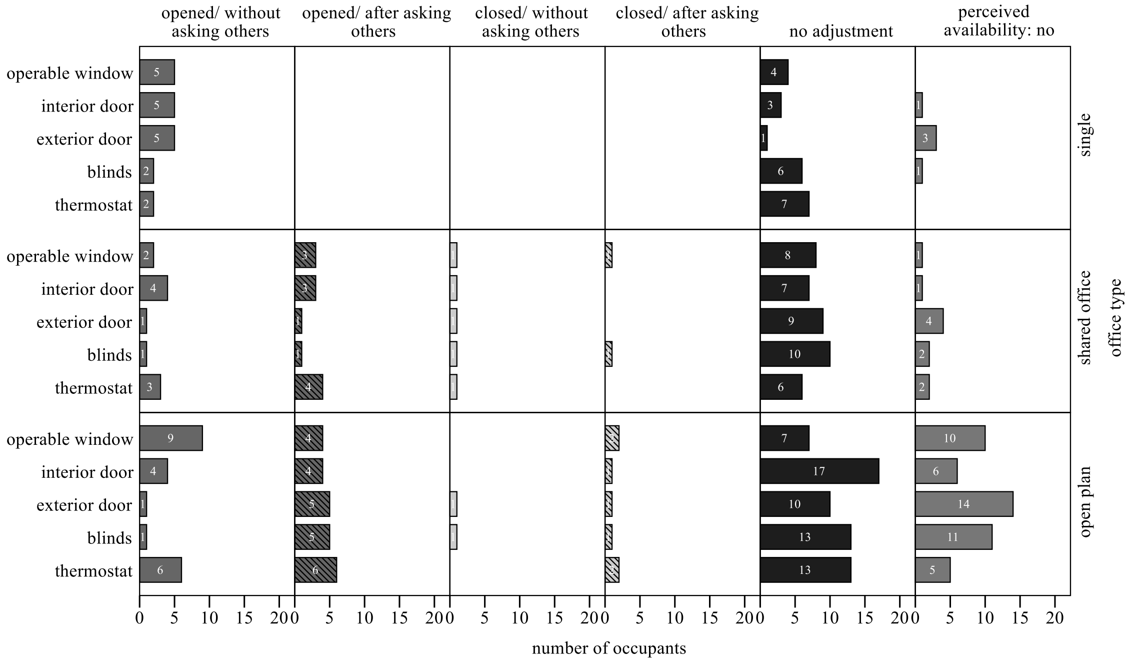


Figure 5-18 Exercised control in autumn in all buildings. Numbers refer to the number of answers.

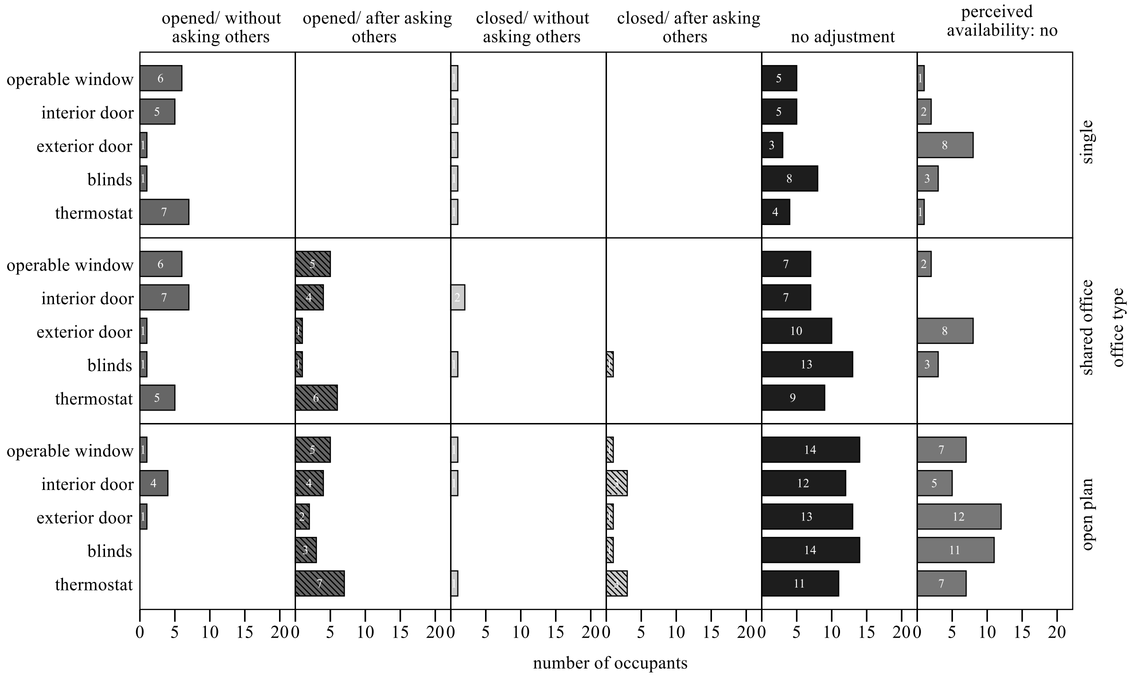


Figure 5-19 Exercised control in winter in all buildings. Numbers refer to the number of answers.

5.7 Reasons for not exercising available adaptive controls

The results showed that the highest response rate to the question on exercised control was ‘no adjustment’, in all seasons. The reasons for not exercising available adaptive controls were divided into three main categories. The first one, ‘**no success expected**’ is applied when the occupants replied: ‘would not have helped’, ‘cannot adjust option any further’, ‘was not agreeable to others in the space’, and ‘not sure if it would be ok with management’. The second category is ‘**not important**’, with the following reasons: ‘not worth asking others’ permission’ and ‘not worth disturbing my work’. The third category is ‘**no need to change**’, with: ‘no need, co-worker did this’, ‘wanted to exhaust other control options first’, and ‘I was comfortable enough’, as reasons given.

Figure 5-20 shows the reasons for not exercising available adaptive opportunities in spring. The most prevalent reason for not using indoor climate controls was: ‘I was comfortable’, with 56% in single offices, 44% and 47% in shared and open-plan offices respectively. The third category ‘no need to change’ was the highest stated percentage category for not using indoor climate controls with 73%, 79% and 69% in single, shared and open-plan offices respectively. The second category was related to ‘no success expected’ with 16%, 15%, and 24% in single, shared and open-plan offices respectively. The category ‘not important’ was the least reported one with 11%, 6% and 7% in single, shared and open-plan offices respectively. The results for the summer, autumn and winter seasons show a tendency similar to that found in spring’s results. The highest percentage for not exercising available adaptive opportunities was ‘I was comfortable’ for all office types among all seasons. Over all, the majority of responses fall in the ‘no need to change’ category, with the smallest percentage of 40% during winter in-open plan offices. This percentage increased to 93% for single offices in summer. The second category ‘no success expected’ reflected the highest percentage of 54% in open-plan offices in winter, while this percentage was 4% in single offices in autumn. Answers related to ‘not important’ were relatively few, with the highest percentage of 14% in shared and open-plan offices during autumn (see Figure 5-21, Figure 5-22, Figure 5-23).

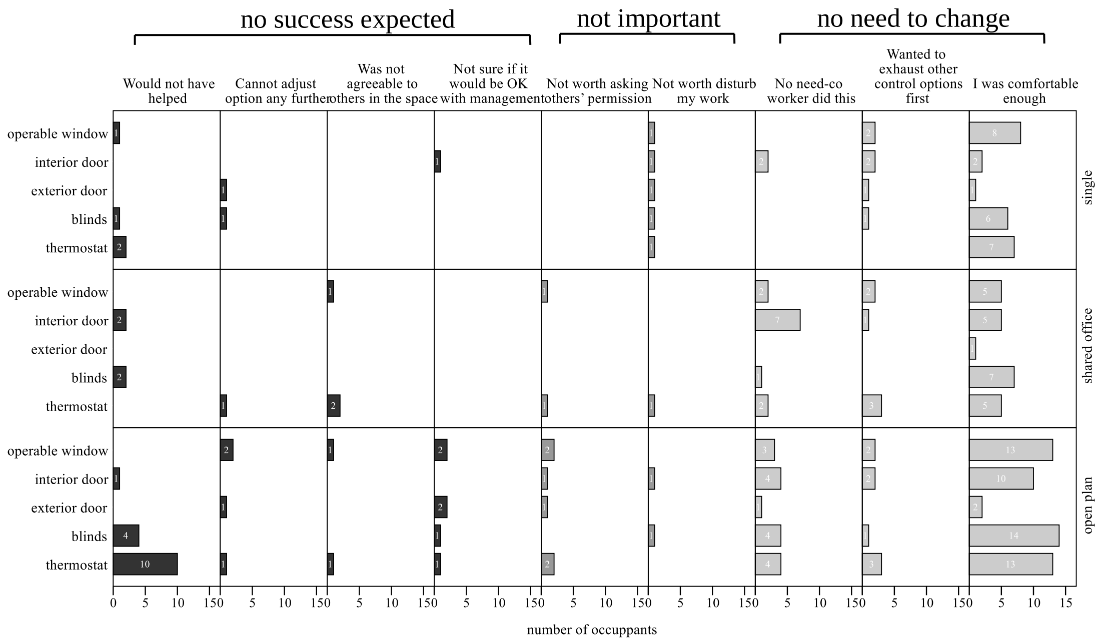


Figure 5-20. Reasons for not exercising available controls in spring. Numbers refer to the number of answers.

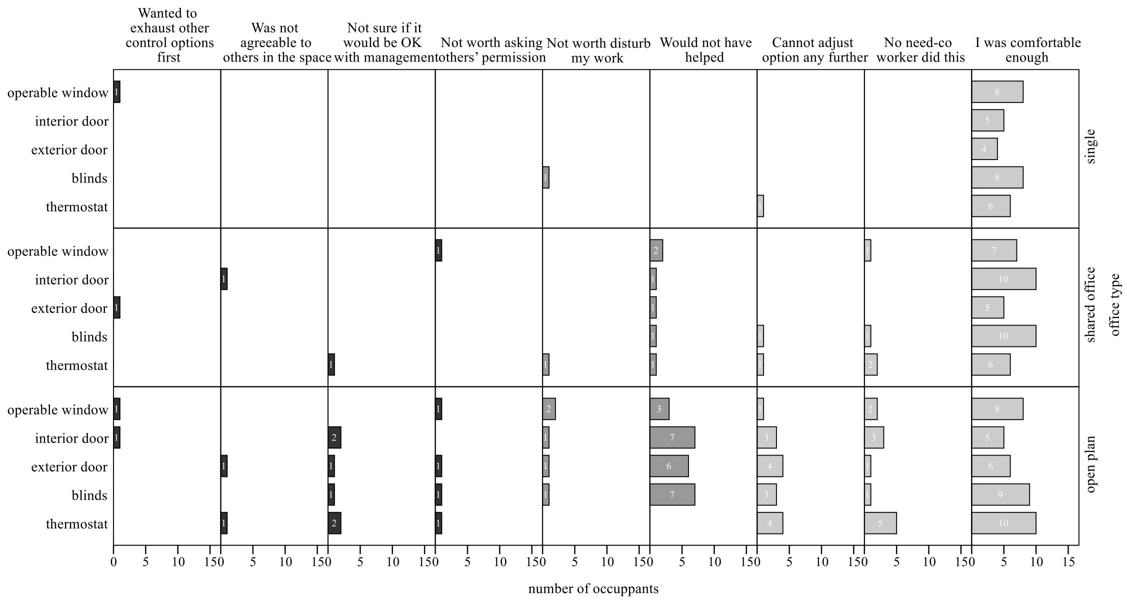


Figure 5-21. Reasons for not exercising available controls in summer. Numbers refer to the number of answers.

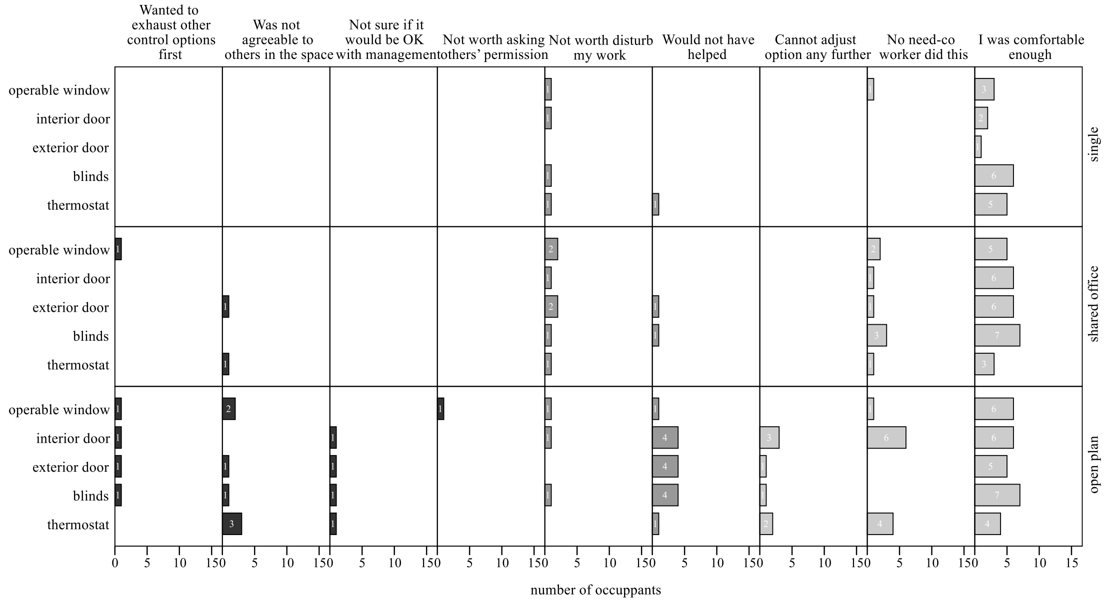


Figure 5-22. Reasons for not exercising available controls in autumn. Numbers refer to the number of answers.

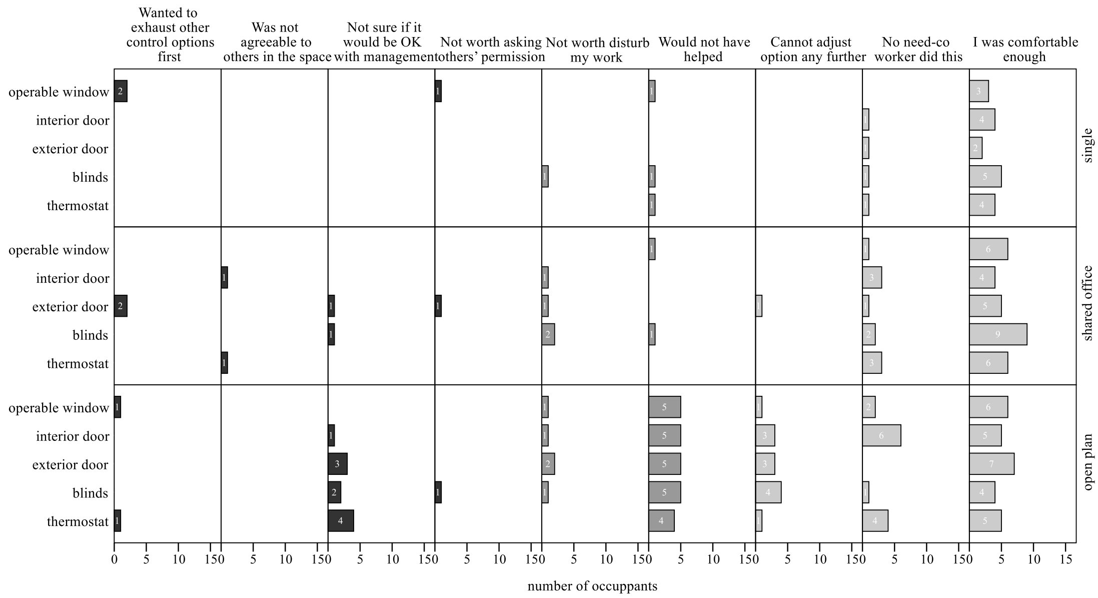


Figure 5-23. Reasons for not exercising available controls in winter. Numbers refer to the number of answers.

In order to understand the effect of the categories of 'reasons for not exercising available adaptive controls' on 'perceived control', the distribution of the occupants' votes on perceived control for each category of reasons ('no success expected, 'not important' and 'no need to change' in each season was displayed and analysed (Figure 5-24). It was expected that those who answered in the category ‘no expected success’ experienced less perceived control in their offices.

The analysis shows significant differences in the three categories’ median of perceived control ($p < 0.05$) in all seasons. Comparing the two categories ‘no success expected’ and ‘no need to change’, the median of the perceived control score for the category ‘no success expected’ lies one unit lower in spring, autumn and winter.

Pairwise tests were applied to analyse the differences between each two categories of ‘reasons for not exercising available adaptive controls’ (Table 5-4). Significant differences appeared between ‘no success expected’ and ‘no need to change’ in all seasons, as well as between ‘no success expected’ and ‘not important’ in autumn.

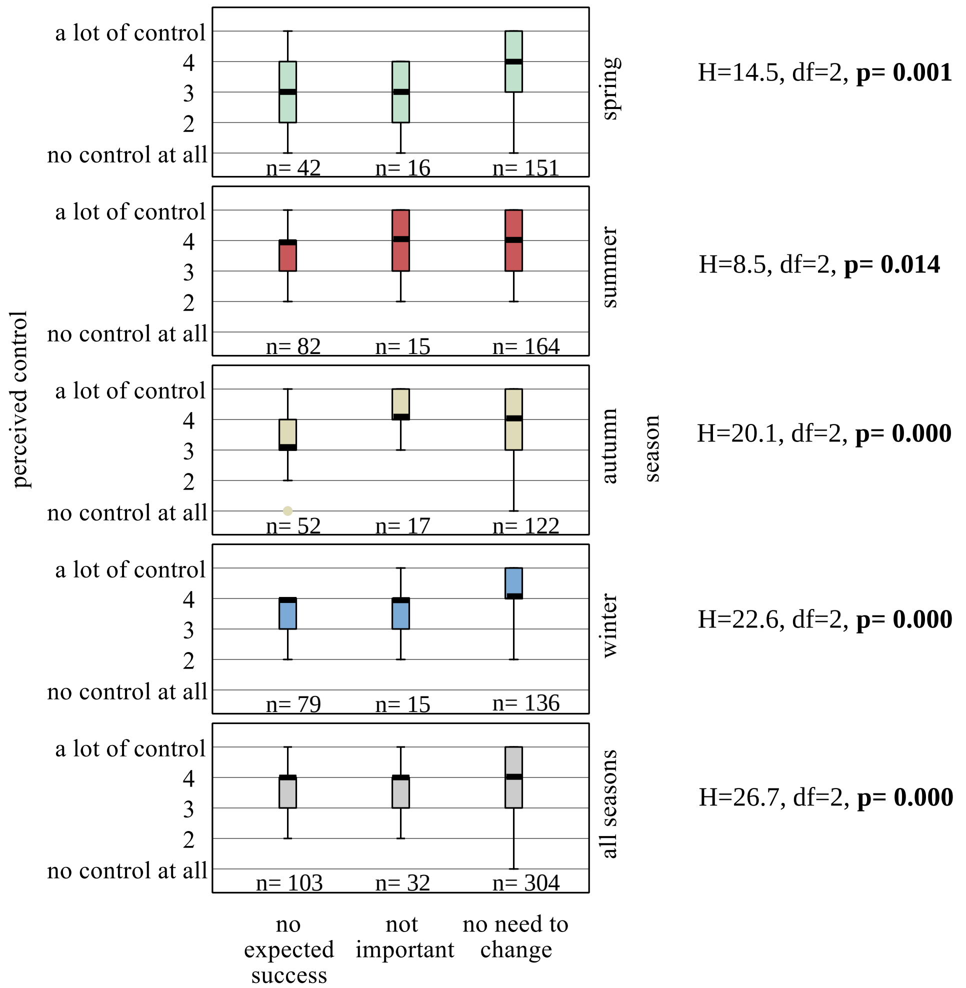


Figure 5-24. Frequencies of perceived control votes for the three categories of ‘reasons for not exercising available adaptive controls’. Analysis based on Kruskal-Wallis test (α=0.05). Numbers refer to the number of occupants.

Table 5-4. Significance values adjusted after Dunn-Bonferroni pairwise post hoc tests of reasons for not exercising available adaptive controls.

	Adj.Sig./ season				
Pairwise groups	spring	summer	autumn	winter	all seasons
no success expected- not important	1.000	1.000	**0.021**	1.000	1.000
no success expected- no need to change	**0.001**	**0.011**	**0.000**	**0.000**	**0.000**
not important- no need to change	0.158	1.000	1.000	0.388	0.015

Asympotic significances (2 sided tests) are displayed. The significance level is 0.05. Significance values have been adjusted by Bonferroni correction for multiple tests.

5.8 Impact of office type and season on perceived control

A significant effect of the impact of office type on perceived control for each season is shown in Figure 5-25. The median value of perceived control for single office type is the highest in all seasons. Pairwise tests were applied to analyse the differences of each of the two types of offices for perceived control (Table 5-5). Significant differences appeared between single and open-plan offices in all seasons, and also between single and shared offices in winter.

Table 5-5. Significance values adjusted after Dunn-Bonferroni pairwise post hoc tests for office types in each season.

	Adj.Sig./ season			
Pairwise groups	spring	summer	autumn	winter
single office- shared office	0.029	0.398	0.154	**0.023**
single office- open plan	**0.001**	**0.002**	**0.001**	**0.001**
shared office- open plan	1.000	0.117	0.149	1.000

Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05. Significance values have been adjusted by Bonferroni correction for multiple tests.

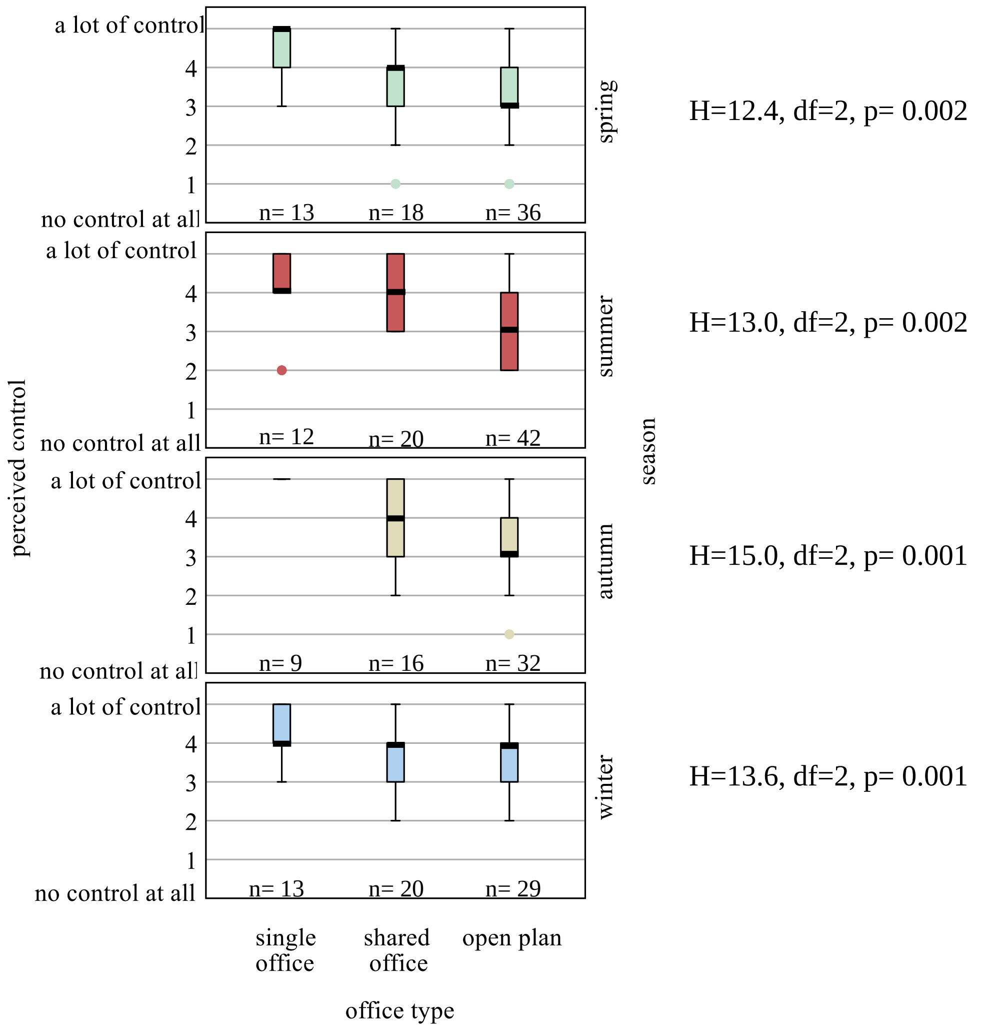


Figure 5-25. Perceived control versus office type in all seasons. Analysis based on Kruskal-Wallis test (α=0.05). Numbers refer to the number of occupants.

With regard to the impact of season on perceived control, overall scores for perceived control did not differ significantly (p=0.52). The median of perceived control was 3 for spring and 4 for summer, autumn and winter. The analysis considered those occupants who responded in all four seasons (N=30) and was based on the Friedman test (α=0.05). See Figure 5-26.

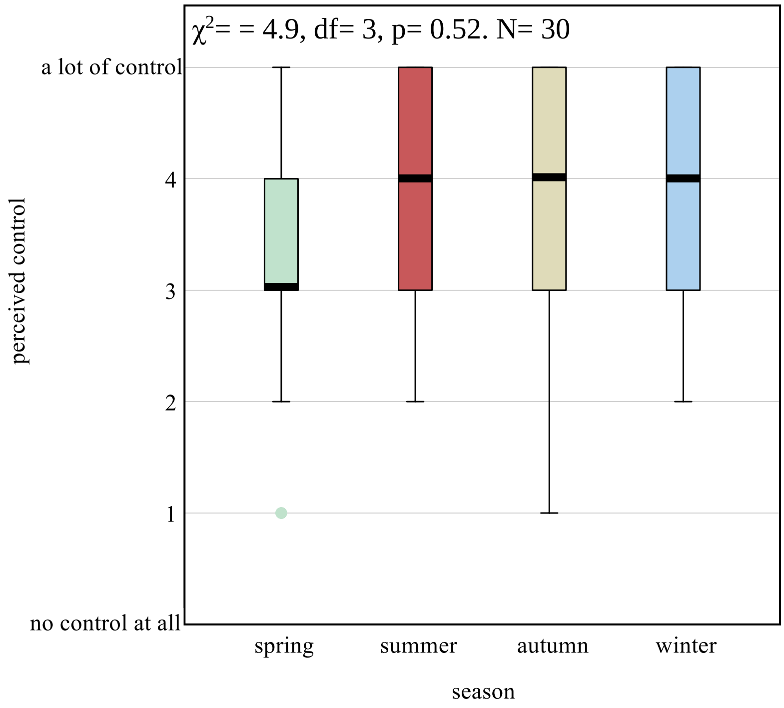


Figure 5-26. Perceived control versus season. Analysis based on Friedman test (α=0.05).

5.9 Impact of perceived control on thermal comfort and air quality perception

Concerning the thermal comfort perception, 92% of the occupants were comfortable (scale points 3 to 5) and only 8% voted for uncomfortable or very uncomfortable. Occupants also perceived good air quality (92%) (scale points 3 to 5) while only 8% voted for bad or very bad air quality.

An analysis using the Spearman rank-order correlation of perceived control versus thermal comfort perception and air quality perception respectively was carried out for all seasons [perceived control: no control at all (1)… a lot of control (5); thermal comfort: very uncomfortable (1)… very comfortable (5), air quality perception: very bad (1)… very good (5)].

The strongest significant correlation was found for summer (rs =0.52; 2-tailed p= 0.00), followed by autumn, all seasons, winter and spring respectively, as shown in table 5. This indicates that individuals, who believe they have control, are generally more thermally comfortable. Perceived control was also found to correlate positively with air quality perception among all seasons. The strongest correlation was found for all seasons (rs =0.51; 2-tailed p= 0.00) as shown in table 5. This suggests that individuals who believe they have control, are more positive towards air quality.

Table 5-6. Spearman rank-order correlation between perceived control and both thermal comfort and air quality perception.

	perceived control versus thermal comfort perception		perceived control versus air quality perception		
	r_s	Sig. (2-tailed)	r_s	Sig. (2-tailed)	N
all seasons	**0.45****	**0.00**	**0.51****	**0.00**	119
spring	**0.34****	**0.005**	**0.32****	**0.009**	67
summer	**0.52****	**0.00**	**0.41****	**0.00**	74
autumn	**0.49****	**0.00**	**0.29***	**0.03**	57
winter	**0.42****	**0.00**	**0.41****	**0.00**	62

* correlation is significant at the 0.05 level (2-tailed)

** correlation is significant at the 0.01 level (2-tailed)

6 Discussion

In this chapter, the main results which were obtained from the analysis of the longitudinal field survey in the previous chapters are discussed and related back to the main aims of this study, as explained in Chapter 1. These aims are:

- to investigate thermal comfort and the applicability of the adaptive models in office buildings located in Jordan, specifically Amman;
- to increase understanding of the role of personal control in office workplaces.

6.1 Thermal comfort

In this part of the study, a detailed longitudinal approach to analysing the adaptive thermal comfort was applied and analysed. The survey took place in the capital city of Amman, which is the most populated city in Jordan and where considerable economic investments have taken place in recent years. In this chapter, the results of the investigations reported in chapter 4 are discussed and related back to the following objectives of this thesis, as defined in chapter 1.

- to investigate the internal and external drivers that affect adaptive thermal comfort;
- to determine the comfort temperature zones of the four seasons;
- to compare the results obtained from this study with those obtained from other adaptive models;
- to investigate the perception of feeling comfortable with the thermal sensation scale, since feeling comfortable on the same thermal sensation vote might differ between the different seasons.

This part is divided into three main sections, the first section discusses the study design; the second section investigates the internal and external drivers that affect adaptive thermal comfort while the third section ‘magnitude of adaptation’ discusses the last three objectives listed above.

6.1.1 Study design

Initially, this project was designed to investigate naturally ventilated buildings, and several office buildings were investigated during its early stages, in order to select suitable and adequate cases for study. This approach was subsequently abandoned, since it proved difficult to find an adequate sample size of this type of office building in the city targeted for the study. Most buildings in the city of Amman were found to rely on air conditioning. Evidently, the use of these devices has increased rapidly in the last few years, due to higher living standards and a more pressing necessity to cope with the higher frequency of heat-waves according to the World Health Organization (2015). Thus, the study was adapted by surveying two mixed-mode buildings and one naturally ventilated building.

A longitudinal thermal comfort survey, conducted during a period of four seasons, forms the basis of this study. In the first survey, the questionnaires were distributed twice a day for a period of 2-3 weeks, firstly in the morning and secondly in the afternoon. This design was deemed appropriate to examine the reliability of individual responses and to analyse the progression of respondents' adaptation during the day. However, after applying this criterion for a week in the Spring of 2016, it was noticed that the respondents were unwilling to answer the second questionnaire later in the day, reporting no changes in their thermal environment and voicing frustration regarding the time-consuming process of answering the questionnaire. Consequently, the experimental design was modified to reduce the frequency of surveying to only a single questionnaire per day, and twice a week for the same period of 2 to 3 weeks. That was a necessary measure to encourage the occupants to continue to take part in the study. The highest response rate to the questionnaires was in the spring season 34.4%, as some occupants responded twice a day during the first week. Autumn had the lowest response rate, of 17.6%. This was attributed to decreased motivation on part of the targeted respondents, due to the short gap between the summer and autumn surveys, since the latter survey was conducted in October only one month after the end of the August summer survey. The percentage of responses rose to 21.6% in the winter survey in January and February of 2017, after a longer time gap since the previous survey was conducted, in October (Table 4-1).

It is also worth mentioning that although the average time required for answering the 'thermal comfort' questionnaire while the physical environmental parameters were being measured was estimated at five minutes, it took the respondents considerably longer to fill in the questionnaire during the first week. Later, when they became familiar with it, less time was required to complete it. It should be pointed out that, when designing the study, the researcher was confronted with the familiar trade-off between reducing the time necessary for respondents to fill in the questionnaires and the need to include certain questions that were indispensable to the objectives of the study.

6.1.2 The internal and external drivers that affect adaptive thermal comfort

The indoor and outdoor environmental parameters were analysed, the major impact on thermal comfort was found to be affected by the indoor air temperature, outdoor temperature (seasons), behavioural adaptations in terms of personal and environmental adjustment, psychological adaptation as well as types of building ventilation.

As the thermal comfort scale used in this study was a five-point scale, statistical analysis showed that adding the votes of the middle part of the scale to the 'comfortable' votes is significant, while it was not significant when adding these votes to the ‘uncomfortable’ votes. This is in line with the findings of Hellwig (2005).

As described in section 4.1 the seven-day running mean outdoor temperature ranged between 19 and 22°C in spring, 28°C in summer, slightly above 23°C in autumn and slightly above 6°C in winter. The median operative temperatures in the mixed-mode buildings 1 and 2 were similar during the four seasons, at 23 to 24°C, while the free running building experienced a variation in the median indoor air temperatures of 24.3°C in spring, 26.4°C in summer, 25.2°C in autumn and 17.8°C in winter. The impact of seasons on the indoor temperatures was noticeable in the investigated free running building compared with the mixed-mode buildings. Occupants of the investigated free running building showed more tolerance to variations in indoor temperatures over the seasons than those in the mixed-mode buildings, which reflects more adaptation to the outdoor climate.

In spring, the difference between the indoor air temperature and the running mean outdoor temperature was +4 to +6 K in mixed-mode buildings. These buildings were mostly running in a free running mode, as the occupants did not make use of the air conditioning around 80% of the time during this season’s survey. The difference related to the free running building was +2 K. The median thermal sensations were ‘neutral’ in all buildings and occupants preferred ‘no change’ in the air temperature (60%). Furthermore, they reported that they felt comfortable, with high percentages of 83%, 90% and 82%, in buildings 1, 2 and 3 respectively. The performance of the free running building is similar to that in the mixed-mode buildings during the spring season in this study.

Whereas in the mixed-mode buildings in summer, air-conditioning (cooling) was in use 67 to 75% of the time, resulting in a -5 K difference from the outdoor temperature, the free running building’s indoor temperature was 26.1°C, which is 3 K higher than those in the mixed-mode buildings and 2 K lower than the outdoor temperature. The investigated offices were north-oriented, and it was observed that the blinds were almost closed during the surveys, moreover, the nature of the building, which has a thick stone façade was noted. Furthermore, one of the occupants reported they often used night ventilation in order to cool down the building. Although the median thermal sensation was found to be slightly warm in the free running building, and the preferences were either ‘no change’ (50%) or cooler (50%), a high proportion (>90%) of the responses reported a feeling of comfort.

Contrary, in the mixed mode buildings, where occupants felt ‘neutral’ and ‘slightly cool’ but preferred ‘no change’ or even ‘cooler’ air temperatures, although the air temperature was already at about 23°C. Also, in these buildings a high percentage of respondents reported feeling comfortable (70 to 90%). Since the temperature was a result of the occupants’ thermostat adjustment, it can be assumed that the occupants targeted these cooler temperatures. It appears that their expectation of having cooler air temperature would be a kind of luxury.

In autumn, the use of air conditioning was equally divided between ON and OFF in the mixed-mode buildings and the difference between the indoor air temperature and the running mean outdoor temperature was around zero. However, this difference was +2 K in the free running building. The median thermal sensation reported was slightly warm in the free running building, while it was slightly cool or neutral in the mixed-mode buildings. Occupants preferred 'no change' in air temperature in the mixed-mode buildings, while cooler temperatures were preferred in the free running building. In all buildings occupants felt comfortable [with high percentages 89%,92%,82%, in buildings 1, 2 and 3 respectively.] In autumn differences in thermal sensation and preference occurred between the two types of buildings.

In winter, air-conditioning was in use 71 to 75% of the time in heating mode, which tended to be 17 K above the outdoor temperature. While the free running building had comparatively low indoor air temperature of 18°C, which was 11 K above the outdoor temperature (6°C). Median thermal sensations were found to be neutral in the mixed-mode buildings but cool in the free running building. Occupants preferred not to change the thermal conditions in the mixed-mode buildings, but a warmer temperature was preferred in the free running building. They reported they felt comfortable in the mixed-mode buildings but only 43% felt so in the free running building.

It seems that expressing a preference for a change in temperature does not necessarily mean that a person feels uncomfortable (e.g. summer in this study) but it could be also an expression of discomfort (e.g. winter responses of building 3 in this study).

The CO_2 concentration for all three buildings during all seasons, except winter in the free running building, was under 1000 ppm, which is a concentration typical of occupied spaces with good air exchange. Despite the high CO_2 concentration in the free running building (Table 4-2) during winter, just 14% responses were related to bad or very bad air quality. Thus, more than 80% of occupants perceived good air quality with (scale points 3 to 5) in all buildings during all seasons.

Air velocity and relative humidity were not found to be important drivers affecting thermal comfort in this study. As the median air velocity ranged from 0.1 to 0.2 m/s in the three buildings, occupants felt no movement, very slight, or slight air movement and preferred no changes, as they felt comfortable, as shown in section 4.1.9. Relative humidity varied between 20 and 65% in all buildings and the ranges were quite similar in all buildings among all seasons. The comfortable percentages indicated a high level of humidity comfort, but it is most likely that occupants answered in this way as they did not really feel humid or dry air. Some occupants commented that this question was difficult to assess, as they were unable to feel the humidity.

Clothing level adjustment is an important adaptation process to maintain the comfort at different temperatures. During the comfort survey, it was found that clothing insulation values have been decreased from winter to summer by about 0.4 clo (Table 4-12). The median clothing insulation of females was found to be slightly higher in spring than that of the males, while it was the same during the other seasons. In many studies the clo values of females have been found to be higher than that of males. Drake et al. (2010) found an average clo value of 0.78 clo for females and 0.62 clo for males. The females' average clo-values were found to be about 0.1 unit lower than males in office buildings environment in diverse climate zones (Kim et al. 2013).

Regression analyses was applied to analyse the dependence of clothing on the running mean temperature. Similar analyses for this correlation were carried out by several researchers (Dear et al. 1997; Bouden and Ghrab, 2005; Singh et al. 2011; Farghal, 2011 and Kumar et al. 2016). Both Singh (2011) and Kumar et al. (2016) found a higher coefficient of correlation than the present study. However, considering the analyses carried out in countries with same cultural background as in Jordan, the value of the mean clothing insulation was around 0.6 clo across the four seasons in Egypt (Farghal, 2011) while the correlation between clothing insulation and outdoor temperature found in the present study was very close to the result in Tunisia (Bouden and Ghrab, 2005). The present study found significant differences in the clothing values between the buildings, as well as the different seasons (Figure 4-22 and Figure 4-23). The most obvious differences in clothing insulation lay between the free running building and mixed-mode buildings, as the clo values of the free running building were higher in winter and lower in summer.

As mentioned in section 4.2, respondents were asked to estimate the temperature during the survey. It was noticed that both measured and guessed air temperatures related to the 'neutral' sensation vote were approximately in the same range, while differences between these temperatures appeared when occupants answered on the warm or cool side of the thermal sensation scale. It was also observed that the guessed temperature was more correlated with some thermal sensation votes. These primary results indicate an interesting and important trend, as occupants answered with reference to their current perception, which may differ from the actual thermal situation. Nevertheless, this study did not address this topic in detail, but future studies may focus on finding further explanation for this observation.

6.1.3 Magnitude of adaptation

The adaptive approach was chosen for this study as the investigated buildings offer many adaptive opportunities to their occupants, such as: operable windows, operable indoor/ outdoor doors, operable blinds and where the occupants can have their personal fans/ heaters and the clothing code is relatively flexible. Further to the decentralized HVAC systems with room-wise adjustable thermostats in the mixed mode buildings. Buildings with such opportunities provide a good basis to investigate occupants' adaptive behaviours to achieve thermal comfort. It is worth mentioning that PMV model was tested. PMV model was found to underestimate the thermal comfort of tenants.

Seasonal panel analysis regression method was applied between the thermal sensation votes and operative temperatures. it has the benefit of being able to examine the reliability of individual responses and analyse the progression of their adaptation during the different seasons. A similar principal was used to develop the residential adaptive comfort in a humid subtropical climate-Sydney Australia where the survey sample was broken down by month and city (de Dear et al. 2018).

The results of the panel analysis regression models between the thermal sensation votes and operative temperatures failed to determine neutral temperatures for the mixed-mode buildings, with one sole exception 'the winter regression of building 2' (Table 4-7), as in these cases the regression model's gradients were around zero which were reflected in almost horizontal regression lines around the neutral thermal sensation vote, as shown in Figure 4-13 (a, b). This could be explained by the high level of control in these buildings, which allowed occupants to adjust the indoor temperatures (though using thermostats) exactly to their needs and preferences, as the temperatures corresponding to the 'neutral' vote spread from 20.3°C to 26.7°C in building 1 and from 19.8°C to 27.3°C in building 2. Furthermore, as mentioned previously, the occupants who voted 'neutral' on the thermal sensation scale preferred 'no change' in their thermal environment and they reported that they felt comfortable, in a high proportion.

On the other hand, significant regression models were found for the free running building in spring, autumn and for the all-season models. The non-significant models for summer and winter refer to the relatively small number of responses during these seasons. The results related to this building represent the concept of adaptive thermal comfort, which tends to show distinct temperature ranges in each season, as shown in Figure 4-13c.

As reviewed in Chapter 2, in the regression method developed by de Dear and Brager (1998, 2002) the comfort temperature is determined by solving each building's regression model for a mean sensation of zero. In ASHRAE 55's adaptive comfort standard, the acceptability boundaries were determined by solving the regression equation for TSV of ± 0.5 for 90% and ± 0.85 for 80% acceptability limits (de Dear and Brager 1998).

Based on the findings of this study, occupants felt comfortable in a broader range of thermal sensations, not only in the case of a 'neutral' thermal sensation vote. This range covers 'cool', 'slightly cool', 'slightly warm' and 'warm' sensations, with high comfort percentages. This view is also expressed by Schiller (1990) who concluded: "*The results suggest that the concept of 'comfort' covered a broader range of thermal sensations than commonly assumed and that people voting within the extreme sensations are not necessarily dissatisfied, based on field data*". These findings were also in line with

(Schweiker et al. 2017) who found that the range of categories regarded as comfortable was encompassed in the area of the scale from cool to warm. Furthermore, the perception of feeling comfortable with the same thermal sensation vote differed between the different seasons. For example, the percentage of those feeling comfortable related to a slightly cool sensation in summer was higher than that in winter. Thus, occupants felt more comfortable from neutral towards the cool side of the scale in summer and towards the warm side in winter, while from neutral towards the warm side of the scale in winter. Votes related to hot or cold were considered as uncomfortable in all seasons and were also rarely voted.

Considering these findings, it appears that applying the standard method of deriving the comfort temperatures will lead to inaccurate results, as well as ignoring ranges of temperatures which should be related to the comfort zone -in this case-. Furthermore, finding the neutral temperatures from the relation of thermal sensation vote and indoor operative temperature failed in this study for both mixed mode buildings. Therefore, the comfort zones were derived from the observed operative temperatures related to the comfort votes with respect to each season where comfort temperatures were derived from the median values, while ranges were from the interquartile as proxy for the comfort ranges, as shown in Table 4-9.

The medians of the comfort temperatures in the mixed-mode buildings were 23°C to 24°C, while the comfort zone range was 22°C to 25°C. The minimum temperature was related to summer, which confirmed the previous findings that respondents preferred cooler temperatures in summer. The highest comfort temperature was in spring and autumn. In the free running building, occupants were adapted to the outdoor temperatures, as the lowest median of comfort temperature was around 18°C in winter, followed by 24.6 °C in spring, 25.7°C in autumn and approximately 26.0°C in summer, which was the highest median of the comfort zone.

The comfort temperatures were related to the running mean outdoor temperatures, using Loess regression for each building, as shown in Figure 4-18 and Table 4-11. In the mixed-mode buildings, the fitted Loess curves were almost flat, which indicates no relation between the comfort temperature and the running mean outdoor temperature. The curves of both mixed-mode buildings evolve towards lower comfort temperature values in summer, at approximately 22°C running mean outdoor temperature, which confirms the results mentioned above regarding cooler temperatures being preferred in summer in the case of the mixed-mode buildings, as well as the same median values of comfort temperatures being observed in the different seasons.

The overall form of the free running building curve appeared to be quite robust, with a linear relation between comfort and running mean outdoor temperature, but not continually increasing, as at 24°C the curve changes into a flat line, indicating that the comfort temperature will not further increase with an increase in the running mean outdoor temperature. The corresponding comfort temperature of 24°C running mean outdoor temperature was found to be approximately 26.0°C. The horizontal line indicates that adaptation stopped after reaching specific outdoor temperatures, as occupants reached the maximum level of adaptation or the building did not develop higher temperatures, so further adaptation was not needed. This finding was also in line with (Schweiker & Wagner 2015). It is important to mention that these findings related to the free running building are based on small sample size, as a bigger sample was not available for this study and it is difficult to find such buildings these days in Amman, as mentioned before. Despite this small sample size, the results reflect the adaptive thermal comfort concept fairly good.

In winter, occupants continued to adapt, even when the outside running mean temperatures fell below 10°C. As reviewed in section 2.3.4 Lowess regression line was used in SCATs project to assess the overall relationship between the running mean outdoor temperature and comfort temperature for the five countries UK, France, Sweden, Greece and Portugal, as well as a for all of them. They concluded that, in overall there is no change in the relationship between comfort temperature and running mean outdoor temperature when outside temperature is below 10°C. On the other hand, a linear relationship exists when outside temperature is above 10°C. The individual model for Portugal of the SCATs project showed that occupants in Portugal continued to adapt at cold temperatures which is in line with the result of the investigated free running building. For the UK, the comfort temperature was not truly constant at cold temperatures, but the slope of line was generally very small. In France the curve was very close to the overall shape. Therefore, it is assumed in SCATs that comfort temperature can be taken as constant (22.88 °C) if the T_{rm} is below 10°C and as in Equation 2-8 and Equation 2-9 if the T_{rm} is above 10°C (McCartney & Nicol 2002).

This was also an issue of discussion when the adaptive comfort standard (ACS) was added to the ASHRAE Standard 55 (de Dear & Brager 2002). This was because several members of the ASHRAE Committee felt that the lower end was extreme and did not reflect what the data actually showed, as the original analysis of RP-884 extended from a mean outdoor air temperature of 5 – 33°C. However, in the end, it was presented in the ASHRAE Standard 55 ending at 10°C mean outdoor air temperature. It was also discussed whether the graph should end sharply at the end points, or whether the lines should extend horizontally when the outdoor temperature extended beyond the 10 – 33°C (de Dear & Brager 2002). This was shown in the previous findings in this study related to the free running building, but the line extended horizontally at 24°C running mean outdoor temperature.

An explanation of the constant median comfort temperature of 24°C in the mixed-mode building during the different seasons is related to a personal control study which was conducted in the same buildings, where it was found that occupants were aware of the adaptive opportunities they had in their work environments and adjusted them to reach their personal thermal comfort. It was also found that operable windows and thermostats were the highly desired features of workspaces (Al-Atrash et al. 2018). Occupants tended to use the available technology to adjust the thermostats to reach their comfort temperature, as this provided rapid and noticeable changes with positive feedback in the environmental conditions occupants experienced in their offices. This is in line with the findings of Nicol & Humphreys (1973), Heerwagen & Diamond (1992), Gossauer et al. (2006) and Hellwig (2018), indicating that people prefer behavioural methods of thermo-regulation rather than other types of thermo-regulation, as these enable them to perceive immediate reward to improve their thermal state.

The comparison between the adaptive model related to the free running building and the ASHRAE Standard 55- 80% acceptability showed that occupants in this particular office building in Amman were more tolerant of, or more adaptable to temperature variations until the running mean outdoor temperature reached 24.0°C. The comfort temperatures of the mixed-mode buildings were within the 80% acceptable range of ASHRAE Standard 55 in spring and autumn, while several temperatures of those voted comfortable were lower than the 80% range in summer. This is due to the finding of preferring lower temperatures in summer. The regression coefficient of the free running building, of 0.5, was found to be higher than that in the SCATs project of 0.3 (Equation 2-9), in the ASHRAE Standard's 55 of 0.31 (Equation 2-5) and also in the EN 15251 standard of 0.33 (Table 2-4) for $T_{rm} \leq 24$°C. Thus, the regression line is steeper, as shown in Figure 4-19 until the regression line becomes horizontal when reaching approximately 24.0°C running mean outdoor temperature.

Considering the comparison with EN 15251, it was found that the spring comfort temperatures were within the second category range, while several temperatures in both autumn and summer were lower than the lower limit of EN 15251-II. In winter, many data values were above the upper limit of EN 15251- II (Figure 4-20).

The both ASHRAE 55 and EN 15251 standards were developed based on the analysis of huge sets of data compiled from field studies in numerous buildings located in different climatic zones. They are internationally accepted as reference standards, even in those countries which were not part of the original data base. This raises the question of to what extent these standards are adequate to be applied worldwide. Furthermore, the comparison between the standards and field data from a few case studies only is questionable. The comparison done in this study is intended just to give a general idea about how the data based on the investigated buildings fits with these standards.

6.2 Personal control

This section discusses the results related to personal control over indoor climate, which were explained in chapter two. In this study, a detailed longitudinal approach to analyse the impact of available control (objective and perceived) and desired controls on perceived control has been performed.

The first step related to this objective was to collect information on the available adaptive control opportunities in offices, which was assessed by the researcher at the beginning of the first field survey. It was observed that the mixed-mode buildings tended to provide bigger office units, as the majority of occupants in building 1 (75%) worked in an open-plan office environment, while in building 2 the majority (64%) worked in shared offices. An open layout is one of the most popular office designs in today's organisations (Samani 2015). There are two main reasons behind this: the first reason refers to financial issues, as the layout requires less space for each occupant, which reduces the cost. The second one is to enhance knowledge sharing, teamwork and communication, productivity, and creativity (Hedge, 1982). However, as reviewed in section 2.4, several studies indicate that having control over the work environment is very important for employees' environmental satisfaction and productivity. The ability of occupants in open-plan offices to control their work environment is more complicated, as it is affected by both physical and psychological aspects, such as the need for prior negotiation, the location of the available control option in relation to occupants' work-space and how to reach it (Hellwig (2015) and Samani (2015).

As shown in (Figure 5-3, Figure 5-4 and Figure 5-5), the single offices of the surveyed buildings offered more objectively available control options compared to shared and open-plan offices. Non-operable windows were found in three shared offices in both buildings 1 and 2, and in two open-plan offices in building 1. This is surprising, as both buildings are LEED certified, aiming for high occupant comfort and satisfaction. Indoor environmental quality is a main section of the LEED scorecard, which includes the category of providing controllability over thermal comfort systems. The point related to this category was awarded for building 2, while it was not achieved in building 1. LEED certified buildings must achieve a certain number of points, depending on the specific rating system. However, it is not a must to achieve all the indoor environmental quality criteria, which leaves the decision to include these points to be made by the designer and owners of the buildings. Although availability of control has not been an obligatory evaluation criterion in most green building evaluation systems, it has been known for many years and from numerous SBS studies (e.g. Bischof et al. 2003) that sealed facades and non-operable windows contribute considerably to the prevalence of sick building syndrome.

‘Perceived availability’ and ‘desired control’ were introduced, defined and implemented in the ‘thermal comfort and personal control’ questionnaires in this study. ‘Perceived availability’ is the subjective perception of availability of certain controls, which depends on the subjective opinion or belief of having or not having adaptive control options available. ‘Desired control’ was defined as the occupant’s wish for control options to adjust the indoor climate. The most desired control options were operable windows (77% of the occupants) and thermostats (82%), in the three buildings. This proportion is somewhat lower but of similar magnitude as that in previous findings, e.g. the ProKlimA – study which showed that 85% of office workers wished to have control over their indoor environment (Bischof et al. 2003). The most desired control features should be provided to the occupants, as these are the features the occupants are likely to use, and this will lead to a positive perception of self-efficacy (Hellwig, 2015). The least desired control options in the mixed-mode buildings were personal fans and heaters, as occupants had the option to adjust the thermostat, which provided them with the preferred indoor thermal conditions. However, these options were desired by occupants in the free running building in order to reach thermal comfort.

The occupants’ perceived availability of all control options was lower in shared and open-plan offices compared to single offices, as shown in Figure 5-6, Figure 5-7 and Figure 5-8. Some occupants reported no availability of operable windows and blinds in open-plan offices in both mechanically ventilated buildings, although these opportunities were available. Furthermore, restrictions accessing the available control options obviously appeared in shared and open-plan offices (Figure 5-12). This is related to the nature of these office types, as many individuals with different personalities and needs had to work close to each other. Some occupants were sitting relatively far away from the mentioned control options and stated not having exercised them for these reasons: ‘would not have helped’, ‘cannot adjust option any further’, ‘was not agreeable to others in the space’, and ‘not sure if it would be OK with management’. Thus, they perceived restrictions to making adjustments. This is in line with the study by Leaman and Bordass (1999), who found that when negotiations with others are needed before exercising the control options, constraints may appear.

The reasons for not exercising available adaptive controls were divided into three main categories: ‘no success expected’, ‘not important’ and ‘no need to change’. The reasons referring to each category are shown in Figure 5-16. Significant differences in the three categories’ median of perceived control were found in all seasons. Based on the pairwise tests, significant differences appeared between ‘no success expected’ and ‘no need to change’ in all seasons, as well as between ‘no success expected’ and ‘not important’ in autumn.

New variables have been introduced in this study: consistency of perceived and objective availability and conformity to expectation. Overall, the vast majority of votes showed consistency of objective and perceived availability of control. This means that the majority was aware of the adaptive opportunities available at their workplace. Less than 13% expressed perceived restrictions with regard to all control opportunities in all seasons.

The median difference of perceived control among the categories, consistency between perceived and objective availability was not significant for most of the adaptive opportunities during the different seasons, apart from the analysis related to interior door adaptive opportunity in spring ($p= 0.04$). However, votes expressing perceived restrictions in accessing controls showed a one scale point lower level of perceived control for operable window, blinds, interior door and thermostat adaptive opportunities (Figure 5-13). Restrictions may result from the objective availability of control options in the buildings or the social environment, for example, management, negotiations, norms, leading to a lower level of perceived control in the workspace (Hellwig, 2015).

Conformity to expectation was also introduced in this study, as it is seen as part of a person's evaluation system for judging the indoor environment (Hellwig, 2015). An expectation which is not met by the indoor climate or the building can also have an impact on perceived control or comfort perception. The majority of votes demonstrated conformity to expectation. This means that the expectation of the majority towards control was met. Less than 14% of the votes expressed a non-conformity to expectation, where their expectation was not met.

The median difference of perceived control of conformity between perceived availability and desired controls was significant for operable windows in spring, summer and all seasons, as well as for blinds in spring. The analysis regarding the other adaptive opportunities shows no significant differences among the three categories' medians of perceived control ($p > 0.05$) as shown in Figure 5-15.

Votes expressing negative non-conformity led to a one scale point lower level of perceived control compared to all other votes for most adaptive opportunities in all seasons (Figure 5-15). A higher degree of conformity to expectation was shown to be prevalent in naturally-ventilated office types compared to mixed-mode buildings. If offices lacked some control options, occupants in these offices desired to having these missing control options. Those who lacked some control options scored at a lower level on the perceived control scale. The results related to exercised control opportunities were similar among the four seasons. The highest percentage of exercised control opportunities was 'no adjustment' in all buildings among the four seasons, as occupants generally felt comfortable. Even if 'no adjustments' were made most of the time, this would not justify reducing the availability of control opportunities, as availability is an important positive feature as such in a workspace (Haldi and Robinson 2008, Stevenson et al., 2013, Hellwig 2015). Boerstra's (2016) findings emphasise that having access to an operable window and the use of controls such as thermostats and operable windows has a positive and significant effect on perceived control over indoor environments.

Furthermore, the correlation between perceived control and both thermal comfort and air quality perception was also investigated. Perceived control showed a positive significant correlation with thermal comfort and air quality perception during all seasons (Table 5-6). This was also shown by Boerstra (2016) who found that perceived control acts as a mediator of the relation between indoor climate and comfort perception.

No significant differences in perceived control level with regard to season were found, although the median of perceived control in spring was 1 scale point lower compared to the other seasons. In contrast, Gossauer, Leonhart & Wagner (2006) found that the effectiveness of temperature changes was lower in summer compared to winter, negatively affecting the satisfaction with the thermal conditions in summer.

Votes on perceived control showed significant differences between office types among the four seasons, as perceived control in single offices was the highest among all seasons. This was reflected in a higher level of perceived control, thermal comfort and air quality perception in single offices (Figure 5-25).

7 Conclusion

This chapter draws together and forms the main conclusions from the whole study and addresses the research aims. It also points out the limitations of the research and suggests areas for future research.

The primary aims of this PhD study were to investigate adaptive thermal comfort in office work environments in a Mediterranean hot summer climate- in Amman, Jordan, and to increase understanding of the role of personal control over the indoor climate in office workplaces. A framework and analytical longitudinal approach were introduced and applied to achieve these aims, drawn from field surveys which were conducted in three office buildings, two mixed-mode buildings and the third a free running building over a period of four seasons starting from spring 2016 undertaken in April, until winter 2017 undertaken in January and February. The approaches and methods of assessment followed in this study can be applied for future similar research areas.

This chapter describes the conclusions of the research in reference to each of the main research aims and their related objectives. It is split into two parts, the first related to thermal comfort perception and the second related to personal control.

7.1 Thermal comfort

The main aim was to contribute to a better understanding of adaptive thermal comfort in the office environment, as the first research study in this field in Amman, Jordan. This section concludes the results related to investigating adaptive thermal comfort based on the longitudinal approach.

This longitudinal survey collected the required data and information from 119 participants over several periods of time during the four seasons. It had the benefit of being able to examine the reliability of individual responses and analyse the progression of their adaptation during the different seasons. Two mixed-mode buildings and one free running building were investigated. Although frequent surveys are desirable in longitudinal studies, the frequency and the length of the questionnaire have to be well-balanced in order to maintain supportive motivation among the participants.

The free running building experienced variations in the mean and median operative temperatures during the four seasons, while the mean and median temperatures were around 23 to 24°C during all seasons in the mixed-mode buildings. Despite offering many adaptive opportunities, such as operable windows, blinds and fans, occupants preferred to rely on thermostats to achieve their thermal comfort, especially in summer and winter. While these buildings were almost operating in free-running mode relying on natural ventilation (operable windows) during the survey time in both spring and autumn.

The panel analysis regression models between the thermal sensation votes and operative temperatures failed to determine neutral temperatures for the mixed-mode buildings, with one sole exception (the winter regression of building 2), as the regression lines were almost horizontal around the neutral thermal sensation vote because of the high level of control in these buildings, which allowed occupants to adjust the indoor temperatures to their preferences, as they were fully aware of the adaptive opportunities in their working environment. They tended to use the available technology to adjust the thermostats to reach their comfort temperature, as this provided rapid and noticeable changes, with positive feedback, in the environmental conditions occupants experienced in their offices. On the other hand, results related to the investigated free running building represent fairly well the concept of adaptive thermal comfort, which tends to show distinct temperature ranges in each season, as well as significant regression models between the thermal sensation votes and operative temperatures in spring, autumn and for the all-season category. The non-significant models for summer and winter are likely due to the relatively small number of responses during these seasons.

More than 80% of the responses on the seven-point thermal sensation scale were clustered around the central votes (slightly cool, neutral, slightly warm), except for the winter votes in the free running building. A high proportion of occupants in this study felt comfortable with their thermal environment and preferred not to change their environment in spring and autumn but would have liked to be cooler in summer and warmer in winter. Occupants felt comfortable in a broader range of thermal sensations not only in the case of a 'neutral' thermal sensation vote. This range covered 'cool', 'slightly cool', 'slightly warm' and 'warm' sensations and was associated with high comfort percentages. Furthermore, the perception of feeling comfortable with the thermal sensation scale differed between the different seasons. The comfortable percentages related to 'slightly cool' were higher in summer than in winter, as occupants preferred feeling towards the cool side of the thermal sensation scale in summer and towards the warm side in winter.

Therefore, comfort zones were derived from the observed operative temperatures related to comfortable votes with respect to each season. Although the sample size of the free running building was relatively small, the evidence of adaptation was visible, as the thermal comfort zones were 23.2 – 26.5°C in spring, 25.6 – 26.6°C in summer, 24.9 – 26.5°C in autumn and 17.4 – 18.9°C in winter. The medians of the comfort temperatures in the mixed-mode buildings were 23°C to 24°C, while the comfort zone range was 22°C to 25°C. The minimum temperature was related to summer, as respondents in the investigated buildings preferred cooler temperatures in summer.

Linear Loess regression was applied to determine the relation between the comfort temperature and the running mean outdoor temperature. It allowed the details of the structure of the relationship between the two variables to be determined. In the mixed-mode buildings, the Loess curve was almost flat, which indicates no relation between the comfort temperature and the running mean outdoor temperature, but it declined towards lower comfort temperatures values in summer, at appr. 22°C running mean outdoor temperature. The free running building curve showed the concept of adaptation, as an increasing linear relation between comfort and running mean outdoor temperature was found. At 24°C the line flattened out, indicating that the comfort temperature would not further increase with an increase in running mean outdoor temperature. Although the findings related to the free running building are based on a relatively small sample, the approach used can be applied for further studies to validate these findings.

The comparison between the adaptive model related to the free running building and the ASHRAE Standard 55 and EN 15251 showed that occupants in this particular office building were tolerant to temperature variations until the running mean outdoor temperature reached 24.0°C, and they then continued to adapt, even when the outside running mean temperatures fell below 10°C.

For the mixed-mode buildings, the comfort temperatures of the mixed-mode buildings were within the 80% acceptable range of ASHRAE 55 and the second category of EN 15251 in the spring season, while several temperatures of those who voted comfortable were lower than the 80% and EN 15251-II lower limit in summer. This is due to the finding of preferring lower temperatures in summer. In winter, many data are above the upper limit of EN 15251- II, as occupants preferred higher temperatures.

The results related to the variation of clothing insulation showed that clothing insulation values decreased continuously from winter to summer, with a median value of 0.6 in summer and 1.0 in winter. The differences in clothing insulation values were obvious between the free running building and mixed-mode buildings, as the clo values of the free running building were higher in winter and lower in summer. The variations in clothing insulation were found to be significant between seasons.

7.2 Personal control

The second main aim of the study was to increase understanding of the role of personal control in office workplaces by achieving the objectives described in chapter two.

This part of the study introduced and applied a framework and analytical longitudinal approach to analyse the impact of available control (objectively and perceived) and desired controls on perceived control, based on the data collected from the longitudinal field surveys. It also analysed the exercised control that took place in offices and the reasons behind occupants not using the available control options. Another main objective of this study was to investigate whether different seasons and office types affect perceived control.

The analysis showed that larger office units offered less control -not only objectively- but also according to occupant's perceived availability of certain controls and according to the perceived control votes. Occupants' perceived availability of all control options was lower in shared and open-plan offices compared to single offices. Furthermore, restrictions accessing the available control options obviously appeared in shared and open-plan offices, as those who were far away from the mentioned control options stated not having exercised them for these reasons: 'would not have helped', 'cannot adjust option any further', 'was not agreeable to others in the space', and 'not sure if it would be OK with management'. Particularly, this study confirms that operable windows (and thermostats) are a highly desired feature of workspaces and buildings should therefore preferably be designed with operable windows, if external environmental conditions are suitable for that. Windows and thermostats were also the most adjusted control options during all seasons. However, the most prevalent control exercise was 'no adjustment', which related to the most stated reason for not exercising available controls in all buildings and among the different seasons, which was a positive thermal comfort perception. The following highest adjustment responses were distributed between 'opened without asking others' and 'closed without asking others' in single offices and opening the control options 'after asking others' or 'without asking others' in both shared and open-plan offices.

Over all, the majority of responses of reasons for not exercising available controls falls in the 'no need to change' category, followed by the 'no success expected' category, while the answers related to 'not important' were relatively few. The correlation between categories of the reasons for not exercising available adaptive controls correlated significantly with perceived control, as those who reported 'no success expected' perceived less control. Significant differences were also found between 'no success expected' and 'no need to change' categories among all seasons.

New variables have been introduced in this study: consistency of perceived and objective availability and conformity to expectation. Overall, the vast majority of occupants was aware of the adaptive opportunities available at their workplace as less than 13% expressed perceived restrictions with regard to all control opportunities in all seasons. Furthermore, the votes expressing perceived restrictions in accessing controls showed a one scale point lower level of perceived control for operable windows, blinds, interior doors and thermostats adaptive opportunities. However, the median difference of perceived control among the categories, consistency between perceived and objective availability was not significant for most of the adaptive opportunities during the different seasons. Restrictions could have an impact on perceived control but were not found to be significant in this study for most of the adaptive opportunities, due to the low number of votes in this category.

Considering conformity to expectation, the expectation of the majority towards control was met. The median difference of perceived control of conformity between perceived availability and desired controls was significant for operable windows in spring, summer and all-seasons, as well as for blinds in spring. For all adaptive opportunities, the median of perceived control score for the category ‘negative non-conformity’ lies in most cases one unit lower than the median scores for the categories ‘conformity’ or ‘positive non-conformity’.

No significant differences in perceived control level with regard to season were found. Furthermore, perceived control correlates positively with both thermal comfort and air quality perception during all seasons and also in each season separately. Thus, improving the availability of adaptive opportunities in buildings can positively affect occupants’ comfort perception.

Significant impact of office type on perceived control among the four seasons was found, as perceived control in single offices was the highest among all seasons. This was reflected in a higher level of perceived control, thermal comfort and air quality perception in single offices.

This part of the study contributed to a better understanding of what affects personal control and how perceived control is linked to thermal comfort and air quality. It also showed the role of office types and seasons on perceived control.

7.3 Limitations and recommendations for future research

This research was limited by what was possible for the researcher. The main limitation was to find free running office buildings, as nowadays in Amman the majority of buildings are of the mixed-mode building type. Moreover, when this rarely existing building type was found, it was occupied by only a small number of occupants. Mainly these buildings are traditional buildings with small floor areas.

The number of buildings that could be investigated at the same time was limited by the number of available instruments, as well as the ability to collect the required measured data within the framework of the survey in each season, as the surveys were conducted by one person ‘the researcher’ who took the measurements in each investigated office at the time of the ‘thermal comfort and personal control’ questionnaires, two days a week in each building.

In the mixed-mode buildings, it was found that information about the air conditioning status was not monitored and thus not available. Thus, the given thermostat state and set-point temperatures were registered by the researcher while the occupants were filling in the questionnaires which only provided a first impression of the possible operating mode. In early stage of the project, the researcher aimed to monitor this information by replacing temperature and state sensors to the HVAC-outlets. However, it was impossible due to the limited resources. This raises the question about the nature of mixed-mode buildings, which is worth further investigation into how to explore ways to access and analyse mixed-mode buildings.

Further analysis is needed to understand the effect of different seasons on perceived control, as well as tracking the perception and behaviour of occupants over the seasons. Further field studies are highly recommended to investigate more office buildings as well as other types of buildings in the future in order to establish a data base for thermal comfort studies in Jordan and to validate the results based on this study.

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Appendices

Appendix I

The LEED Scorecard of building 1 according to the LEED BD+C: New construction v3 - LEED 2009

SUSTAINABLE SITES		AWARDED: 24 / 26
SSc1	Site selection	1 / 1
SSc2	Development density and community connectivity	5 / 5
SSc3	Brownfield redevelopment	0 / 1
SSc4.1	Alternative transportation - public transportation access	6 / 6
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1 / 1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	3 / 3
SSc4.4	Alternative transportation - parking capacity	2 / 2
SSc5.1	Site development - protect or restore habitat	1 / 1
SSc5.2	Site development - maximize open space	1 / 1
SSc6.1	Stormwater design - quantity control	1 / 1
SSc6.2	Stormwater design - quality control	1 / 1
SSc7.1	Heat island effect - nonroof	1 / 1
SSc7.2	Heat island effect - roof	1 / 1
SSc8	Light pollution reduction	0 / 1

WATER EFFICIENCY		AWARDED: 8 / 10
WEc1	Water efficient landscaping	2 / 4
WEc2	Innovative wastewater technologies	2 / 2
WEc3	Water use reduction	4 / 4

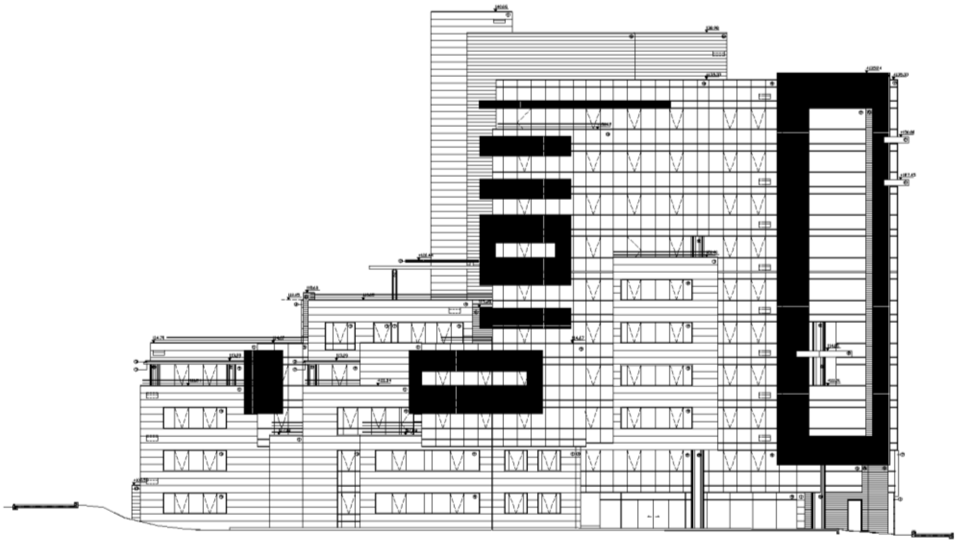
ENERGY & ATMOSPHERE		AWARDED: 14 / 35
EAc1	Optimize energy performance	8 / 19
EAc2	On-site renewable energy	1 / 7
EAc3	Enhanced commissioning	0 / 2
EAc4	Enhanced refrigerant Mgmt	2 / 2
EAc5	Measurement and verification	3 / 3
EAc6	Green power	0 / 2

MATERIAL & RESOURCES		AWARDED: 4 / 14
MRc1.1	Building reuse - maintain existing walls, floors and roof	0 / 3
MRc1.2	Building reuse - maintain interior nonstructural elements	0 / 1
MRc2	Construction waste Mgmt	2 / 2
MRc3	Materials reuse	0 / 2
MRc4	Recycled content	0 / 2
MRc5	Regional materials	2 / 2
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	0 / 1

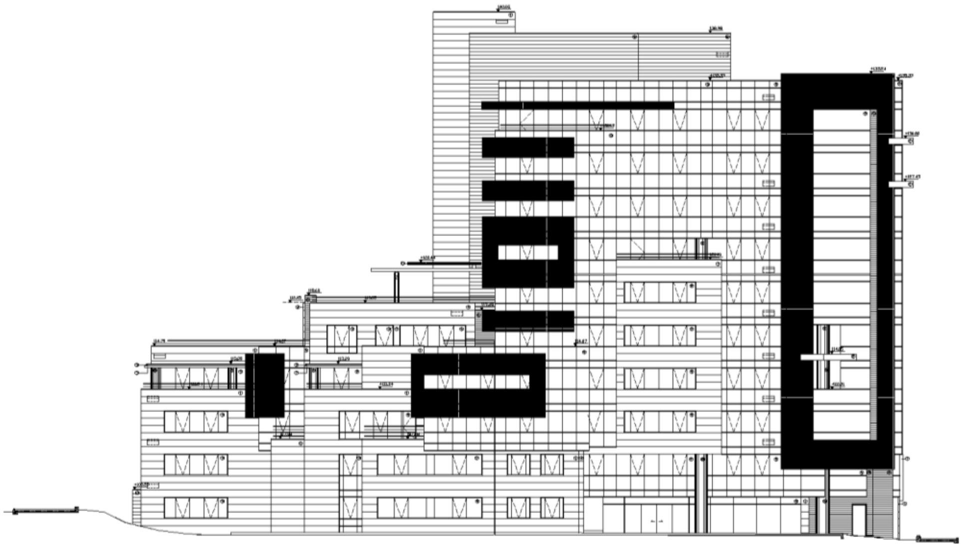
INDOOR ENVIRONMENTAL QUALITY		AWARDED: 8 / 22
EQc1	Outdoor air delivery monitoring	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	0 / 1
EQc6.2	Controllability of systems - thermal comfort	0 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	0 / 1
EQc8.2	Daylight and views - views	0 / 1
EQpc124	Performance-based IAQ design and assessment	required
INNOVATION		**AWARDED: 4 / 6**
IDc1	Innovation in design	3 / 5
IDc2	LEED Accredited Professional	1 / 1
REGIONAL PRIORITY		**AWARDED: 4 / 4**
EAc1	Optimize energy performance	1 / 1
EAc3	Enhanced commissioning	0 / 1
EAc5	Measurement and verification	1 / 1
WEc1	Water efficient landscaping	0 / 1
WEc2	Innovative wastewater technologies	1 / 1
WEc3	Water use reduction	1 / 1
Total		**66 / 110**

40-49 Points: SILVER, 50-59 Points: GOLD, 80+ Points: PLATINUM. LEED BD+C: New Construction v3 - LEED 2009.

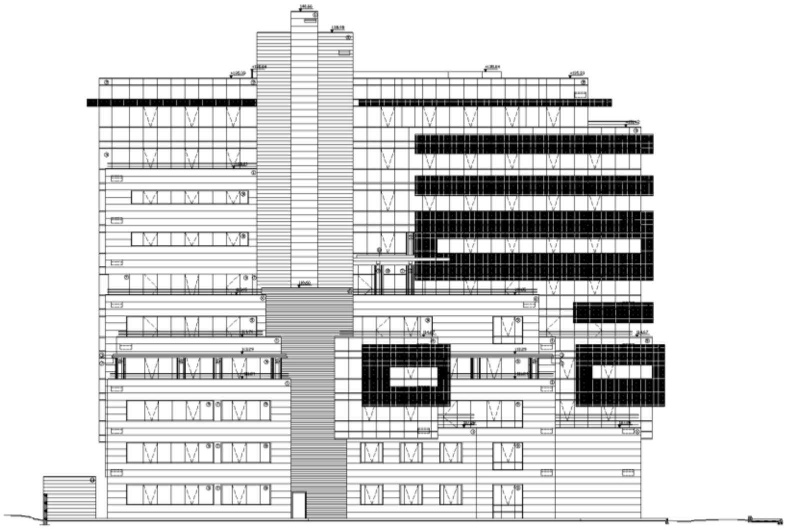
Building 1: elevations and sections



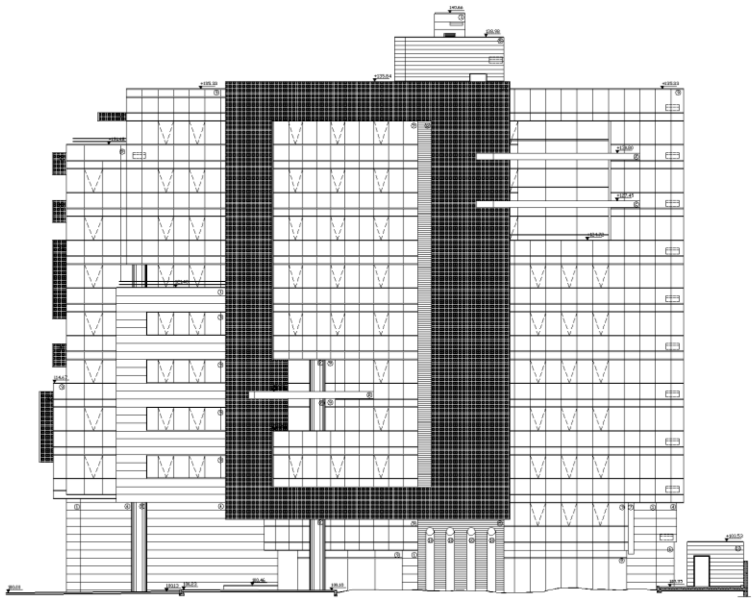
East elevation



West elevation



South elevation



North elevation

The LEED Scorecard of building 2 according to the LEED BD+C: New Construction (v2.2)

SUSTAINABLE SITES		AWARDED: 9 / 14
SSc1	Site selection	1 / 1
SSc2	Development density and community connectivity	0 / 1
SSc3	Brownfield redevelopment	0 / 1
SSc4.1	Alternative transportation - public transportation access	1 / 1
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1 / 1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	1 / 1
SSc4.4	Alternative transportation - parking capacity	1 / 1
SSc5.1	Site development - protect or restore habitat	0 / 1
SSc5.2	Site development - maximize open space	0 / 1
SSc6.1	Stormwater design - quantity control	1 / 1
SSc6.2	Stormwater design - quality control	0 / 1
SSc7.1	Heat island effect - nonroof	1 / 1
SSc7.2	Heat island effect - roof	1 / 1
SSc8	Light pollution reduction	1 / 1

WATER EFFICIENCY		AWARDED: 5 / 5
WEc1.1	Water efficient landscaping - reduce by 50%	1 / 1
WEc1.2	Water efficient landscaping - no potable water use or no irrigation	1 / 1
WEc2	Innovative wastewater technologies	1 / 1
WEc3.1	Water use reduction - 20% reduction	1 / 1
WEc3.2	Water use reduction - 30% reduction	1 / 1

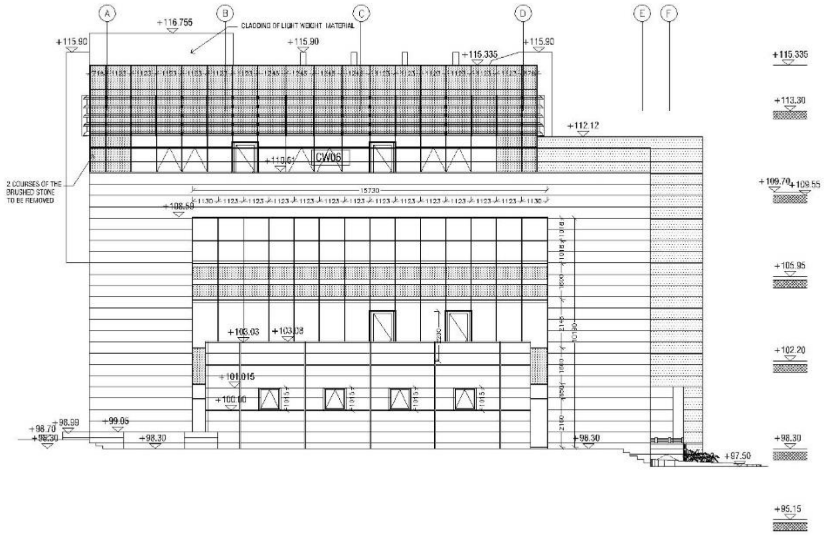
ENERGY & ATMOSPHERE		AWARDED: 6 / 17
EAc1	Optimize energy performance	4 / 10
EAc2	On-site renewable energy	0 / 3
EAc3	Enhanced commissioning	0 / 1
EAc4	Enhanced refrigerant Mgmt	1 / 1
EAc5	Measurement and verification	1 / 1
EAc6	Green power	0 / 1

MATERIAL & RESOURCES		AWARDED: 5 / 13
MRc1.1	Building reuse - maintain 75% of existing walls, floors & roof	0 / 1
MRc1.2	Building reuse - maintain 95% of existing walls, floors & roof	0 / 1
MRc1.3	Building reuse - maintain 50% of interior non-structural elements	0 / 1
MRc2.1	Construction waste Mgmt - divert 50% from disposal	1 / 1
MRc2.2	Construction waste Mgmt - divert 75% from disposal	1 / 1
MRc3.1	Materials reuse - 5%	0 / 1
MRc3.2	Materials reuse - 10%	0 / 1
MRc4.1	Recycled content - 10% (post-consumer + 1/2 pre-consumer)	1 / 1
MRc4.2	Recycled content - 20% (post-consumer + 1/2 pre-consumer)	0 / 1
MRc5.1	Regional materials - 10% extracted, processed and manufactured regionally	1 / 1

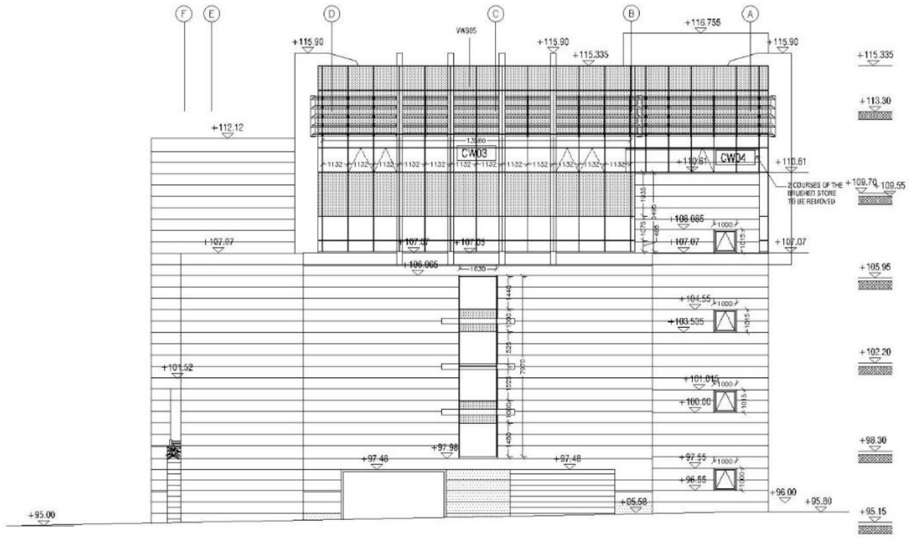
MRc5.2	Regional materials - 20% extracted, processed and manufactured regionally	1 / 1
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	0 / 1
INDOOR ENVIRONMENTAL QUALITY		**AWARDED: 12 / 15**
EQc1	Outdoor air delivery monitoring	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - carpet systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	1 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight 75% of spaces	0 / 1
EQc8.2	Daylight and views - views for 90% of spaces	1 / 1
INNOVATION		**AWARDED: 5 / 5**
IDc1	Innovation in design	4 / 4
IDc2	LEED Accredited professional	1 / 1
Total		**42 / 69**

LEED BD+C: New Construction (v2.2)

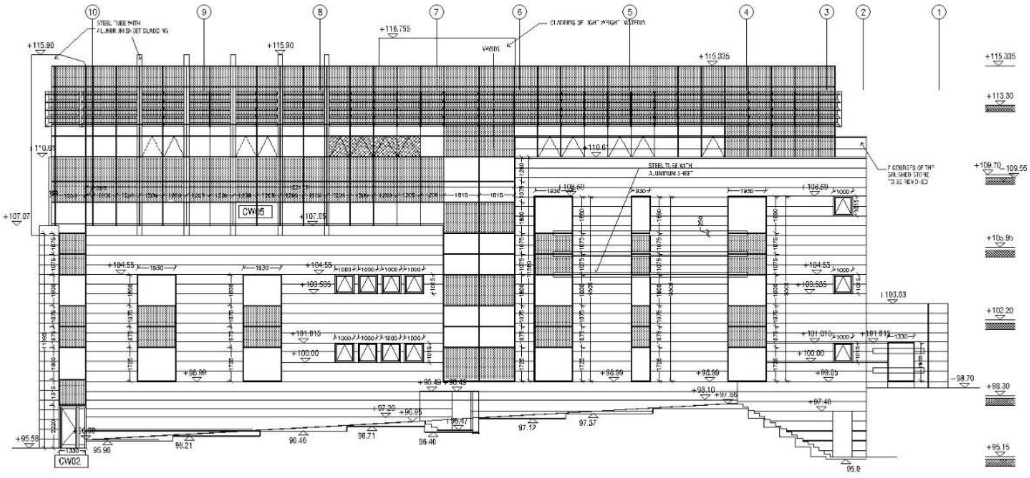
Building 2: elevations and sections



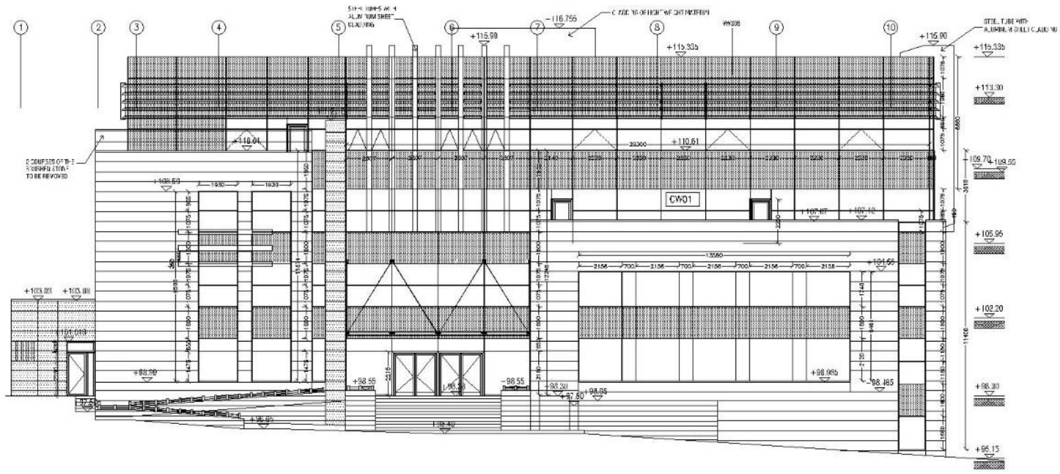
East Elevation



West Elevation



South Elevation



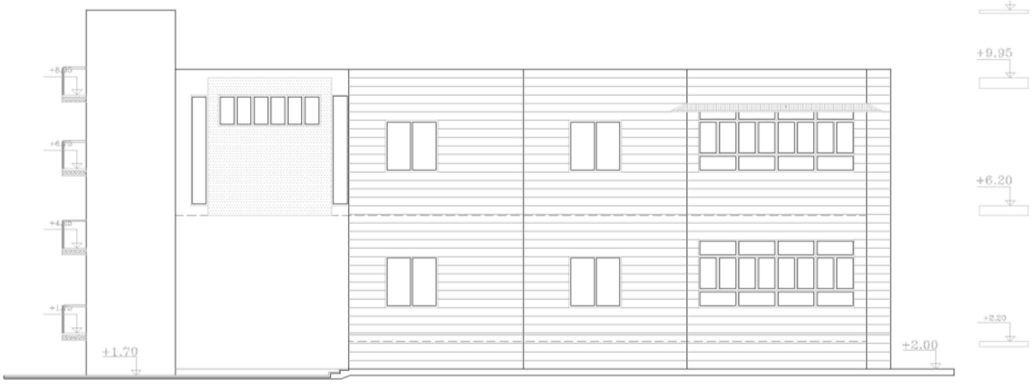
North Elevation

Major changes from LEED-NC v2.2 to LEED 2009 NC

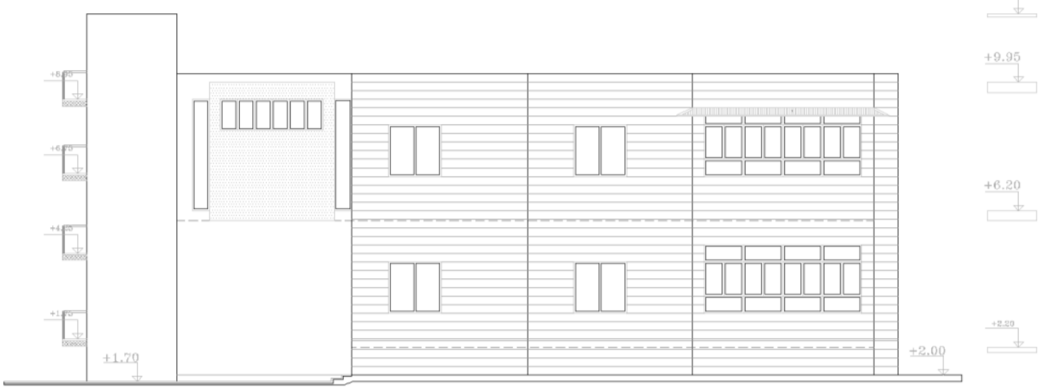
LEED new construction		v2.2	2009	
SUSTAINABLE SITES		14	26	
SSc1	Site selection	1	1	
SSc2	Development density and community connectivity	1	5	
SSc3	Brownfield redevelopment	1	1	
SSc4.1	Alternative transportation - public transportation access	1	6	
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1	1	
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	1	3	
SSc4.4	Alternative transportation - parking capacity	1	2	
SSc5.1	Site development - protect or restore habitat	1	1	
SSc5.2	Site development - maximize open space	1	1	
SSc6.1	Stormwater design - quantity control	1	1	
SSc6.2	Stormwater design - quality control	1	1	
SSc7.1	Heat island effect - nonroof	1	1	
SSc7.2	Heat island effect - roof	1	1	
SSc8	Light pollution reduction	1	1	
WATER EFFICIENCY		5	10	
WEc1.1	Water efficient landscaping - reduce by 50%	1	4	Combined 1.1 and 1.2 in 2009
WEc1.2	Water efficient landscaping - no potable water use or no irrigation	1		
WEc2	Innovative wastewater technologies	1	2	
WEc3.1	Water use reduction - 20% reduction	1	4	Combined 3.1 and 3.2 in 2009
WEc3.2	Water use reduction - 30% reduction	1		
ENERGY & ATMOSPHERE		17	35	
EAc1	Optimize energy performance	10	19	
EAc2	On-site renewable energy	3	7	
EAc3	Enhanced commissioning	1	2	
EAc4	Enhanced refrigerant Mgmt	1	2	
EAc5	Measurement and verification	1	3	
EAc6	Green power	1	2	
MATERIAL & RESOURCES		13	14	
MRc1.1	Building reuse - maintain 75% of existing walls, floors & roof	1	3	Combined 1.1 &1.2
MRc1.2	Building reuse - maintain 95% of existing walls, floors & roof	1		
MRc1.3	Building reuse - maintain 50% of interior non-structural elements	1	1	
MRc2.1	Construction waste Mgmt - divert 50% from disposal	1	2	Combined 2.1 &2.2

MRc2.2	Construction waste Mgmt - divert 75% from disposal	1		
MRc3.1	Materials reuse - 5%	1	2	Combined 3.1 &3.2
MRc3.2	Materials reuse - 10%	1		
MRc4.1	Recycled content - 10% (post-consumer + 1/2 pre-consumer)	1	2	Combined 4.1 &4.2
MRc4.2	Recycled content - 20% (post-consumer + 1/2 pre-consumer)	1		
MRc5.1	Regional materials - 10% extracted, processed and manufactured regionally	1	2	Combined 5.1 &5.2
MRc5.2	Regional materials - 20% extracted, processed and manufactured regionally	1		
MRc6	Rapidly renewable materials	1	1	
MRc7	Certified wood	1	1	
INDOOR ENVIRONMENTAL QUALITY		15	22	
EQc1	Outdoor air delivery monitoring	1	1	
EQc2	Increased ventilation	1	1	
EQc3.1	Construction IAQ Mgmt plan - during construction	1	1	
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1	1	
EQc4.1	Low-emitting materials - adhesives and sealants	1	1	
EQc4.2	Low-emitting materials - paints and coatings	1	1	
EQc4.3	Low-emitting materials - carpet systems	1	1	
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1	1	
EQc5	Indoor chemical and pollutant source control	1	1	
EQc6.1	Controllability of systems - lighting	1	1	
EQc6.2	Controllability of systems - thermal comfort	1	1	
EQc7.1	Thermal comfort - design	1	1	
EQc7.2	Thermal comfort - verification	1	1	
EQc8.1	Daylight and views - daylight 75% of spaces	1	1	
EQc8.2	Daylight and views - views for 90% of spaces	1	1	
EQpc124	Performance-based IAQ design and assessment	-		Required in 2009
INNOVATION		**5**	**6**	
IDc1	Innovation in design	4	5	
IDc2	LEED Accredited professional	1	1	
REGIONAL PRIORITY		**-**	**4**	
EAc1	Optimize energy performance	-	1	
EAc3	Enhanced commissioning	-	1	
EAc5	Measurement and verification	-	1	
WEc1	Water efficient landscaping	-	1	
WEc2	Innovative wastewater technologies	-	1	
WEc3	Water use reduction	-	1	
Total		**69**	**110**	

Building 3: elevations



South elevation



North elevation

Appendix II

The thermal comfort and personal control questionnaire- English

KIT Karlsruher Institut für Technologie — Fachgebiet Bauphysik & Technischer Ausbau fbta

Development of Adaptive Thermal Comfort Model and Understanding the Effect of perceived Control on Occupant's Satisfaction in Office Buildings

Dear participants,

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Yours sincerely,
Farah Al-Atrash

M. Eng.Farah Al-Atrash
Doktorandin
PhD researcher

Karlsruher Institut fuer Technologie (KIT)
Karlsruhe Institute of Technology (KIT)

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Building Science Group

Englerstr. 7, D-76131 Karlsruhe, Germany
Phone +49 15257090804/ +962 772757210
http://fbta.arch.kit.edu

Thank you very much for your cooperation!

Please write down the date and time when you start filling out the questionnaire

Date ___.___.2016 **Time** ____:____

1- At what time did you arrive in your office this morning?

2- How do you perceive the Air Temperature at the moment in your office?

cold	cool	slightly cool	neutral	slightly warm	warm	hot
☐	☐	☐	☐	☐	☐	☐

3- How do you prefer the Air Temperature at the moment in your office?

much cooler	cooler	no Change	warmer	much warmer
☐	☐	☐	☐	☐

4- How do you rate the temperature in your office?

not Comfortable ☐ ☐ ☐ ☐ ☐ **Comfortable**

5- How do you rate the Humidity in your office?

not Comfortable ☐ ☐ ☐ ☐ ☐ **Comfortable**

6- How do you perceive the Air Quality at the moment in your office?

very bad ☐ ☐ ☐ ☐ ☐ **Very good**

7- Do you perceive at the moment any air movement?

no	very slight	slight	strong	very strong
☐	☐	☐	☐	☐

1

8- How would you prefer the Air movement at the moment in your office?

much weaker	a bit weak	no Change	a bit stronger	much stronger
☐	☐	☐	☐	☐

9- How do you rate the air movement in your office?

not comfortable						Comfortable
	☐	☐	☐	☐	☐	

10- Did the addressed parameters significantly change during the morning? if yes, please name the one which did change mostly.

11- Do you have these options in order to control the indoor climate (at the moment)?

	Yes	No
Operable window	☐	☐
Door to interior space	☐	☐
Door to exterior space	☐	☐
Blinds	☐	☐
Personal Fan	☐	☐
Personal Heater	☐	☐
Thermostat	☐	☐
Room Air Conditioning	☐	☐

2

11- What type of adjustment **did** you make to the given 'options to control indoor climate' during the last hours?

	Opened/ Turned On/ Turned Up		Closed/ Turned Off / Down	
	without asking others	after asking others	without asking others	after asking others
Operable window	☐	☐	☐	☐
Door to interior space	☐	☐	☐	☐
Door to exterior space	☐	☐	☐	☐
Blinds	☐	☐	☐	☐
Personal Fan	☐	☐	☐	☐
Personal Heater	☐	☐	☐	☐
Thermostat	☐	☐	☐	☐
Room Air Conditioning	☐	☐	☐	☐

12- Please indicate the current state of the given "options to control indoor climate'.

	All the way Open / ON / Adjusted Up	Partially open / Medium setting	All the way Closed / OFF / Adjusted Down
Operable window	☐	☐	☐
Door to interior space	☐	☐	☐
Door to exterior space	☐	☐	☐
Blinds	☐	☐	☐
Personal Fan	☐	☐	☐
Personal Heater	☐	☐	☐
Thermostat	☐	☐	☐
Room Air Conditioning	☐	☐	☐

3

13- What were the reasons you did not take the given 'options to control indoor climate?

	Wanted to exhaust other control options first	Was not agreeable to others in the space	Not sure if it would be OK with manage ment	Not worth asking others' permission	Not worth obstruct ion to my work	Would not have helped	Cannot adjust option any further	No need-co worker did this	I was comfort able enough
Operable window	☐	☐	☐	☐	☐	☐	☐	☐	☐
Door to interior space	☐	☐	☐	☐	☐	☐	☐	☐	☐
Door to exterior	☐	☐	☐	☐	☐	☐	☐	☐	☐
Blinds	☐	☐	☐	☐	☐	☐	☐	☐	☐
Personal Fan	☐	☐	☐	☐	☐	☐	☐	☐	☐
Personal Heater	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thermostat	☐	☐	☐	☐	☐	☐	☐	☐	☐
Room Air Conditioning	☐	☐	☐	☐	☐	☐	☐	☐	☐

14- How much control do you have to change 'the thermal conditions' of your office (at the moment)?

no control ☐ ☐ ☐ ☐ ☐ **much control**

15- Would you like to have more control to change the indoor climate (at the moment)?

no control ☐ ☐ ☐ ☐ ☐ **much control**

16- Do you prefer having control to adjust these 'options to control indoor climate (at the moment)?

	Yes	**No**
Operable window	☐	☐
Door to interior space	☐	☐
Door to exterior space	☐	☐
Blinds	☐	☐
Personal Fan	☐	☐
Personal Heater	☐	☐

4

Thermostat	☐	☐
Room Air Conditioning	☐	☐

17- Did you drink a beverage during the last hours?

	Yes		
	a lot	a little bit	
Beverage at room temperature	☐	☐	☐
Cold beverage	☐	☐	☐
Warm beverage	☐	☐	☐

18- Please indicate any activities engaged in over the past half hour:

	Yes
PC- Activity	☐
Reading/Writing/ Filing (Seated)	☐
Reading/Writing/ Filing (Standing)	☐
Having Conversation (Seated)	☐
Having Conversation (Standing)	☐
Eating	☐
Walking (Inside)	☐
Walking (Outside)	☐
conversation/ phone call	☐

5

Remarks

In case I have forgotten to mention something important OR If you would like to share comments about your **workplace**, the **building in general** or the **questionnaire**. Please write them down here.

About the Workplace

About the Building

About the Questionnaire

Thank you very much for your cooperation and support!

The thermal comfort and personal control questionnaire- Arabic

KIT Karlsruher Institut für Technologie

Fachgebiet Bauphysik & Technischer Ausbau fbta

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يرجى كتابة التاريخ والوقت عند البدء في ملء وتعبئه الاستبيان

الوقت:____:____ التاريخ: ____.____.2016

1- متى وصلت إلى مكتبك هذا الصباح/ بعد استراحة الغداء ؟

____

2- مـا هـو تقييمك لدرجة حرارة الهواء التي تشعر بها الأن في مكتبك؟

حار	دافئ	دافئ قليلا	معتدل	بارد قليلا	بارد	شديد البرودة
☐	☐	☐	☐	☐	☐	☐

3- كيف تفضل أن تكون درجة حرارة الهواء الأن في مكتبك ؟

أكثر دفئا	أدفى	لا تغير	أبرد	أكثر برودة
☐	☐	☐	☐	☐

4- كيف تشعر بدرجة الحرارة الأن في مكتبك؟

مريح 👍 ☐ ☐ ☐ ☐ ☐ 👎 غير مريح

5- يرجى تخمين، كم درجة حرارة الغرفة المئوية ؟

[   ]

6- كيف تشعر بالرطوبة الأن في مكتبك؟

مريح 👍 ☐ ☐ ☐ ☐ ☐ 👎 غير مريح

7- كيف تلمس جودة ونوعيه الهواء الأن في مكتبك؟

جيد جداً 👍 ☐ ☐ ☐ ☐ ☐ 👎 سيئ جداً

8- هل تشعر بحركة الهواء الأن في مكتبك؟

قوية جداً	قوية	خفيفة	خفيفة جداً	لا اشعر باي حركة
☐	☐	☐	☐	☐

9- كيف تفضل حركة الهواء في مكتبك في هذه اللحظة؟

قوية جداً	قوية قليلا	لا تغيير	ضعيفة قليلا	بدون حركة
☐	☐	☐	☐	☐

10- - ما هو تقيمك لحركة الهواء الأن في مكتبك؟

جيد جداً ☐ ☐ ☐ ☐ ☐ سيئ جداً

11- هل العوامل السابقة تغيرت بشكل كبير خلال هذا الصباح؟ إذا كانت الإجابة نعم، من فضلك أذكر أكثر العوامل تغيراً.

	نعم	لا	كيف
درجة الحرارة			
الرطوبة			
حركة الهواء			

12- هل تمتلك إمكانيه التحكم في تغيير المناخ الداخلي وذلك بضبط هذه الاختيارات في الوقت الحالي؟

	نعم	لا
نافذة قابلة للفتح	☐	☐
باب موصل لفراغ داخلي	☐	☐
باب موصل لفراغ خارجي	☐	☐
وسائل تظليل	☐	☐
مروحة شخصية	☐	☐
مدفأة شخصية	☐	☐
منظم حرارة Thermostat	☐	☐

13- ماهي أنواع التعديلات التي تمت للإختيارات التالية للتحكم في المناخ الداخلي في الساعات الماضية؟

	فتح / تشغيل / رفع الدرجة		غلق / اطفاء/ تقليل الدرجة		لا تعديل	غير قابل للتعديل
	بعد استئذان الاخرين	بدون استئذان الاخرين	بعد استئذان الاخرين	بدون استئذان الاخرين		
نافذة قابلة للفتح	☐	☐	☐	☐		
باب موصل لفراغ داخلي	☐	☐	☐	☐		
باب موصل لفراغ خارجي	☐	☐	☐	☐		
وسائل تظليل	☐	☐	☐	☐		
مروحة شخصية	☐	☐	☐	☐		
مدفأة شخصية	☐	☐	☐	☐		
منظم حرارة Thermostat	☐	☐	☐	☐		

14- ما هي الأسباب التي جعلتك لم تأخذ بإختيارات التحكم في المناخ الداخلي السابقة؟

	أريد أن استنفذ الخيارات الأخرى أولاً	لم أحصل على موافقة الأخرين بالمكان	غير متأكد من موافقة الادارة	لا يستحق استئذان الآخرين	لا يستحق عرقلة عملي	غير مساعد	لا يمكنني تعديل الأختيارات أكثر من ذلك	لا حاجه لذلك لأن الزملاء في العمل قاموا بذلك	كنت مرتاحا ما فيه الكفاية	غير قابل للتعديل
نافذة قابلة للفتح	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
باب موصل لفراغ داخلي	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
باب موصل لفراغ خارجي	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
وسائل تظليل	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
مروحة شخصية	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
مدفأة شخصية	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
منظم حرارة Thermostat	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

15- ما هي إمكانيه التحكم المتوفره لديك حالياً لتغير "الظروف الحرارية"بمكتبك ؟ أو ما هو مقدار السيطرة التي تمتلكها للتحكم لتغير "الظروف الحرارية"بمكتبك (حالياً)؟

الكثير من السيطرة ☐ ☐ ☐ ☐ ☐ لا سيطرة

16- هل تفضل الحصول على تحكم أكثر لتغيير المناخ الداخلي (حالياً)؟

الكثير من السيطرة ☐ ☐ ☐ ☐ ☐ لا سيطرة

17- هل تفضل بان يكون لديك إمكانيه التحكم في تغيير المناخ الداخلي وذلك بضبط هذه الاختيارات في الوقت الحالي؟ أو هل تفضل ان تمتلك السيطرة للتحكم بتغيير المناخ الداخلي بضبط هذه الاختيارات (حالياً)

	نعم	لا
نافذة قابلة للفتح	☐	☐
باب موصل لفراغ داخلي	☐	☐
باب موصل لفراغ خارجي	☐	☐
وسائل تظليل	☐	☐
مروحة شخصية	☐	☐
مدفأة شخصية	☐	☐
منظم حرارة Thermostat	☐	☐

18- هل تناولت أي من المشروبات خلال الساعات الماضية؟

	نعم: قليلاً	نعم: كثيراً	لا
مشروبات بدرجة حرارة الغرفة	☐	☐	☐
مشروبات مثلجة	☐	☐	☐
مشروبات ساخنة	☐	☐	☐

19- من فضلك حدد أي من الأنشطة التالية قمت بها خلال نصف الساعة الماضية:

	نعم	لا
أنشطة على جهاز الحاسب الآلي	☐	☐
قراءة/كتابة/أرشفة (جالساً)	☐	☐
قراءة/كتابة/أرشفة (واقفاً)	☐	☐
تبادل أطراف الحديث (جالساً)	☐	☐
تبادل أطراف الحديث (واقفاً)	☐	☐
تناول الطعام	☐	☐
المشي (بالداخل)	☐	☐
المشي (بالخارج)	☐	☐
الحديث / محادثة تلفون	☐	☐

20- مـا هـو تقييمك لدرجة حرارة الهواء التي تشعر بها الأن في مكتبك؟

حار ———————————————— شديد البرودة

21- كيف تفضل أن تكون درجة حرارة الهواء الأن في مكتبك ؟

أكثر دفا ———————————————— أكثر برودة

22- هل تشعر بحركة الهواء الأن في مكتبك؟

قوية جداً ———————————————— لا اشعر باي حركة

23- كيف تفضل حركة الهواء في مكتبك في هذه اللحظة؟

قوية جداً ———————————————— بدون حركة

ملاحظات

في حال كنت قد نسيت أن أذكر شيئا مهماً أو إذا كنت ترغب في مشاركة أي من التعليقات حول مكان عملك، المبنى بشكل عام أوالاستبيان.
الرجاء كتابة هذه الملاحظات هنا.

عن مكان عملك:

عن المبنى بشكل عام:

عن الاستبيان:

شكرا جزيلا لتعاونكم ودعمكم!

The background questionnaire- English

Fachgebiet Bauphysik & Technischer Ausbau

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Phone +49 15257090804/ +962 772757210
http://fbta.arch.kit.edu

Thank you very much for your cooperation!

1

Please write down the date and time when you start filling out the questionnaire

Date ___.___.2016 **Time** ____:____

Personal Data

1- Gender:

☐ Female ☐ Male

2- Age:

☐ till 25 Years ☐ 26 to 35 Years ☐ 36 to 45 Years ☐ 46 to 55 Years
☐above 55 Years

3- Height (approximately in cm): ………………………………………………..

4- Weight (approximately in kg): ………………………………………………..

5- Do you smoke?

☐ Yes ☐ No

General questions about your work activity and your workplace

6- When did you start working in this building?

for…………Year(s) Month(s)…………..

7- How long have you been working at your workplace in this office room?

for…………Year(s) Month(s)…………..

8- On which floor is your workspace located?

☐ Ground floor ☐ First Floor ☐ Second Floor ☐Third Floor ☐ Fourth floor

9- How many hours per week do you usually work in this workplace?

☐Less than10 Hours ☐ 10-20 Hours ☐ 21-30 Hours ☐ more than 30 Hours

10- When do you usually work in this workplace?

☐ Only in the morning ☐ only in the afternoon
☐ Once morning/ once afternoon ☐ morning and afternoon

11- Do you deal with customers in your workplace?

☐Yes ☐No

2

12- Which type of offices do you have at your work?

☐ **Single office with** …………………………… Door(s)……………………………Window(s)

☐ **Multi person office with** …… Persons, the office has: ………Door(s)……….Window(s)

☐ **Open-plan concept** with ………………………………….other Persons

13- Do you share your workplace with another person(s)?

☐Yes ☐No

14- How dissatisfied or satisfied are you with the following conditions at your workplace?

	very dissatisfied	**dissatisfied**	**neutral**	**satisfied**	**very satisfied**
Size of the office	☐	☐	☐	☐	☐
Opportunity to decorate your workplace (eg. using pictures, plants..)	☐	☐	☐	☐	☐
Partitions which separate the different workplaces	☐	☐	☐	☐	☐
the position of your workplace to the nearest window	☐	☐	☐	☐	☐
the position of your workplace to the nearest door	☐	☐	☐	☐	☐

15- If you are working with other persons at the same office:

	very dissatisfied	**dissatisfied**	**neutral**	**satisfied**	**very satisfied**
Your sitting position to the another person(s) at the room	☐	☐	☐	☐	☐
Distance between your workplace and the other workplaces in the room	☐	☐	☐	☐	☐
work without distraction	☐	☐	☐	☐	☐
undisturbed talk / calls	☐	☐	☐	☐	☐

My workplace is separated by partitions or furniture: (room walls are exempted.) Namely:

☐ direct in front of me ☐ to my left ☐ to my right ☐ behind me

☐There is no partitions in the room.

16- In general, how dissatisfied or satisfied are you with the conditions of your workplace?

very dissatisfied ☐ ☐ ☐ ☐ ☐ **very satisfied**

3

17- Please select how important do you consider the listed factors below for your working environment satisfaction.

Please select the most appropriate answer for each point

	Very Unimportant	Unimportant	neutral	important	Very important
A friendly atmosphere	☐	☐	☐	☐	☐
A comfortable room temperature	☐	☐	☐	☐	☐
Sufficient fresh air	☐	☐	☐	☐	☐
If possible, no drafts	☐	☐	☐	☐	☐
A pleasant humidity	☐	☐	☐	☐	☐
Good artificial light	☐	☐	☐	☐	☐
View through a window	☐	☐	☐	☐	☐
Adequate daylight	☐	☐	☐	☐	☐

Lighting conditions at your workplace / daylight conditions / artificial lighting conditions

18- How far are you sitting from the nearest window away?

up to 1 meter away	up to 2 meters	up to 3 meter away	4 Meters and more
☐	☐	☐	☐

19- Location of the window from your workplace

☐directly in front of me ☐to my left ☐to my right ☐behind me

20- How do you assess the overall window size in your room?

very small ☐ ☐ ☐ ☐ ☐ **very large**

21- In which direction located the window?

North	South	East	West	I don't know
☐	☐	☐	☐	☐

22- How do you find the daylight in this time of year (between sunrise and sunset) at your workplace?

Very dark	Dark	neutral	Bright	Very bright
☐	☐	☐	☐	☐

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23- How do you prefer the daylight (between sunrise and sunset) at your workplace?

much darker	darker	-	brighter	much brighter
☐	☐	☐	☐	☐

24- How dissatisfied or satisfied are you with the daylight conditions?

	very dissatisfied	**dissatisfied**	**neutral**	**satisfied**	**very satisfied**
while working on the PC	☐	☐	☐	☐	☐
at other workplaces	☐	☐	☐	☐	☐
Throughout the room	☐	☐	☐	☐	☐

25- What kind of artificial lightings are available in your room? You can choose more than one option.

☐ **ceiling light** ☐ **wall light** ☐ **floor Lamp** ☐ **Table lamp**

26- How dissatisfied or satisfied are you with the artificial lighting conditions?

	very dissatisfied	**dissatisfied**	**neutral**	**satisfied**	**very satisfied**
while working on the PC	☐	☐	☐	☐	☐
at other workplaces	☐	☐	☐	☐	☐
Throughout the room	☐	☐	☐	☐	☐

27- How often do you face glare in this time of the year?

	almost always				almost never	inapplicable
Glare from **artificial light**	☐	☐	☐	☐	☐	☐
Glare from **sunlight**	☐	☐	☐	☐	☐	☐

Sun Protection/ glare protection

28- How dissatisfied or satisfied are you in this time of the year?

	very dissatisfied	dissatisfied	neutral	satisfied	very satisfied	inapplicable
With the sun protection and glare protection in your workplace	☐	☐	☐	☐	☐	☐
Relation to outside when the sun protection/ glare protection are closed?	☐	☐	☐	☐	☐	☐
with the view to the outside without sun protection/ glare protection?	☐	☐	☐	☐	☐	☐

29- How dissatisfied or satisfied are you with respect to all the lighting conditions

	very dissatisfied	dissatisfied	neutral	satisfied	very satisfied	inapplicable
with the technical possibilities at the room, the effective influence of lighting conditions?	☐	☐	☐	☐	☐	☐

☞ ***If you work with other persons in your office:***

with the coordination with your colleagues on this point?	☐	☐	☐	☐	☐	☐

30- All in all, how dissatisfied or satisfied are you in this time of year with the lighting conditions (daylight, Sun Protection/ glare protection) at your workplace?

very dissatisfied ☐ ☐ ☐ ☐ ☐ **very satisfied**

Importance and need of change concerning comfort zones

31- How important are the following conditions for your well-being at work?

	extreme unimportant				extreme important
Lighting	☐	☐	☐	☐	☐
temperature	☐	☐	☐	☐	☐
Air quality	☐	☐	☐	☐	☐
Acoustic conditions / noise	☐	☐	☐	☐	☐
privacy	☐	☐	☐	☐	☐
Furniture / design	☐	☐	☐	☐	☐
Cleanliness	☐	☐	☐	☐	☐

Perceived Behavioral Control

32- Which of the following controls can you adjust?

	Yes	**No**
Operable window	☐	☐
Door to interior space	☐	☐
Door to exterior space	☐	☐
Blinds	☐	☐
Personal Fan	☐	☐
Personal Heater	☐	☐
Thermostat	☐	☐
Room Air Conditioning	☐	☐

33- Do you prefer having control to adjust these controls?

	Yes	**No**
Operable window	☐	☐
Door to interior space	☐	☐
Door to exterior space	☐	☐
Blinds	☐	☐
Personal Fan	☐	☐
Personal Heater	☐	☐
Thermostat	☐	☐
Room Air Conditioning	☐	☐

Self-assessment of the indoor air conditions

34- Which of the indoor air conditions do you feel important for the wellbeing? How do you organize your sensitivity to following Parameters?

	sensitive	insensitive
Temperature (cold)	☐	☐
Temperature (heat wave)	☐	☐
Air movement (Draft)	☐	☐
Air quality	☐	☐
Dry air	☐	☐
Humid air	☐	☐

35- All in all, how dissatisfied or satisfied are you with the overall conditions (workplace environment, lighting, indoor climate, furnishing / design) of your workplace?

very dissatisfied ☐ ☐ ☐ ☐ ☐ **very satisfied**

Remarks

In case I have forgotten to mention something important OR If you would like to share comments about your **workplace**, the **building in general** or the **questionnaire**. Please write them down here.

About the Workplace

About the Building

About the Questionnaire

Thank you very much for your cooperation and support!

The background questionnaire- Arabic

Fachgebiet Bauphysik & Technischer Ausbau fbta

KIT Karlsruher Institut für Technologie

Development of Adaptive Thermal Comfort Model and Understanding the Effect of perceived Control on Occupant's Satisfaction in Office Buildings

Dear participants,

You are kindly invited to participate in this research study which is part of a PhD project at the Building Science Group/ Institute for Building Design and Technology at the faculty of Architecture, Karlsruhe Institute of Technology (KIT).

The purpose of this research 'Development of Adaptive Thermal Comfort Model and Understanding the Effect of perceived Control on Occupant's Satisfaction in Office Buildings' is to investigate whether the current Adaptive Thermal Comfort Model which is included in the ASHRAE 55 or EN 15251 standards, has to be adjusted due to Jordan's specific climate conditions. The work will also include studies on behavioral options at office workplaces with respect to thermal comfort which can be incorporated in requirements and recommendations for improving building design with regard to thermal performance and energy use for space conditioning.

The results of this study will be used for scholarly purposes only, this is why it is very important to get precise and comprehensive responses. This survey is anonymous. In order to compare the questionnaire data with the measurements, a code to each participant is needed.

Please write down your participant code. Your code consists of the first two letters of your father's first name, the first two letters of your mother's first name and the two digits of your own day of birth.

If you have any questions, please don't hesitate to ask me.

Yours sincerely,
Farah Al-Atrash

M. Eng.Farah Al-Atrash
Doktorandin
PhD researcher

Karlsruher Institut fuer Technologie (KIT)
Karlsruhe Institute of Technology (KIT)

Fachgebiet Bauphysik & Technischer Ausbau
Building Science Group

Englerstr. 7, D-76131 Karlsruhe, Germany
Phone +49 15257090804/ +962 772757210
http://fbta.arch.kit.edu

Thank you very much for your cooperation!

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يرجى كتابة التاريخ والوقت عند البدء في ملء وتعبئه الاستبيان

الوقت:____:____ التاريخ: ____.____.2016

بيانات شخصية

1. **الجنس:**

☐ أنثى ☐ ذكر

2. **العمر:**

☐حتى 25 عام ☐بين 26 و35 عام ☐بين 36 و45 عام ☐بين 46 و55 عام
☐أكبر من 55 عام

3. **الطول (تقريبا بالسنتيمتر)** ....

4. **الوزن (تقريبا بالكيلو جرام)** ....

5. **هل أنت مدخن؟**

☐نعم ☐لا

أسئلة عامة عن أنشطة العمل ومكان العمل:

6. **متى بدأت العمل في هذا المبنى؟**

منذ .... سنة و............ شهر

7. **كم مضى من الوقت وانت تعمل في غرفة المكتب هذه بالتحديد؟**

منذ ....سنة و...........شهر

8. **في أي طابق يقع مكان العمل الخاص بك؟**

☐ الدور الأرضي ☐ الدور الأول ☐ الدور الثاني ☐ الدور الثالث ☐ الدور الرابع

9. **كم ساعة في الأسبوع تعمل عادة في مكتبك؟**

☐ أقل من 10 ساعات ☐ 10-20 ساعة ☐30-21 ساعة ☐ أكثر من 30 ساعة

2

10. متى تعمل عادة في مكتبك؟

☐ فقط في الصباح ☐ فقط بعد الظهيرة
☐ احيانا في الصباح / احيانا بعد الظهيرة ☐ في الصباح وبعد الظهيرة

11. هل تتعامل مع زبائن /عملاء في مكتبك؟

☐ نعم ☐ لا

12. ما هي نوعية مكتبك

☐ **مكتب فردي فيه عدد .... شباك و...................باب**

☐**مكتب متعدد المستخدمين فيه عدد .... شباك و..........باب**

☐**مساحة مفتوحة بها عدد .... مستخدم**

13. هل تتشارك في غرفة مكتبك مع الأخرين؟

☐ نعم ☐ لا

14. ما مدى رضاك عن الأمور التالية في مكتبك؟

	غير راض تماما	غير راض	محايد	راض	راض جدا
مساحة مكتبك	☐	☐	☐	☐	☐
إمكانية تزين مكتبك (وضع الصوروالنباتات......)	☐	☐	☐	☐	☐
القواطع التي تفصل بين المكاتب	☐	☐	☐	☐	☐
موقع مكتبك لأقرب نافذة	☐	☐	☐	☐	☐
موقع مكتبك لأقرب باب	☐	☐	☐	☐	☐

15. إذا كنت تعمل مع أشخاص أخرين في نفس المكتب:

	غير راض تماما	غير راض	محايد	راض	راض جدا
موقع جلوسك بالنسبة للأخرين في الغرفة	☐	☐	☐	☐	☐
المسافة بين مكتبك ومكاتب الأخرين في الغرفة	☐	☐	☐	☐	☐
العمل بدون إلهاء	☐	☐	☐	☐	☐
العمل بدون إزاعاج من الاحاديث الجانبيه /الاتصالات الهاتفيه	☐	☐	☐	☐	☐

مكتبي مفصول بقواطع أو أثاث (ليست حوائط) وهي:

☐ أمامي مباشرة ☐ على يساري ☐ على يميني ☐ خلفي ☐ لا يوجد قواطع في الغرفة

3

16. عموما، ما مدى رضاك بالنسبة لعوامل العمل المحيطة؟

راض تماماً	☐	☐	☐	☐	☐	غير راض تماماً

17. من فضلك أختار مدى أهمية هذه العوامل للعمل في بيئة مرضية

من فضلك أختر أكثر الإجابات موائمة لكل نقطة

	غيرمهم جداً	غير مهم	محايد	مهم	مهم جداً
جو ودي	☐	☐	☐	☐	☐
درجة حرارة غرفة مريحة	☐	☐	☐	☐	☐
هواء نقي كفاية	☐	☐	☐	☐	☐
لو متاح وممكن ، لا تيارات هواء	☐	☐	☐	☐	☐
نسبة رطوبة مريحة	☐	☐	☐	☐	☐
إضاءة صناعية جيدة	☐	☐	☐	☐	☐
مناظر جيدة من النافذة	☐	☐	☐	☐	☐
ضوء النهار كاف	☐	☐	☐	☐	☐

حالات الإضاءة في مكتبك / حالات الإضاءة الطبيعية / حالات الإضاءة الصناعية

18. كم تبعد أقرب نافذة منك؟

حتى متر	حتى مترين	حتى ثلاثة أمتار	أربعة أمتار وأكثر
☐	☐	☐	☐

19. موقع النافذة من مكتبك

☐ أمامي مباشرة ☐ على يساري ☐ على يميني ☐ خلفي

20. كيف تقيم مقاس النوافذ في غرفتك عموما؟

كبير جدا	☐	☐	☐	☐	☐	صغير جدا

21. ما هو أتجاه نافذتك؟

لا أعرف	غرب	شرق	جنوب	شمال
☐	☐	☐	☐	☐

4

22. كيف تجد الإضاءة الطبيعية في مثل هذا الوقت من العام (بين الشروق والغروب) في مكتبك؟

أكثر إضاءة	مضيئ	محايد	مظلم	أكثر ظلمة
☐	☐	☐	☐	☐

23. كيف تفضل الإضاءة الطبيعية (بين الشروق والغروب) في مكتبك؟

أكثر إضاءة	مضيئ	محايد	مظلم	أكثر ظلمة
☐	☐	☐	☐	☐

24. ما مدى رضاك عن حالة الإضاءة الطبيعية؟

	غير راض تماما	غير راض	محايد	راض	راض جدا
أثناء العمل على جهاز الحاسب الألي	☐	☐	☐	☐	☐
في مكاتب أخرى	☐	☐	☐	☐	☐
في جميع أنحاء الغرفة	☐	☐	☐	☐	☐

25. أي أنواع إضاءات صناعية موجودة في غرفتك؟ **يمكنك أختيار أكثر من إختيار**

☐ إضاءة السقف ☐ إضاءة الحائط ☐ إضاءة أرضية ☐ إضاءة على منضدة

26. ما مدى رضاك عن حالة الإضاءة الصناعية؟

	غير راض تماما	غير راض	محايد	راض	راض جدا
أثناء العمل على جهاز الحاسب الألي	☐	☐	☐	☐	☐
في مكاتب أخرى	☐	☐	☐	☐	☐
في جميع أنحاء الغرفة	☐	☐	☐	☐	☐

27. هل تواجه بريق/ وهج الإضاءة في مثل هذا التوقيت من العام؟

	دائما				أبدا	لا ينطبق
بريق / وهج الإضاءة الصناعية	☐	☐	☐	☐	☐	
بريقة / وهج أشعة الشمس	☐	☐	☐	☐	☐	

5

الحماية من الشمس / الحماية من وهج الإضاءة

28. ما مدى رضاك في مثل هذا التوقيت من العام عن:

	راض جدا	راض	محايد	غير راض	غير راض تماما	لا ينطبق
للحماية من الشمس وللحماية من بريق الإضاءة بمكتبك	☐	☐	☐	☐	☐	
للعلاقة بخارج مكتبك عندما تكون الحماية من الشمس أو الحماية من بريق الإضاءة مغلقة	☐	☐	☐	☐	☐	
للمنظر بخارج مكتبك عندما تكون الحماية من الشمس أو الحماية من بريق الإضاءة مغلقة	☐	☐	☐	☐	☐	

29. ما مدى رضاك عن عوامل الإضاءة؟

	راض جدا	راض	محايد	غير راض	غير راض تماما	لا ينطبق
مع الإمكانيات التقنية في الغرفة، والتأثير الفعال لظروف الإضاءة؟	☐	☐	☐	☐	☐	

إذا كنت تعمل مع عدة أشخاص في الغرفة:

بالإشتراك مع زميلك في العمل	☐	☐	☐	☐	☐

30. عموما، ما مدى رضاك لكل عوامل الإضاءة (إضاءة طبيعية، تكون الحماية من الشمس أو الحماية من بريق وهج الإضاءة) في مكتبك لهذا الوقت من العام ؟

راض تماماً 👍 ☐ ☐ ☐ ☐ ☐ 👎 غير راض تماماً

6

الأهمية والإحتياج للتغيير بما يخص مجال الراحة

31. ما مدى أهمية الظروف التالية للرفاهية في العمل؟

	غير مهم				مهم للغاية
الإضاءة	☐	☐	☐	☐	☐
درجة الحرارة	☐	☐	☐	☐	☐
جودة الهواء	☐	☐	☐	☐	☐
الصوتيات / الضجيج	☐	☐	☐	☐	☐
الخصوصية	☐	☐	☐	☐	☐
الأثاث / التصميم	☐	☐	☐	☐	☐
النظافة	☐	☐	☐	☐	☐

السيطرة والتحكم

32. أي من هذه التحكمات يمكنك ضبطها؟

	نعم	لا
نافذة قابلة للفتح	☐	☐
باب موصل لفراغ داخلي	☐	☐
باب موصل لفراغ خارجي	☐	☐
وسائل تظليل	☐	☐
مروحة شخصية	☐	☐
مدفأة شخصية	☐	☐
منظم حرارة Thermostat	☐	☐
مكيف	☐	☐

33. هل تفضل السيطرة على هذه التحكمات؟

	نعم	لا
نافذة قابلة للفتح	☐	☐
باب موصل لفراغ داخلي	☐	☐
باب موصل لفراغ خارجي	☐	☐
وسائل تظليل	☐	☐
مروحة شخصية	☐	☐
مدفأة شخصية	☐	☐
منظم حرارة Thermostat	☐	☐
مكيف	☐	☐

7

التقييم الذاتي الشخصي لأحوال الهواء الداخلية

34. أي من الأحوال وظروف الهواء الداخلي تشعر أنها مهمة للرفاهية؟ كيف يمكنك تنظيم حساسيتك / إستشعارك للأحوال الآتية؟

	حساس	غير حساس
درجة الحرارة (باردة)	☐	☐
درجة الحرارة (حارة)	☐	☐
تيار الهواء	☐	☐
جودة الهواء	☐	☐
هواء جاف	☐	☐
هواء رطب	☐	☐

35. عمومـاً وفي كل الأحوال، ما مدى رضاك لعموم الظروف والأحوال (بيئة العمل، الإضاءة، المناخ الداخلي، الأثاث / التصميم) لمكتبك؟

راض تماماً ☐ ☐ ☐ ☐ ☐ غير راض تماماً

8

ملاحظات

في حال كنت قد نسيت أن أذكر شيئا مهماً أو إذا كنت ترغب في مشاركة أي من التعليقات حول مكان عملك، المبنى بشكل عام أوالاستبيان. الرجاء كتابة هذه الملاحظات هنا.

عن مكان عملك:

عن المبنى بشكل عام:

عن الاستبيان:

شكرا جزيلا لتعاونكم ودعمكم!

9

Appendix III

Garment Insulation

TABLE B2
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.

ANSI/ASHRAE STANDARD 55-2004 19

TABLE B3
Typical Added Insulation when Sitting on a Chair
(Valid for Clothing Ensembles with Standing Insulation Values of 0.5 clo < I_{cl} < 1.2 clo)

Net chair[a]	0.00 clo
Metal chair	0.00 clo
Wooden side arm chair[b]	0.00 clo
Wooden stool	+0.01 clo
Standard office chair	+0.10 clo
Executive chair	+0.15 clo

a A chair constructed from thin, widely spaced cords that provide no thermal insulation. Included for comparison purposes only.
b Chair used in most of the basic studies of thermal comfort that were used to establish the PMV-PPD index.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process.)

Metabolic rates for typical tasks

(This is a normative appendix and is part of this standard.)

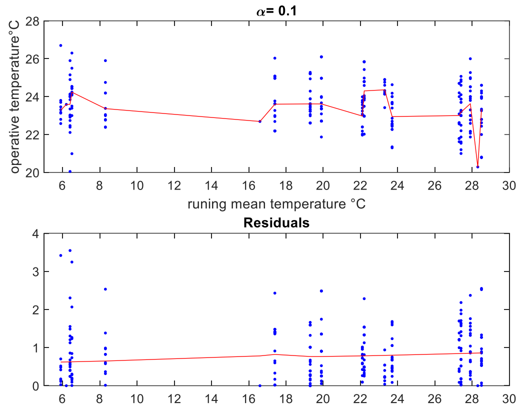
NORMATIVE APPENDIX A—ACTIVITY LEVELS

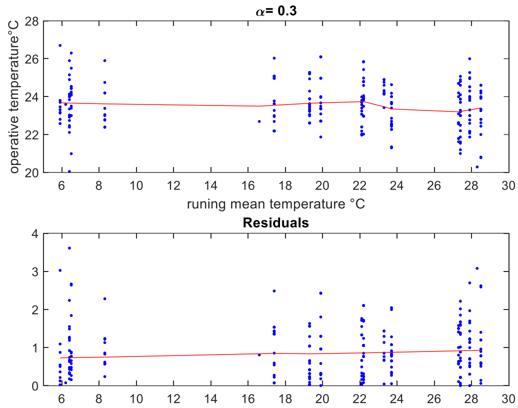
Metabolic Rates for Typical Tasks

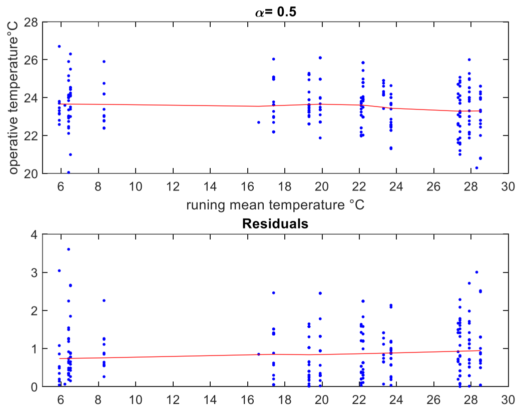
Activity	Met Units	Metabolic Rate W/m^2	(Btu/h·ft^2)
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	45	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level surface)			
0.9 m/s, 3.2 km/h, 2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	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)

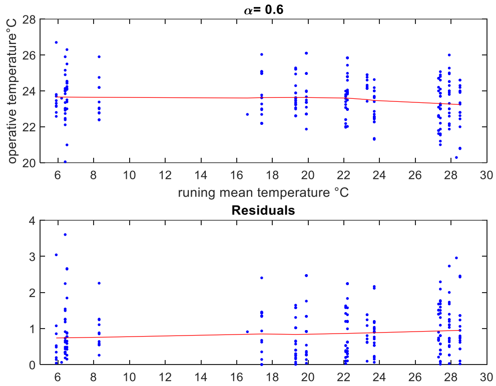
Appendix IV

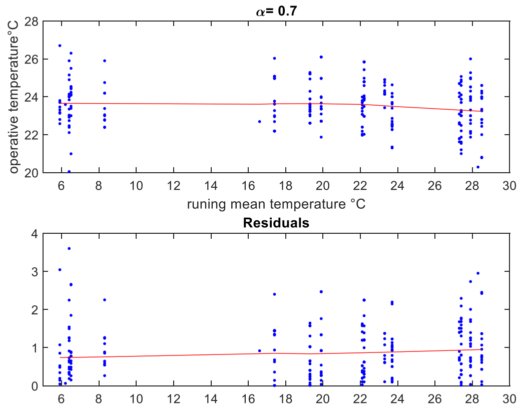
Building 1 ‘all data’ with absolute residuals. LOESS regression lines with smoothing factors from 0.1 to 0.9

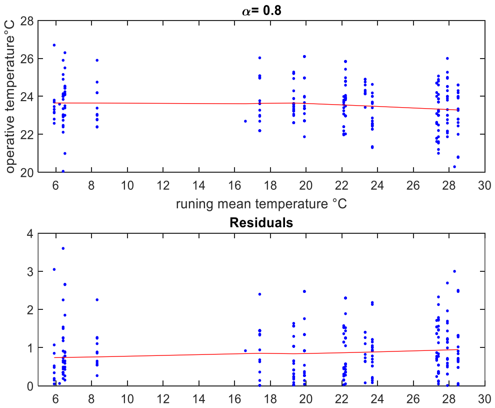


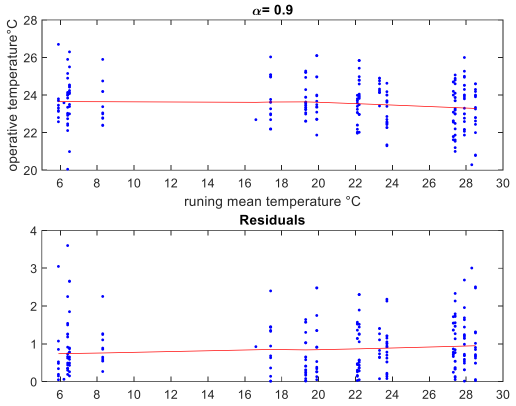




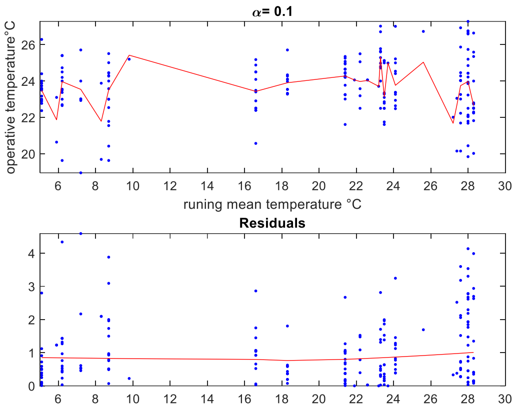


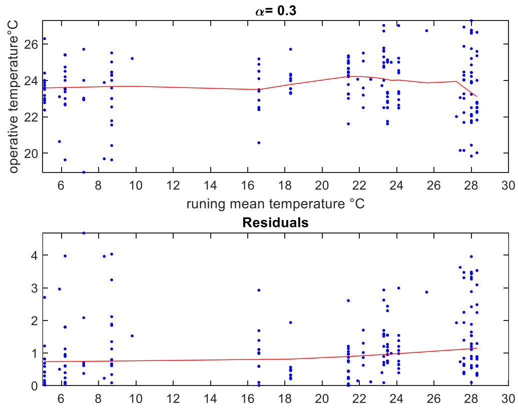


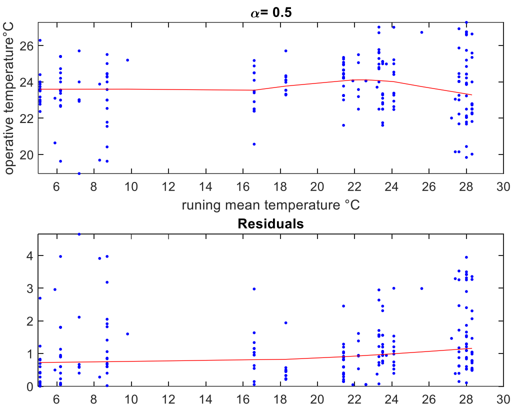


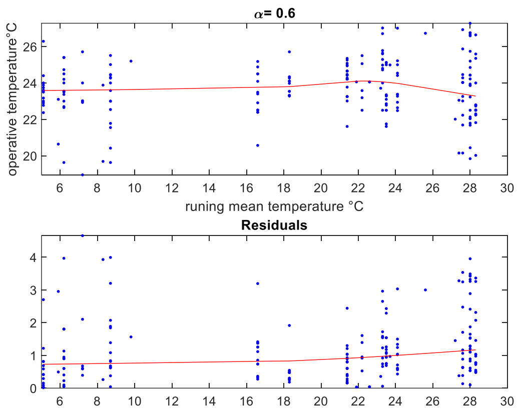


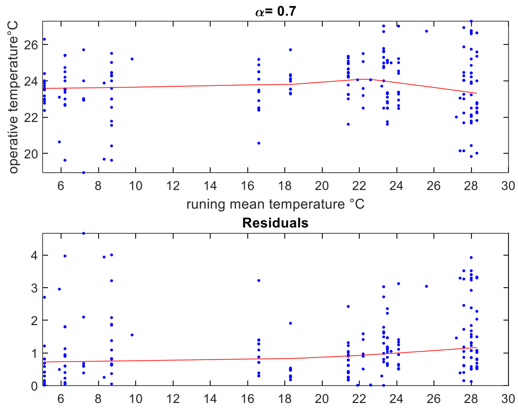
Building 2 ‘all data’ with absolute residuals. LOESS regression lines with smoothing factors from 0.1 to 0.9

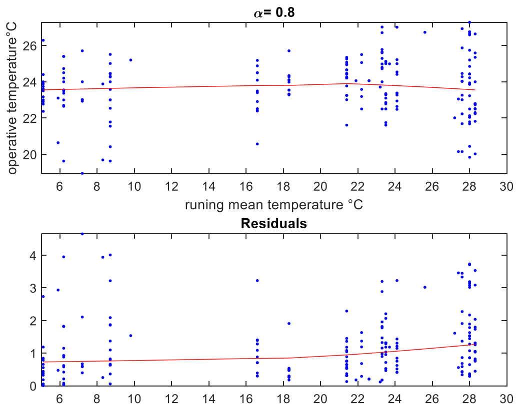


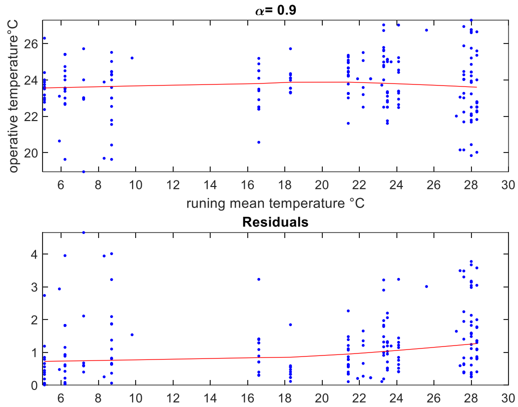




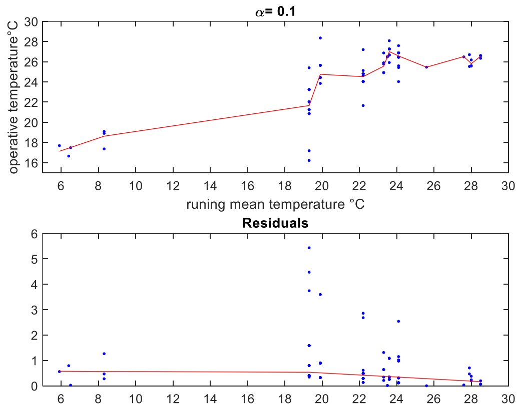


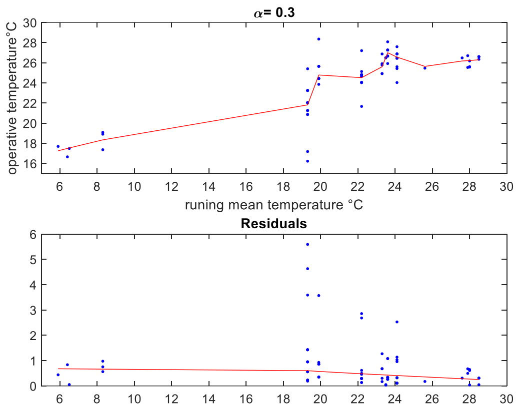


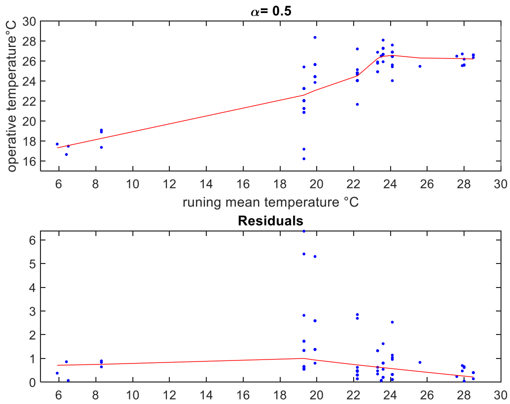




Building 3 ‘all data’ with absolute residuals. LOESS regression lines with smoothing factors from 0.1 to 0.9



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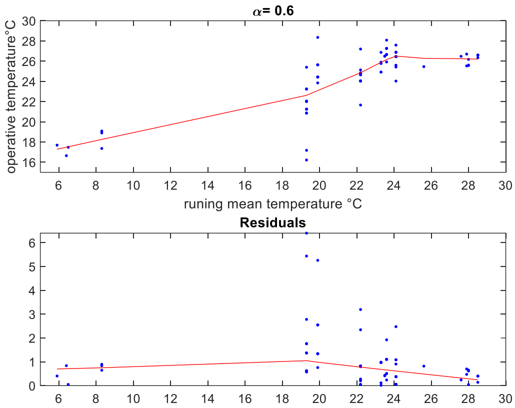
runing mean temperature °C
Residuals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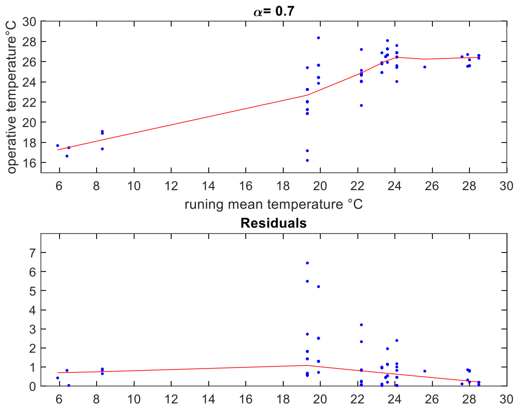
runing mean temperature °C
Residuals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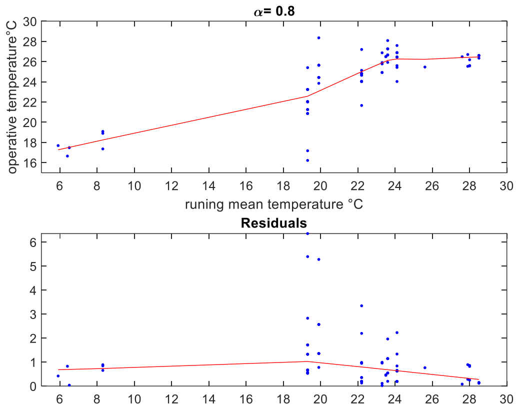
runing mean temperature °C
Residuals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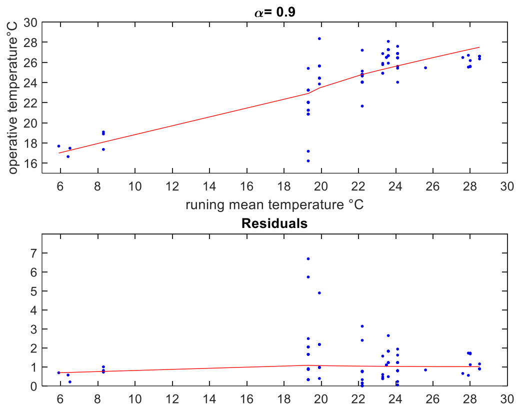
runing mean temperature °C
Residuals


α= 0.9
operative temperature°C
runing mean temperature °C
Residuals