CARDIFF UNIVERSITY

PRIFYSGOL CAERDYDD

An investigation of thermal comfort and the use of indoor transitional space

Thesis for the degree of Doctor of Philosophy

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Dedicated to my son Zifan Xiang

Abstract

Indoor transitional space plays an important role in the modern building. The thermal environment in indoor transitional spaces can significantly influence users' thermal perceptions and therefore potentially their use of such spaces. Improving thermal conditions in indoor transitional spaces may encourage people to spend more time in these spaces, and improve the energy performance in indoor transitional spaces and their potential contribution in minimizing cooling and heating loads of the adjacent building.

This thesis investigates thermal conditions in indoor transitional spaces, thermal comfort and the relationship between these and people's use of space. Three case studies were carefully selected in different kinds of buildings in Cardiff, UK to represent a variety of users in similar climatic contexts. The field surveys were carried out during winter and summer and research methods were used: interviews with a structured questionnaire, thermal environment monitoring and observations of human activity.

The results show that a solely physiological approach is insufficient to evaluate the thermal comfort in indoor transitional spaces. The results from the occupant comfort survey established the adaptability of users to a wider range of thermal conditions. Environmental variables such as operative temperature could have a great impact on the use of the indoor transitional spaces, and may determine the number of people and activities in them. The study also shows that participants in indoor transitional spaces have a higher thermal tolerance and can accept lower temperature than in other types of spaces, which creates a potential for saving energy.

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ΔT	Difference in air temperature change °C
θ_{com}	The comfort temperature
$\theta_{e(d)}$	The daily mean outdoor temperature for the previous day
$\theta_{e(d-1)}$	The daily mean outdoor temperature for the day before that.
θ_{rm}	The running mean of the daily mean outdoor air temperature.
$\theta_{rm(n)}$	The running mean temperature for day n.
$\theta_{rm(n-1))}$	The running mean temperature for day n-1.
AMV	Actual mean vote
AC	Air conditioning
ANOVA	Analysis of variance test
AS	Air movement speed
Clo	Cloth value
m/s	Meters per second
M/met	Metabolic rate
NV	Natural ventilation
PMV	Predicted Mean Vote
PPD	Predicted percentage of discomfort
RH	Relative humidity
T_a	Air temperature
T_{ai}	Indoor air temperature
T_{air}	Outdoor air temperature
T_{co}	Comfort Temperature ° C
T_g	Globe temperature
T_i	Mean indoor air temperature
T_o	Operative Temperature °C
T_{out}	Outdoor monthly mean temperature
T_n	Neutral temperature
T_r	Mean radiant temperature
T_{ref}	The prevailing mean outdoor air temperature (it is for a time period between last 7 and 30 days before the day in question) (ASHRAE 2010).
T_{rm}^{7}	The exponentially weighted running mean of the daily outdoor temperature of the previous seven days
T_{RMT}	The running mean temperature
V_r	Relative air speed

Key terms

Air speed: the rate of air movement at a point, without regard to direction.

Adaptive opportunity: An opportunity that elements of the building design offer to the users to make themselves thermally comfortable.

Air Conditioned buildings: Buildings in which internal thermal environments are controlled by adjusting the air supply, ventilation, air humidity and air temperature.

ASHRAE scale: The seven point ASHRAE scale is a set of seven options given to people to tag their thermal comfort perception to a given environment (cold, cool, slightly cool, neutral, slightly warm, warm and hot).

Clo: The unit for evaluate the thermal insulation of clothing, where clo=0.155 mw.K.W^{-1}.

Draught: Unwanted local cooling of the body caused by air movement.

Indoor transitional spaces: Spaces located within a building but which are also connected with the exterior environment.

Mean radiant temperature: The uniform surface temperature of a radiantly black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space.

Metabolic rate: The rate used to express people physical activity, this rate is expressed in met units, where 1 met=58.2W/m^2

Naturally ventilated buildings: Buildings in which interior spaces are thermally operated without using any heating, ventilation and air conditioning (HVAC) system, but can use other operable building elements such as doors and windows to provide thermal comfort.

Operative temperature: The combined effect of the air temperature and mean radiant temperature, represented in a single value. It is a weighted average that depends on the heat transfer coefficients by convection and radiation at the clothed surface of individuals.

Physical measurements: Refers to the measurements of air velocity, air humidity, air temperature and globe temperature.

Predicted Mean vote (PMV): An example of a steady-state heat balanced model. It combines the influence of air temperature, mean radiant temperature, air movement and humidity with clothing and activity level into a single value on a thermal sensation scale. It is a predicted mean value of the votes on the ASHRAE scale of a large group of people, exposed to the same environment, with the same clothing and activity.

Predicted Percentage Dissatisfied (PPD): The predicted percentage of people uncomfortable in a given environment. It is a function the PMV; it applies to large groups of individuals in the same thermal conditions with the same clothing and activity level.

Relative humidity: The ratio of water pressure to saturation vapor pressure at the same dry bulb temperature, expressed as a percentage (%RH).

Thermal comfort: 'That condition of mind which expresses satisfaction with the thermal environment' (ASHRAE 2004).

Thermal experience: People's previous thermal conditions that influence they current thermal perception of the environment.

Thermal preference: The thermal conditions people say they would prefer to experience, which may differ from their current state even if they express satisfaction with it.

Chapter 1 Introduction

1.1. Introduction

This chapter introduces the subject of thermal comfort in indoor transitional spaces, provides a basic background to the topic, and states the research problem, gaps and articulates the research questions. In addition, this chapter defines the research aims and objectives, outlines the limitations of the study and describes the thesis structure.

1.2. Background

Transitional space is the space not directly occupied to accommodate the main activity of the building, it is a buffer space between inside and outside space. It poses an interesting and fruitful area for energy and comfort research, and it is popular and unavoidable in the design of many non-domestic buildings. The percentage of this type of areas varies between 10-40 percent of the total volume in different types of buildings (Pitts 2007). In modern society, transitional space is often seen as an important part in an architectural design terms because of the increased interest in symbiotic building. It also impacts on a wide range of senses and perceptions of human occupants and so has an important role in improving the physical environment in buildings. Such spaces cannot be treated simply as an extension of the interior environment, since different occupants used and thought of these kind of spaces in a different way, they therefore require their own research and design standards (Pitts 2013).

The imitation of modern architectural style with widely used glass especially in office and commercial buildings with less concern for climatic considerations has created an artificial indoor environment. In these buildings, transitional spaces are generally located in the front of building and with a wide façade of glass. The complexity of thermal conditions in indoor transitional space increases with the diversification of building spaces. In addition, the use of electrically driven ventilation and heating systems can cause excessive energy consumption for heating and cooling the buildings. Transitional spaces are always defined as an ancillary space compared with the fully occupied heart of a building (heart of the work environment), which can be identified as foyers, lift lobbies, corridors, stairwells, circulation spaces, atria and other spaces that act as a linking space between indoor rooms or between the exterior and the interior (Pitts 2013, Chun 2004, Hwang 2008).

To improve transitional space' design and investigate the possibility of energy consumption in transitional spaces, thermal comfort needs to be considered. Thermal comfort is defined as 'the state of human mind, which expresses satisfaction with thermal environment' (ASHRAE Standard 55). In terms of space type and architectural characteristics, the investigation of thermal comfort is related closely to the physical environment of building. In terms of the end users, the research of thermal comfort is related to the human activity of physical, physiological and psychological.

Over the past few decades a considerable number of studies have been done on thermal comfort to improve energy consumption, mainly focused on interior environments of buildings. However, the increased interest in diversified space in buildings creates a need for researching into the thermal environment and thermal comfort of different type spaces, including transitional spaces that closely related to the fully occupied spaces. The thermal requirement of occupants in transitional space is more complex than in fully occupied space because of the special physical characteristics and heterogeneous function of transitional spaces. In a general way, transitional spaces do not require the same high level and close environmental control of more fully occupied spaces, thus transitional spaces maybe permit a wider variation in environment conditions and thermal comfort requirement. Pitts suggests that the possibility of useful energy savings (particularly for heating) can realize by the way of allowing for a modest (and realistic) relaxation of comfort standards regulation in transitional spaces.

Currently it is common to find that the thermal environment of transitional spaces required considerable amounts of energy to sustain the comfort levels in accordance with various prescribed building standards. Chun (2004) suggests that transitional spaces can help to save energy if they can be developed depends on their climatic needs. Pitts (2007) indicates that "the energy consumption in transitional spaces, per unit area or volume, may be as high as three times that of the remainder of the inside of a building".

As transitional spaces have large implications for occupants' experience and building energy consumption, many research studies in recent years have examined their conditions and characteristics (Jitkhajornwanich et al. 1998, Chun and Tamura 2005, Hwang, et al. 2008, Jitkhajornwanich and Pitts 2002, Kwong and Adam 2011, Kwong et al. 2009, Mohanmmad et al. 2012, Potvin 2000, Pitts 2013, Alonso et al. 2011, Hui and Jiang 2014).

As seen in above paragraphs, scholars have investigated different forms and types of transitional space under different culture and region background, and a wide aspect of transitional spaces' characteristics and issues of thermal performance and energy have been covered and analyzed. However, there is still a lack of information on responses to conditions in non-domestic buildings in the UK and current thermal comfort standards do not clearly address such spaces (Chun and Tamura 2005). Both ASHRAE and ISO 7730 not have clear design criteria of temperature for indoor transitional spaces. CIBSE provides seasonal comfort criteria for place of public assembly includes foyer which is a typical transitional space in buildings, it is base on standard activity and clothing insulation levels as 13-20°C temperature in winter and 21-25°C temperature in summer (CIBSE, 2006). Comparing to ASHRAE and ISO 7730, CIBSE always allowing for wider temperature ranges.

Indoor transitional spaces are a particularly complex building space type where the needs of very special location and function are conferred. They often need to accommodate multiple activities and functions. In some cases, people will be working in the space on a continuous basis, whereas other people may pass through the space or spend only a short time there. It is likely the different groups of people who use the space will show different levels of activity and clothing level, along with time spent in the area and overall expectations. The diversity of spaces and the various functions across the different indoor transitional space areas further contribute to the thermal comfort conflicts. Understanding such conflicts contributes is the first step in improving thermal comfort, while reducing the amount of energy consumption required for conditioning indoor transitional spaces.

The cases presented in this research are three foyers in educational institutions and entertainment and culture building in UK region. The research explores the relationship between thermal comfort and human activity, to find the thermal requirement of occupants in transitional spaces and how thermal comfort influence people's using of indoor transitional spaces, lastly consider if it can help building to save energy. The current study is one of the most extensive works available to date, using field surveys with a large population sample drawn from three transitional spaces in public buildings in Cardiff, UK.

1.3. The importance of research on thermal comfort in transitional spaces

Thermal comfort is an important field when scholars research sustainable and low carbon built environment. Transitional spaces play a more and more important role in modern buildings and in the field of investigating how to reduce energy consumption in buildings. Despite increasing interest in transitional spaces thermal comfort studies, little attention has been paid to the UK climate and the big transitional space in the non-domestic buildings with a multiple functions and close related to the fully occupied indoor space. There are few specific regulations, standards or guidelines for thermal comfort in transitional spaces. Most thermal comfort research on transitional space is derived from studies of regular interior space.

Most former studies are in the hot arid climate and focus on the interaction between the environmental elements and the physical setting of the space, with little attention on the human factor. The former research of thermal effect on users was studied using standard thermal indexes. Thus, in the majority of cases, little considerations were given on the adaptive actions on the perceptions of the thermal environment. However, the clearly understanding of adaptive factors should provide designers with valuable information about the people who will be using the indoor transitional space. Further more, a failed designed indoor transitional space can be a result of neglect of the important roles of adaptive opportunities a public space can offer to visitors.

This research is provides a research into the area of thermal comfort in indoor transitional spaces in non-domestic building in the UK, which currently has not been thoroughly investigated. This study not only uses the traditional standard thermal indexes, but also significantly considers the thermal adaptive opportunities of visitors. This study can help to expand research of thermal comfort in indoor transitional spaces and its influence on using of indoor transitional spaces. In additionally, it also can help to improve the possibility of reduces energy consumption in indoor transitional spaces and other components of buildings.

1.4. Research questions

After stating the research problems and the gaps in the area of transitional space thermal comfort, the following questions were carefully articulated to draw the research outlines:

- Whether people will accept lower stands of thermal comfort (requiring less energy) in indoor transitional space than in other types of spaces?
- How relevant is adaptive thermal comfort model to indoor transitional spaces?
- How thermal comfort influence on how people use of indoor transitional space?

1.5. Aims and Objectives

The aim of this research is to understand the relationships between thermal conditions, thermal comfort and people's use of indoor transitional space with a view to determining if indoor transitional space can help the building save energy.

Objectives:

The study has the following specific objectives:

1. to investigate the occupants' thermal comfort perceptions in indoor transitional spaces.
2. to calculate and compare neutral temperature, preferred temperatures and comfort temperature range of the occupants in different indoor transitional spaces, using the mean thermal sensation vote responses.
3. to decide whether occupants have lower comfort requirements for transitional spaces that could lead to savings in energy consumption.
4. to examine physical and psychological factors that affect thermal adaptation in different transitional spaces by studying behavior of people; and
5. to investigate the relationship between the environment parameters and the actual sensation vote in different indoor transitional spaces, and examine the impact of this relationship on the use of indoor transitional space.

1.6. Methodology

Two principal methodologies used in this study are questionnaires and physical measurements.

1.6.1. Questionnaire

The main method of survey chosen in this research is the questionnaire, to understand the occupant's perception of the thermal condition in existing transitional spaces in buildings, then meshing the collection data with measurement result. The information about occupants' perceptions includes thermal sensation, thermal preference and thermal adaptation. In recent years, thermal sensation and adaptation has become an important issue in studies of indoor and outdoor thermal environments (Lin 2009). The questionnaire is used in this research since this method can get the occupants' respond directly.

The questionnaire survey can be divided into subjective and objective variables. The objective variables include gender, age group, and occupation. The subjective variables include occupants' satisfaction with their thermal environment and occupants' health related categories. The second section asks subjects to rate their thermal satisfaction, sensation and preference. Thermal satisfaction is ranged as 5 degrees, from very poor to very good. Thermal sensation is rated on ASHRAE 7-point thermal sensation vote (TSV) scale (i.e., -3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, and 3 hot). The thermal preference will assess by the occupant's wished different thermal comfort change scales. In the pilot study (Appendix 2), the calculation of thermal satisfaction rate is based on the result of thermal sensation rate. It was improved as an independent question in formal studies (Appendix 1) to get a more reliable satisfaction rate of participants. The records of the responses also need kept and catalogued according to time and date.

1.6.2. Physical measurements

Physical measurement is a traditional and necessary step for collecting climatic data. Air temperature, radiant temperature, humidity and air movement speed are the four basic environmental variables that define participants' thermal environment. The information of thermal environment is collected by the method of measurement. The aim and objectives of the field experiments are: 1) to quantify the thermal environment in indoor transitional spaces and combine the results with questionnaire to investigate participant's thermal perception in indoor transitional spaces; 2) to establish the range of interior and external thermal conditions found in indoor transitional space.

Obtaining permission to conduct field experiment in buildings with indoor transitional space in Cardiff was the first step. After granting permission to study three selected buildings in Cardiff, the field experiments were conducted.

Although the sample type is not a representative of the transitional spaces' type as a whole in Cardiff, these three buildings have been selected as case studies to compare their environmental condition and to establish some initial information on indoor transitional spaces. The field experiments have been carried out during the hottest season (July and August) and the coldest season (January and February) in Cardiff. The measurements were made in occupied indoor transitional spaces.

1.7. Outline of the thesis

This thesis has two main parts: part one describes the background and theoretical study, and includes chapters one to three, introducing the study and the research conducted in the literature; part two describes and discusses the experimental work, in chapters four to seven, introducing the methodology, the finding and discussion, and the conclusions and recommendations. The chapters are organized as follows:

Chapter One describes the research background, the research necessity, the aim and objective of research, the research scope and limitation and the summary of each chapter.

Chapter Two is a literature review chapter of transitional space, includes the definition, classify and functions of different transitional spaces, and the related researches about transitional space. In addition, the definition of indoor transitional space and related researches of it.

Chapter Three is a literature review chapter of thermal comfort, it gives a review of thermal comfort definition and history, thermal comfort theory and related standards, and the reviews of key studies concerned to thermal comfort in transitional spaces.

Chapter Four explains the methodology that is applied for the research that is based on field surveys. This chapter gives an introduction of different methodology, the framework upon which the research designed. This chapter explains how the physical data were measured, how people's perception of environment is got, and how human behavior and activities were monitored, and describe the locations where field study took palace and procedure of investigations.

Chapter Five describes the results and analysis of them obtained from field surveys. It includes a description of the participants interviewed and the environment profile of the study area. This chapter also describes the comparison between the findings of different indoor transitional spaces and of different seasons. The chapter also presents the relative contribution of heat balance parameters to thermal perception by people in indoor transitional space.

Chapter Six presents and discusses the finding of this research, how people evaluate their thermal environment in different indoor transitional space. The results help in understand whether the thermal sensation of subjects can be explained by heat-balance indices alone, and comparing thermal comfort requirements in the indoor transitional spaces with different physical characteristic and service system. The chapter also presents how thermal perception of participants influences the way of them using indoor transitional spaces.

Chapter Seven is bringing together the major themes covered by thesis to make conclusions and recommend further improvement for future work.

Chapter 2 Transitional space

2.1. Introduction

This chapter provides the background to the topic of transitional space, beginning with a definition and historical review of transitional space, which lead on to, how they are designed and used today. The chapter includes two sections: the first is a literature review of transitional space, with a definition of "transitional space", the description of generic form of transitional space, its historically development as a building type, and its function as a space. The second section focuses on the definition, classification and existing research on thermal comfort in transitional spaces.

2.2. The transitional space

At the end of 19th century, architectural space was defined as stable space enclosed by walls, until Frank Lloyd Wright proposed a theory of "flowing space" in the Charter of Machu Picchu of the International Association for Architecture. It contributed to the definition of the generally accepted cognitive of "Continuity of space" in the later centuries (Frank Lloyd Wright, 1978).

Based on his theory, John Portman put forward the idea of "sharing space" and practiced it in his design projects. He defined sharing space as interior space, often meaning a space as high as the whole building or several floors in the vertical direction. This kind of space always has the function of circulation, display, meeting, leisure and rest et al.. At the same time, sharing space with a spiritual meaning: the meaning of “sharing”, not only refers to sharing the same space; it also means promoting communication between different people.

The structuralism architect, Aldo Van Eyck, is the first person to propose the theory of “intermediary space”. He described “intermediary space” as the space that “neither belongs to interior, or to exterior space”, because it functions “both with in-and-outside space”. Van Eyck suggested that architecture must set a clearly intermediate zone, and it should between interior space and exterior space, between one space and another. At the same time, transition must consider the importance of both sides, connect by the intermediate zone defined by both sides, and it is also a space providing a public space for the resolution of these two sides. However, it should be noticed that Van Eyck’s “intermediary space” theory is not as same as the definition of transition space in modern architecture: although Van Eyck emphasizes that the intermediate space in a middle form from one space to another, he did not make strict limits on both ends of the space. His “intermediary space” can be a middle space between the interior and exterior spaces, but it also can be a space between two interior spaces.

The American postmodern architect, Robert Charles Venturi, put forward his theory “indefinite form” of architecture. He stated that: architecture results from the intersection of the function of indoor and outdoor, at the same time the uncertainty of architecture can be uncertain and that contradictions exist everywhere in the complex and contradictory construction. The indefinite form of architecture specially designed by architects is based on the uncertainty of life, which reflects the element of architecture. Therefore future architectural space should develop from simplification to complexity, from clearness to ambiguity (Venturi, 1966). The greatest contribution of Venturi to transitional space is that he clearly defined the ambiguity of transitional space. He emphasized that the ambiguity of the expression of spatial sequence, and thought that this kind of indefiniteness intangibly forms of space is necessary.

The Japanese architect Kisho Kurokawa put forward the concept of “grey space” based on the oriental traditional architectural culture. One aspect of “grey space” refers to the grey colour, but another aspect is refers to the transitional space between indoor and outdoor. The former aspect is based on the founder of Japanese tea ceremony Sen no Rikyu's theory of "Rikyu ash", which means mixed with red, blue, yellow, green and white then creating the different tendency of grey. For the latter aspect, "grey space" refers to a kind of spatial form that cannot be clearly defined as either indoor or outdoor space. It acts as an insertion space between indoor and outdoor space; it is the third domain between inside and outside. It can be defined as interior space because it has a roof, but it also can be defined as exterior space because it is open to the outer space. The characteristic of "grey space" is neither separates from inside and outside space, but also is not independent from inside and outside space, it is an intermediary space of indoor and outdoor space (Kurokawa, 1981). The "edge side of" space in the traditional Japanese architecture is such a typical "grey space". It should be said Kisho Kurokawa defined transition space in an elaborate and profound way. He clearly illustrated the spatial morphology of transition space: with a top interface but with the side interface open to the outside in different degrees, it can be defined as a spatial form "in and out". Kisho Kurokawa also described the function of transitional space as between inside and outside space, it is a medium of internal and external binding region.

The Chinese architect, Yigang Peng, proposed that modern architectural space should obtain the spatial transition and become unified by using geometrical form. There is a connection and transition between inner and outer spaces, architectural interior space and natural exterior space, which is mutually communicated. He also stated that transitional space should be inserted between the interior and exterior space when people go into the interior space of a building from the outside in order to avoid unwelcome shocks (Peng, 1998).

There are many different definitions of transitional space, which define it just from certain aspects and according to certain elements. Some scholars think that in addition to vertical structural elements, transitional space can be defined by planes or forms that do not touch ground. In Japanese architecture, for example, the long roof eaves create an occupied sphere underneath them, called the "noki-shita", which create the aforementioned "transitional space" (Nitschke, 1993). Some scholars research on thermal environment of transitional space define it as the space located between outdoor and indoor environments; it is a buffer space and physical link (Chun 2004). Also some scholars define transitional space from the relationship between nature and building. Bolos, for example, considers transitional spaces as an overlap of the qualities of interiority and exteriority, creating liminal spaces where nature and building each accomplish their respective task while relating in a non-threatening way to each other (Bolos, 2009).

2.3. The form of transitional space

Form is an important element of building transitional spaces, which determines the basic content of a transitional space. This part classifies transitional space in terms of space enclosure, interface and linear features. Space form includes space enclosure, space shape, space size and scale, and divided of space function.

2.3.1. Spatial enclosure

Although the Japan architect Yoshinobu Ashihara defines the Interior space and exterior of building by observing if it has a roof or not, but side interfaces also are important elements of enclosure space. Full indoor space should have four sides surrounding it. If interior space loses any of its sides or there are frequent open gates, it cannot be called a full interior space, since it blends with outdoor features and could not be defined as a purely indoor space. These kinds of spaces should be defined as transitional space, because they have the special feature of “in and out” form.

The lower level of enclosure results in transitional spaces with the environment closer to the outside environment, whereas a higher level of enclosure results in its environment closer to the inside environment. The former transitional space is more open and public, while the latter is more close and private.

The transitional space studied in this research belongs to public building, as the foyer of public building entrance. They always have a very close connection in one to three interfaces, but also have a very close or frequency connections with outside environment in other interfaces. These transitional spaces always have a high level of enclosure.

2.3.2. Space interface

Unidirectional interface space: The unidirectional interface space is the space missing three sides. This kind of transitional space is effectively an open space because the only interface for this space is just a boundary of the spaces; it cannot define a space perfectly. So to qualify a three-dimensional space volume, it always needs to be combined with the vertical line. Unidirectional interface space is the most popular transitional space form in architecture. They are always located at the entrance of building, such as a building awning, porch, gallery, or colonnade (Figure 2.1). This transitional space's only side is the key interface and the door to interior space is in it, and it always forms a visual center. The opposite of this key interface always needs vertical pillars further to define the extent of the space, also these vertical lines elements are becoming important visual elements of space.

Figure 2.1 Canopy of a building (Source: Website).

Parallel space: Transitional space missing two side interfaces can be divided into two types: lost parallel interfaces and lost adjacent side interfaces. Former called parallel surface space and the latter known as the L-shaped space. The open ends of parallel surface space are formed by the edge of two parallel side interfaces, which giving the space a strong sense of direction. Its spatial direction is along the axis of symmetry for the two sides. Due to the parallel sides parallel to each other to generate angle and therefore cannot be fully lined this region of space, so parallel surface space is a form of extrovert spaces. Thus, the two open ends of parallel surface space connecting to the outside space, to build the connection with inside space, windows and doors should opened on two parallel interface. It will form a secondary axis in the space and adjusting space direction, enriching the forms of space Figure 2.2.

Figure 2.2 Porch of a building (Source: Website).

The L-shaped space: The L-shaped space is formed by the adjacent side interface, forming a space from the corner along the diagonal line. At the corner of L-shaped space, the space is limited and enclosed strongly, but it gradually decreases outward from corner to outside. The open end of the L-shaped space provides the visual link with outside space, but to link with inside space, windows and door should opened at the adjacent sides of the interface. Sometimes, to make the space of L-shaped space clear, pillars should be set at the intersection of two open ends. Fukuoka Bank is designed by Kisho Kurokawa to create a huge L-shaped space, as shown in Figure 2.3, which is a “lateral” space between the indoor and outdoor.

Figure 2.3 L-shaped transitional space (Source: Website).

2.3.3. Space size and scale

People’s perceptions in the transition space cannot be accurate about scale and proportion. A harmonious spatial scale and proportion can give people feelings of comfort. So spatial scale and proportion is one of the important aspects of spatial form. It is important to adjust the proportion of building transition spaces and building itself. The percentage of transitional spaces may vary between 10-45 percent of the total volume in different types of buildings (Pitts and Saleh 2008).

2.3.4. Classifying area functions

Transition spaces in public buildings can be considered as circulation areas and static space. Circulation space is mainly using for people passing through while the static space supports activity within the space. The entrance and axis of the space is always uses as circulation space when the space with a clear direction, pavements and furniture usually divide these two areas. Circulation space and static space are often marked by different floor materials or different installation method, to remind people of the different functions of the space. It always helps to remind people not to dwell in circulation space while static spaces may introduce natural elements or furniture to attract people to stay and rest.

2.4. Function of transitional space

People have a long history of using available ranges in shelter are a common way to adapt local climates (Knowles 1999). Transitional spaces can increase the available range of thermal zones so that people can select the microclimates most suited to their thermal needs. In this context, transitional spaces have become an important architectural form in citizen's life. Transitional spaces are use widely in the city depend on the function as follows:

Shelter from rain and sunshine: The original role of public building transitional space was to keep out the rain, and in hot summer, block out sunshine and reduce the solar radiation using devices such as a canopy.

Traffic guidance space: Public building transition spaces not just acts as a traffic hub between external and internal spaces, it also played as transport guidance. It is a convergence area inserted between inside and outside spaces, can worked as a traffic compatible and grooming space to solve the problem of flow aggregation and dispersion. It is an important part of the building, as the large porch of the building, indicating where the entrance to help people quickly finding the entrance.

Enrich building facade and space level: Public building transition space is a subsidiary part of the main building, with very flexible form and can enrich the effect of façade of the building. Some even become the most prominent visual feature of the building and a symbol of architectural artifacts.

Transfer of visual, auditory, tactile: When people move through interior, transitional and exterior spaces, these three different environments cause the changes in physical sensations. And this physical change mainly includes gradually transition and formation of sight, hearing and touch. Transitional space inside and outside public buildings is extremely important on visual function and visual comfort of the building. Transitional space relieves the transfer from interior and exterior light environment; improve the visual discomfort sense between inside and outside effectively. When public buildings internal environment directly connected with the external environment, it is easy to impact by outdoor noise environment. Especially the building facing a noisy street, vehicles and throngs of people in the street creating noise and reduce indoor environmental quality, affecting people’s interior lives. If inserting an intermediary space between interior and exterior environments – transitional spaces, the impact of outdoor noise to indoor environment can be reduced to a certain degree, improving the quality of indoor environments. When people travel from quieter interior environment into quiet transitional space then go into a noisy environment, their sense of hearing can gradually adapt to the environment, and people’s moods also can have a smooth process. Human touch can be divided into direct and indirect touch, direct touch is refers to the tactile feelings obtained through direct contact with the material, while indirect tactile experience through the visual observation and mobilizing of brain to realize tactile memory. Essential differences of the internal and external environment leading to a big difference between exterior and interior materials used. Outdoor space utilizing materials tend to have rough texture, while the interior space utilizing exquisite material. If a transition space material is carefully designed, it can make the tactile feelings either directly or indirectly goes from inner and outer forms. It also enhances the quality of the environment as a whole.

Psychological aspects of experiencing transition spaces: Public building transition spaces work on human psychological functions mainly for suggesting that people behave transformation and transition space can give people a sense of security, so as to give people a sense of feeling pleasure. Public transition space reminds people that indoor and outdoor space will be transformed, which can lead people to make the corresponding changes in behavior. People behavior in the outdoor environment tends to be more relaxed, and when entering the interior environment, especially in formal situations, tends to be dignified in mannerisms and spirit. When people enter the transition space, it provides time and space for human behavior and state of mind to adjust. In transitional spaces, people can quickly go into the internal environment, and can pay attention to the outdoor environment at the same time; it is an ideal place to defend. Although we no longer need to defend ourselves like in ancient times, security is still one of the basic needs of the people. It has a positive influence on people’s psychology, and people can truly relax at a safe place.

Provide space for social communicating: Transitional space within and outside public buildings, both connected to indoor environment and can easily observe the various outdoor activities. Transition space with the function of ventilating and providing shelter of sunshine and rain, which decided it as an ideal space for stay and an ideal place to social interaction. It is an important part of the urban space, people use it for staying, resting, chatting, reading, eating, watching pedestrians and other acts, these events also attract the more people involved, and got very good communication from person to person.

2.5. The relationship between transitional spaces and the building

The special characteristic of transitional spaces is “transit”, it indicates this type spaces should be the transition space between inside and outside environments. In another words, the space should be the interior space but significantly open to the outdoor environment or the exterior space but provided indoor environment characteristic. These type spaces possess free space form and flexible using function, so it is widely used in the modern buildings.

Researchers have used many terms when referring to transitional spaces, such as: semi-outdoors buffer zone, buffer spaces, in-between, physical links, semi-enclosed or half-opened (Chen et al. 2011, Hwang et al. 2008, Saleh 2007, Pitts and Bin Saleh 2007). The distinction between indoor space, outdoor space and transitional space is mainly based on spatial form. Yoshinobu Ashihara defines indoor space as a space with roof and defines the outdoor space as a space without a roof. Transitional space is the space between them, it belong to indoor space because of it has a roof interface, and it also belong to outdoor space because of the lack of four-side interfaces in different degrees, therefore transitional space is an “in-outside” space.

Chun, Kwok and Tamura (2004) who state that transitional spaces are ‘locations where the physical environment bridges between the interior and exterior environments’, they divided transitional spaces in three categories depends on their proximity to interior spaces (Figure 2.4). Type one transitional space is totally located in the building, such as entrance area and lobby. The thermal environments of this type area are complicated on account to the frequently open and close door when people move in and out. Type two is the space between or connected to two buildings with cover shelter, such as balcony, porch, corridor, covered street or arcade. The thermal environment is predominates by outside climate. Type three transitional spaces is a completely outdoor space independent of a building, not attached to a building and is essentially an outdoor room, such as pergolas, bus stations, or pavilions. The thermal environment of this type of space is decides by how the design of the structure modifies the outdoor climate.

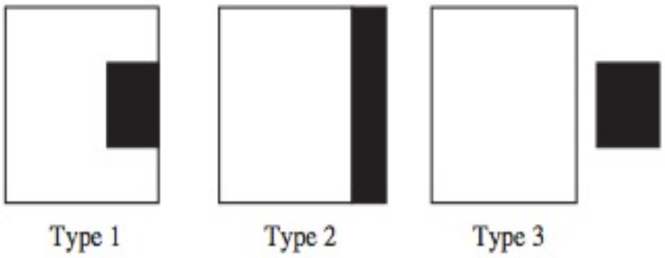

Figure 2.4 Classification of transitional space (Source: Chun 2004).

Transitional space should be classified as outside transitional space and inside transitional space. Outside transitional spaces defined as the space connect or around building, it with a roof but lack of one to four sides interfaces. The climate environment of it is mainly decided and infected by outside climate. Inside transitional spaces defined as the space inside building but with an interface open to outside or door on this interface open frequently. The inside transitional space environment is decide by indoor climate but infect obliviously by outside climate, which is the most clearly different from inside transitional space and fully occupied space.

In terms of space forms, transitional space can classified as inside and outside transitional space in the different forms bases on the above discussion. This study researches internal transition space, the basic form of it is as type 1 and type 2 in Figure 2.4.

2.6. Indoor Transition Space

While many definitions of the term transitional spaces have been suggested, this thesis utilizes the definition given by Kwong and Adam (2011) who state that transitional spaces are often referred to as those spaces which are located within a building but which are also connected with the exterior environment. To further clarify the definition, the word 'indoor' is added to as the indoor transitional space that is researched in this study. Transitional spaces are unavoidable in the design of most non-domestic buildings. Transitional spaces in the buildings direct open to the outside environment are frequently experiences significant air exchange with the outside environment. Such as transitional spaces may consume more energy on account of provide a higher level of building services. Some research has shown that transitional spaces can help to save energy if they can design depends on the local climate (Chun et al. 2004). Indoor transitional spaces are the areas that not directly occupied in respect of the activity of the buildings; they are modifying experience and expectation of persons moving through them. The role of environmental conditions in such spaces is that they lie between internal and external conditions and so may offer benefits such as reduction of thermal shock for occupants moving into and out of spaces as well as modifying their thermal comfort expectations.

2.6.1. Function of indoor transition space

An indoor transitional space is a space within a building and connect indoor and outdoor environment. It often is a large, vast room or complex of rooms (in a theatre, opera, hotel, concert hall, showroom, cinema etc.) adjacent to the auditorium or other fully occupied space. It is not only a repose area for spectators and place of venues, especially used before performance and during intermissions or celebrations after performance, but also provide venues for festivities activities. In the educational institute, it also uses for meeting, working or study, resting, eating and drinking and so on.

Many office buildings, hotels and skyscrapers go to great lengths to decorate their indoor transitional space (lobby, foyer) to create the right impression and convey an image, or "power lobby". Many educational institutions are setting their building transitional spaces as resting and social area, even as appendage of restaurant and café.

Since the mid-1980s, there has been a growing trend to think of indoor transitional space as more than just ways to get from the door to the elevator but instead as spaces for social and commerce. Some researches has even been done to develop scales to measure indoor transitional space atmosphere to improve the design of indoor transitional space (Countryman 2001).

Many indoor lobby transitional places that offer public services, such as a doctor’s office, and sky lobby. Doctor’s office uses their lobby as more of a waiting room for the people waiting for a certain service. Comfortable furniture such as couches and lounge chairs always provided in these lobbies to make the customers feel comfort when they are waiting. The indoor transitional space appear in the super tall skyscrapers always as a sky lobby, it work as a temporarily space for people to waiting elevator.

Another common indoor transitional space type is foyer. The word foyer comes from the French language and it is means “the place where the fire is kept”. Traditionally, foyer is defied as a large hall specially designed, but sometimes, it can be a corridor surrounding the main hall. This type space always is furnished and big enough to enable spectators to get together. In the modern building, foyer are commonly connected with the fully café, store and other functioned spaces, which enable it sharing the function with other spaces such as people eating and drinking, reading, working on computer in this space. Sometimes it works as a space for permanent or temporary exhibitions related to the activity of the institution, and a refreshment room or buffet etc.

2.6.2. Classification of indoor transitional space

Some scholars classifying indoor transitional space in a relatively simply categorization: open to the environment space (corridor) and fully enclosed space (lift lobby, passageway, etc.) (Kwong et.al. 2009). Pitts and Saleh (2007) classified the transitional spaces into four types depending on their location in the building layout (Figure 2.5). Type A includes linear transitional spaces located in the short side of buildings with a rectangular layout plan and connected with the facade. Type B includes transitional spaces located in the central area of buildings and connected with the exterior, such as lobby spaces. Type C includes linear transitional spaces typically located in the central area of buildings and in parallel with one of the axis of the building. Finally, type D includes linear transitional spaces located in the perimeter of the building connected with the facades. This classification attempts to show the impact they have in terms of energy use in the whole building. Having a larger effect on energy saving the linear transitional spaces located in the perimeter of the façade (Type A and D) than those located in the center of the building (Type B and C). Gloria Vargas (2016) suggested that although transitional spaces type A and D could reduce energy in buildings (from 11.4 to 32.7% used for heating and from 2.2 to 6.6% used for cooling), more research is needed to quantify which transitional spaces are the most typical in buildings or use the major percentage of area. Although, type B and C seem to have less impact on energy reduce (from 4.2 to 6.6% of energy used for heating and from 0.7 to 0.9% used for cooling) they could be more typical or could be using the largest percentage in buildings. Besides, in the real cases, there are lots of indoor transitional spaces exist as a mixed and un-rectangular type, for instance: A+B, B+C, or A+C. In additionally, Pitts (2013) classified indoor transitional space according to the function and location as three categorizations: entrance zones: attached areas with strong connections to the exterior; circulation zones: internal spaces with greater compartmentalization and separation from exterior; long-term Occupancy Zones: semi-occupied places with secondary use.

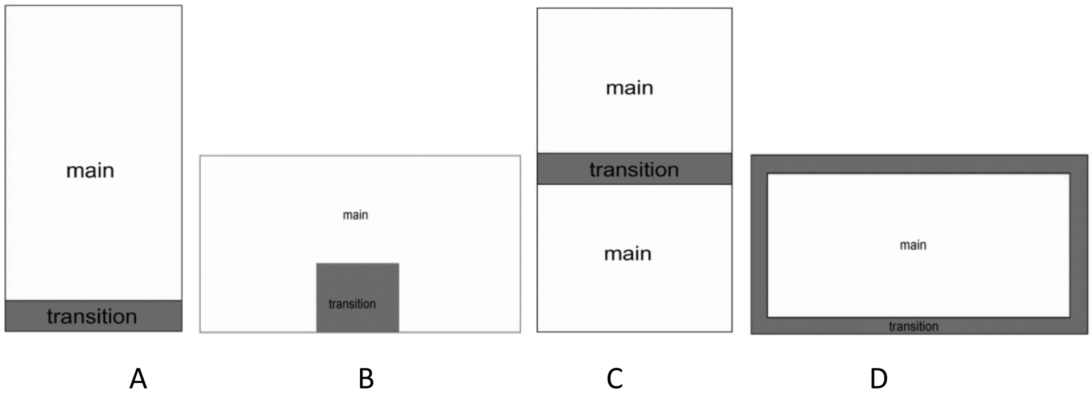

Figure 2.5 Classification of transitional spaces based on their location in the interior space (Pitts and Saleh 2007).

The transitional space in this study is the combination of Type 1 and type 2 transitional spaces located in the center of the buildings (type A+B+C), which connecting the exterior (Figure 2.6). The function of the indoor transitional space is includes all the three types Pitts suggested: entrance zones, circulation zones and longer-term occupancy zones.

(A)

(B) (C)

Figure 2.6 Indoor transitional space type of A, B and C (foyer areas connect interior, exterior environment and corridor in central area of building), Atrium, The University of Glamorgan, UK.

2.6.3. Activities in indoor transitional space

Generally, the human activity type and quality in indoor transitional space is mostly depends on the facilities provided in indoor transitional space and the thermal condition in it, as well as the aim of visiting. In the modern buildings, indoor transitional space always share the function of fully occupied space, thus people's activity in indoor transitional space is same with when they stay in other space of the building. People sitting in indoor transitional space, talking with each other, working or study on computer, waiting, eating or drinking or just resting.

2.7. Researches about transitional spaces

Transitional spaces have been studied in building entrances, lobbies, train stations, corridors, air sports, arcades, atria etc. The literature review of main researches about transitional spaces and relevant spaces are list as Table 2.1. However, there is still a lack of research in this topic, a lack of fieldwork research to validate the laboratory work and stress the importance of exploring this area further and more deeply. For instance, still little is known about people's experiences in indoor transitional spaces in educational institute and cultural & commercial interiors. Apart from the physical characteristics of indoor transitional spaces, little has been discussed in previous work about people's adaptive behavior and thermal perception's influence on the way of use indoor transitional spaces.

Table 2.1 Research related to transitional space

Researcher	Year	Location	Space type	Research Method
Jitkhajornwanich et al.	1998	Bangkok	Schools and offices	Questionnaires Physical Measurements
Tsujihaha	1998,2004	South Korea	Arcade	Measurements
Potvin	2000	Cardiff,UK	Arcades	Surveys
Jitkhajornwanich and Pitts	2002	Bangkok, Thailand	Schools and offices	Questionnaires Physical Measurements
Nakano	2003	Waseda, Japan	Semi-outdoors Environments	Laboratory and Field Experiments
Spagnolo and de Dear	2003	Sydney, Australia,	Outdoor and semi-outdoor space	Questionnaire survey
Chun et al.	2004	Yokohama, Japan	Lobbies, balconies, pavilions	Physical Measurements Observations
Chun and Tamura	2005	Yokohama, Japan	Train station, Passageway, Shopping Mall	Laboratory work Field work
Nagano et al.	2005	Kyushu, Japan	Climatic Chamber	Laboratory work
Kaynakli and Kilic	2005	Bursa, Turkey		Mathematical Model
Nakano et al.	2006	Tokyo, Japan	Train Station	Surveys
Kim	2006	Korea	Arcade	Measurements
Hwang and Lin	2007	Taiwan	Outdoors Spaces	Fieldwork Surveys

Pitts and Bin Saleh	2007	East Pennines area, UK	4 types of transitional spaces	Simulation Tool
Zhao	2007	Beijing,China	Chambers	Laboratory work
Yokoe et al.	2007	Nagoya, Japan	Thermally controlled buffer space	Laboratory
Bouyer et al.	2007	Paris,France	Stadium	Simulation
Hwang et al.	2008	Taichung, Taiwan	AC building Service Centre	Questionnaires Physical Measurements
Chun et al.	2008	Seoul, Korea Yokohama, Japan	University Campus and Climatic Chamber	Laboratory Experiment
Pitts et al.	2008	Sheffield, UK	University Building Transitional Spaces (AC, NV)	Surveys
Kim et al.	2008	Korea	Markets	Fieldwork Surveys
Kwong and Adam	2009	Malaysia	Lift lobby	Fieldwork Surveys
Pitts	2010	Sheffield, UK	NV Academic Building	Surveys Physical Measurements
Ghaddar et al.	2011	Beirut, Lebanon	Bio-heat model	Parametric study Fieldwork validation
Kwong and Adam	2011	Putra, Malaysia		AC Lift lobby
Pitts	2013	Review of previous work	AC NV	Review of previous work
Wu and Mahdavi	2014	Vienna, Austria	Thermal Chamber	Laboratory Experiments
Kotopouleas and Nikolopoulou	2014	Manchester and London, UK	Airport Terminal	Questionnaires Measurements
Taleghani et al.	2014	Netherlands	Transitional spaces of low-rise dwellings	Simulation
Hui and Jiang	2014	Hongkong, China	Lift lobby	Fieldwork and Simulation
Gloria Vargas	2016	Sheffield, UK	Lobby	Fieldwork

Chapter 3 Thermal comfort

3.1. Introduction

In modern society, people spend most of their time indoors therefore the indoor environment has a great impact on occupants, including their productivity, health and emotion etc. (Fanger 1970). As a result, achieving a high quality internal space is a dominant issue in architectural design. Thermal comfort has been accepted as one of the most important aspects of the indoor environment quality.

This chapter aims to review the developments in indoor thermal comfort research and practice in transitional spaces, and the important factors that determine its success. There are three sections in this chapter: the first section introduces the theory of thermal comfort. It begins with a definition and brief history of thermal comfort, and then follows by explaining the importance of studying thermal comfort. The second section looks at research methods in assessing thermal comfort, and discusses and compares them. In the third section research on thermal comfort in transitional spaces is listed and compared.

3.2. Definition of Thermal Comfort

Thermal comfort is defined as '*the state of mind, which express satisfaction with thermal environment*' by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2004). Hensen (1991) also define it as "*a state in which there are no driving impulses to correct the environment by the behavior*"; which has the similarities with Givoni's (1976) opinion that thermal comfort is ' *the absence of irritation and discomfort due to heat or cold, and as a state involving pleasantness'*. Alternatively, it is the state that the person is entirely unaware of thermal condition of surroundings, neither considering whether the space they stay in is too hot or too cold (Strathclyde 2007). There is one concept all of these and other definitions of thermal comfort represent and emphasis: thermal comfort is the condition that individual feels neither too cold nor too warm while wearing an amount of clothing suitable to the task they need to perform (Fanger 1973).

Thermal comfort is influenced by personal difference, such as mood, culture and other individual, organization and social factors. As such, the definition of thermal comfort is not a state condition, but rather a state of mind (Noel et al. 2010). The definition of thermal comfort is meant by the condition of mind, which correctly emphasizes that, the judgment of comfort or not is a cognitive process involving many inputs influenced by physical, physiological, and other factors (Lin 2008).

3.3. Neutral temperature and comfort temperature

Thermal neutrality is defined as the situation that in which subject would prefer neither warmer nor cooler surroundings (Fanger 1970). Markus and Morris (1980) give a similar definition of neutral temperature: "*the state that in which people will judge the environment they stay neither too cold nor too warm, it is a kind of neutral point defined by absence of any feeling of discomfort*".

It is defined that the mean thermal sensation vote of subjects in neutral temperature is neutral or at the middle point of the seven point ASHRAE scale. Comfort temperature is the temperature at which the subjects express comfort feelings voting with the middle category of the comfort scale. Therefore the comfort temperature can be the same as the neutral temperature. It is noticeable that the neutral temperature or the comfort temperature is the optimum for the group (Heidari 2000).

3.4. Thermal acceptability and preferred temperature

McIntyre (1980) found that the temperature that a group prefers might correspond to a sensation above or below middle category on the warmth scale. Fox et al (1973) found that although subjects reported a sensation of thermal neutrality, they often said that they would prefer a warmer temperature. If all neutral temperature is what a person want is debated for a long time, and from the view of related researches that neutral and preferred condition may not match (Mishra and Ramgopal 2013). Humphreys and Hancock (2007) expressed the mismatch situation of these two parameters as "*people prefer sensation on the warm side of neutral if it is warm indoors and cool outdoors, while they prefer sensations cooler than neutral if it is warm outdoors and cool in doors".*

Preferred temperature can be found by asking the direct question and using a present-time condition: would you like to be: Cooler or No change or Warmer? (McIntyre scale). Answer of No change can be acceptable condition for subject. Another more widely used method is an indirect measure that equates acceptability with the three central categories (-1, 0, +1) of the seven-point thermal sensation scale. ASHRAE standard 55 defines an acceptable thermal environment as one that satisfies at least 80% of the occupants.

3.5. Physiological basis of comfort

Human body is a thermodynamic machine, and has a dynamic thermoregulatory system. The main methods that human body produces heat are metabolism, exchanges heat with the environment (mainly by radiation and convection) and loses heat by evaporation of body fluids (Hensen 1991). Seventy-five percentages of the energy is dissipated by radiation and convection while the heat balance is dissipated by evaporation (Zingano 2001). Thermal discomfort occurred when the ambient temperature is higher than the body temperature while it is results from the body heat cannot be dissipated to the surrounding environment.

The average normal vital organ temperature is near 37 °C results from the heat transfer processes during normal rest and exercise. Once the thermal disturbances occurred, the body's temperature control system tries to maintain this temperature. Hensel (1981) suggests that the human thermoregulatory system is much more complicated and incorporates more control principles than any other actual technical control systems. Hensen (1991) further defined that the human thermoregulatory system has two ways of control: autonomic thermoregulation and behavioral thermoregulation. Autonomic thermoregulation is controlled by the hypothalamus and different autonomic control actions such as adjustment of: heat production, external thermal resistance, internal thermal resistance, water secretion and evaporation. Besides autonomic thermoregulation, behavioral thermoregulation is another way that with control actions such as active movement and adjustment of clothing. Behavioral thermoregulation is associated with sensible temperature as well as with thermal comfort or discomfort.

3.6. Thermal comfort approach

At present, there is three main approaches have been developed to define thermal comfort: the rational approach or heat balance approach, the adaptive approach, and social practices approach. The rational approach is based on laboratories and chamber studies by Fanger (1970); the adaptive approach through field studies developed by researches (Aulicieem 1981; de Dear and Brager 1998; Humphreys and Nicol 1998); the practices approach does not use any measurements insisting that conceptions of thermal comfort developed by physical scientists fail to account for the cultural context in which definitions of comfort are created. The following sections will review more details of these approaches.

3.6.1. The heat-balance approach

Steady-state experiments showed that cold discomfort is significantly related to the mean skin temperature, and the warmth discomfort is strongly related to the skin wetness caused by sweat secretion. Dissatisfaction also can cause by whole body discomfort or local discomfort (unwanted heating or cooling of a particular part of body) (Hensen 1991). These relations are the basis of scholars' methods to develop the research model of thermal comfort including Fanger's comfort model.

The heat balance approach is based on Fanger's experiment in which occupant subjects were in controlled environment or climate chambers; occupants were dressed in the standardized clothing and acted completed standardized activities, while exposed to different thermal environments; then occupants record how hot or cold they felt using the seven-point ASHRAE thermal sensation scale ranging (Table 3.1). Fanger (1970) developed a comfort equation based on six variables: four physical variables include: air temperature, mean radiant temperature, air velocity and relative humidity; two personal variables include: clothing insulation and activity level. Fanger has developed the PMV-PPD model on thermal comfort, which has been a path breaking contribution to the thermal comfort theory and to the evaluation of indoor thermal environments in buildings. Predicted Mean Vote (PMV) is the method to measure the level of occupant thermal comfort and Predicted Percentage of Dissatisfied (PPD) is to predicted percentage of dissatisfied people. The PMV-PPD model is a method prescribed by ISO 7730 for evaluating general or whole-body thermal comfort, which also included in ANSI/ASHRAE Standard 55.

Table 3.1 ASHRAE seven points thermal sensation scale (ASHRAE Standard 55 2004)

-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

The Predicted Mean Vote (PMV)

The PMV-index is used for predicting the mean value of the subjective ratings of a group of people in a given environment. Fanger suggests this scale according to the ASHRAE thermal station scale (ASHRAE Standard 55 2004), it predicts the thermal sensation as a function of clothing, activity and the four classical environmental parameters (Fanger 2001), and the average value of thermal comfort equation based on steady-state heat transfer between the body and the environment. The PMV not only can using for check the compliance of a stated thermal environment with comfort but also use to establish different levels of acceptability requirement (ISO 7730 2005 and ASNI/ASHRAE Standard 55). The PMV model has been used frequently to emphasis the effect of adaptation in outdoor and transitional settings. However, it is significant to emphasize that the PMV model was meant to indoor, fully conditioned buildings.

The steady-state heat-balance theory takes the human body for a passive recipient of thermal stimuli (Brager and de Dear 1998), and the PMV does not take adaptation opportunities into consideration. In the recent years, some scholars have conducted studies to widen the applicability of the original PMV. For instance, Fanger and Toftum (2002) introduced an extension to the PMV by proposing an expectancy parameter “e” to explain the overestimation of thermal sensation in non-air-conditioned boiling in warm climates. Yao et al. (2009) proposing an aPMV model have considered factors such as culture, climate, and social psychological and behavioral adaptations.

The Predicted Percentage of Dissatisfied (PPD)

The PPD index predicts the mean value of thermal dissatisfied people that likely to feel more than slightly warm or slightly cold among a large group people (the percentage of people who complain about their thermal environment). Fanger using the 7-point thermal sensation scale (ISO 7730 2005) to declare uncomfortable: all these people who respond ±2 and ±3 are declared uncomfortable, who are respond to ±1 and 0 are declared comfortable (Djongyang 2010).

The relationship between PMV and PPD is shown in Figure 3.1. It reveals a perfect symmetry with respect to thermal neutrality (PMV=0). The Figure 3.1 shows that, although all the occupants’ cloth insulation and activity level is in a similar way, when the PPD index is 0, some occupants still dissatisfaction with their thermal environment. This is because that the different person has the different approach to evaluate thermal comfort. It is shown that when PMV index is 0, a minimum rate of dissatisfied 5% exists (Hwang 2009). Based on the ranges of PPD and PMV, there are three kind comfort zone can be obtained shown in Table 3.2 (Orosa 2009).

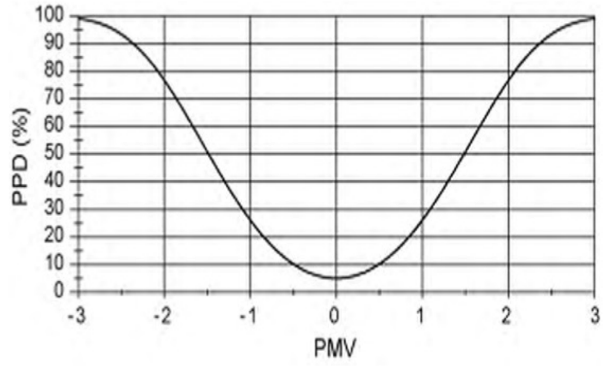

Figure 3.1 Relationship of PMV versus PPD (Source: ASHRAE Standard 55)

Table 3.2 Predicted percentage of dissatisfied (PPD) based on the predicted mean vote (PMV) (Orosa 2009)

Comfort	PPD	Range of PMV
1	<6	-0.2<PMV<0.2
2	<10	-0.5<PMV<0.5
3	<15	-0.7<PMV<0.7

The Physiological Equivalent Temperature (PET)

PET (Mayer and Höppe 1987) is another heat balance thermal index that gives the thermal assessment of a given environment. PET is based on the Munich Energy-balance Model for Individuals (MEMI, it is an energy-balance model that takes into account the body heat regulation processes such as constrictions, dilation of peripheral blood vessels) (Höppe 1984) is defined as the air temperature at which, in a typical indoor setting (without solar radiation and wind), the heat budget of the human body is balanced with the same skin and core temperature as under the complicated outdoor conditions to be assessed. He further give a example that the direct solar in summer days irradiation the PET value may be more than 20 K higher than the air temperature when on a windy day in winter it is up to 15 K lower.

3.6.2. The adaptive approach

Though heat balance approach of thermal comfort have a significant breaking in the thermal comfort research field, it also with certain limits. It is now widely accepted that though laboratory studies offer static and corresponding conditions for measurement not possible in the field studies (Djongyang 2010), the previously used climate chambers fail to provide the participants with so-called “experimental realism” in determining their thermal comfort (Schiavon 2008). Since in the normal life style, people live in the changeable, unstable and inconsistent environments, which may cause a deviation when the standards are applied on the occupants living in real-world situation (Han et al. 2007). Fanger’s climate chamber work and Humphreys’s field study in 1976 have been compared (McIntyre 1978). It indicated that certain intervening variables that occur in the “real” world might not be reproducible in the climatic chamber. It is reported on the significant inconsistency between predicted mean votes (PMV) and actual mean votes (AMV) values (Oseland 1995). This result obtained in offices and homes as compared with climate chamber studies, which attribute the difference to contextual and adaptation effects as follows: “*since the development of the PMV equation, many field studies have shown differences between the occupants’ reported thermal sensation and those predicted by PMV and the corresponding neutral temperatures*’’ (Djongyang 2010). Thus, the situation of field studies closer to the “*real*” world may be more desirable to climate chambers (Ealiwa 2001). So the adaptive approach is used frequently in the research correlated to thermal comfort.

The adaptive comfort theory was first proposed in the 1970s in response to the huge increase in oil price (Brager 1998). Adaptive approach is based on a variety of field studies all over the world, the purpose of adaptive approach is to analyze the real acceptability of thermal environment, which strongly depends on the behavior of occupants, their experience and expectations. The adaptive approach to thermal comfort proposing that people can take actions to ease their comfort conditions by adjusted their activity levels and clothing insulation or by interacting with the built environment (Sugawara et al. 2008). The concepts of “*adaptive model*” is based on this propose and which indicates the level to which people can thermally adapt to their ambient. When the adaptive opportunity is insufficient, deviate from thermal neutrality leads to thermal discomfort (Baker and Standeven 1996).

As Brager and de Dear (1998) suggested that adaptive models are linear regression model relate indoor design temperatures or acceptable ranges of temperature to outdoor meteorological or climatological parameters. Thus thermal neutrality became a significant element of adaptation approach. Thermal neutrality is defined as the temperature which gives a neutral thermal sensation, neither warm nor cool, in the environment (Humphreys 1975) or the thermal index value (temperature) corresponding with a maximum number of building occupants voting neutral on a thermal sensation scale (Brager 1998). There are three adaptive categories: behavior adaptation, physiological adaptation and psychological adaptation (De Dear 2004). As used in ASHRAE RP-884, adaptation included all physiological mechanisms of acclimatization, in addition to all behavioral and psychological processes which building occupants experience in order to improve the adapt of the indoor environment to their personal or group requirements. Within this wide definition it is possible to clearly distinguish three categories of adaptation (Prosser 1958, Folk 1974, 1981, Goldsmith 1974, Clark and Edholm 1985).

a. Behavior adaptation

Behavior adaptation includes all consciously or unconsciously modifications people make to modify heat and mass fluxes governing the body's thermal balance. It defined adjustment in terms of three subcategories as Figure 3.2 (de Dear and Brager 1997).

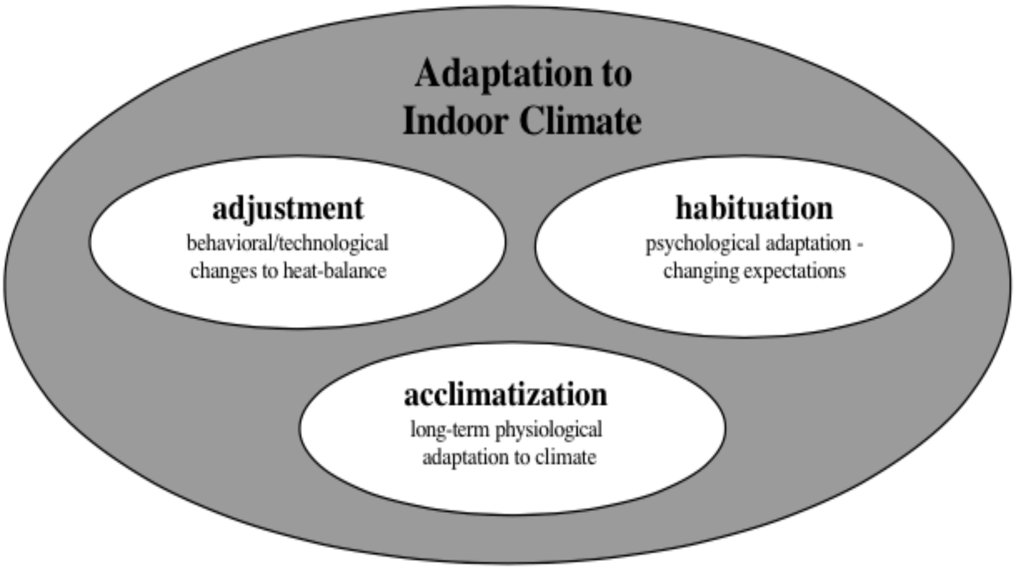

Figure 3.2 The three components of adaptation to indoor climate (Source: de Dear and Brager 1997).

Personal adjustment: adjusting to the ambient by changing personal variables, such as take on/off clothing, adjusting activity and posture, drinking /eating some hot/cold food or beverages, or moving to a different location. Among these parameters, activity level and clothing insulation are the individual parameter of the six basic parameters of decides thermal comfort. Activity level influences energy production in human body and can considerably affect the comfort level. Activity level is expressed by met: each met is the metabolic rate of a seated relaxed adult and equals 58 W/m^2 (Clark and Edholm 1985). Clothing influences human thermal sensation by offering thermal insulation that is suitable to one’s environment. It is expressed by m^2K/W or in CLO units that equals 0.155 m^2K/W.

Environmental or technological adjustment: modifying the surroundings themselves, when control is available, for instance, opening/closing windows or shades, turning on/off fans or heating, blocking air diffusers, or operating other HVAC controls, etc.;

Cultural adjustments: including scheduling activities, siestas, dress codes etc.

b. Physiological adaptation

To define the physiological adaptation comprehensively, it would include all of the changes in the physiological responses, which result from exposure to thermal environmental factors, and which lead to a gradual decrease in the strain induced by such exposure. Two subcategories of physiological adaptation are genetic adaptation and acclimation or acclimatization:

Genetic adaptation: alterations were became part of the genetic heritage of an individual or group of people, but the development of the time scales beyond that of an individual’s lifetime.

Acclimation or Acclimatization: changes in the establishment of the physiological thermoregulation system over a period of days or weeks, which is the way of response to the exposure to a variety of thermal environmental stressors. The physiological adaptation is not of fundamental importance in this context because it is caused by exposure to a stimulus, leading to a gradually declining strain from such exposure (Clark and Edholm 1985).

c. Psychological adaptation

The psychological adaptation of indoor climates refers to an altered perception of sensory information and the reaction of it. Thermal perceptions are directly and significantly elongated by people’s experiences and expectations of the indoor climate. This form of adaptation involves building occupants’ “*comfort set points*” which may vary across time and space. Relaxation of indoor climatic expectations can be likened to a psychophysics notion of habituation-chronic or repeated exposure to an environmental stressor leading to a decrease of the evoked sensation's intensity (Glaser 1966, Frisancho 1981).

Naturalness: people tend to have more tolerance to non-artificial changes occur in their physical environments (Griffiths et al. 1987). Therefore, the comfort temperature range in natural ventilated space is wider than in air-conditioned space (ASHRAE 2005). It also found by scholars that people in outdoor spaces tolerate a wide range of air temperatures the changes (Nikolopoulou and Lykoudis 2006).

Expectations and experience: People's perceptions are notably influenced by they think what the environment should be like, rather than what it truly is like (Nikolopoulou and Lykoudis 2006). Expectations and experience also can explain the difference in comfort temperature between the transitional seasons (autumn and spring). Autumn is preceded by warmer temperatures therefore people tend to be less tolerant to cold, hence the temperature in which people feel comfortable is higher than that in spring (Zrudlo 1988).

Time of exposure: Nikolopoulou and Steemers (2003) claimed that thermal perception of people in outdoor spaces influences the period of their stay. This issue is of particular importance when related to the level of activity in outdoor public spaces because level of activity can be stimulated by both large amount of people and by longer individual stays (Gehl 1996). People are able to tolerate thermal discomfort if they anticipate that their exposure to it will be brief (Aljawabra 2014).

Perceived control: Perceived control as opposed to actual control advises available choice. It is a state of being in control over a source of discomfort and according to Evans (1984) this increases tolerance and reduces people's annoyance. Therefore, when an space offers seats in the shade and others in the sun, people are expected to stay longer than if only one option was available, regardless of whether they use the other option or not. Nikolopoulou and Steemers (2003) use this theory to the research of outdoor thermal comfort and claimed that since actual control over thermal discomfort source is limited in outdoor spaces, perceived control is important in such places.

Environmental stimulation: Environmental stimulation is always has an influence in external space. It is one of the main reasons why people spend time outdoors, breaking the boredom and seeking satisfaction. When outdoor spaces offer various types of environmental stimulations, people tend to have higher tolerance to weather conditions in them (Aljawabra 2014). This leads to more people visiting the outdoor space and more time being spent in it. The reason is that neutrality does not necessarily lead to satisfactory; however, environmental stimulations such as sun or fresh air after being in the office for a long time on a warm day do (Nikolopoulou 2011b).

3.6.3. Social practices approach

The social practices approach is an approach that lies outside architectural science and even contests some of the claims that emanate from the dominant architectural science approaches to studying thermal comfort. The social practices approach does not use physical measurements, insisting that conceptions of thermal comfort developed by physical scientists fail to account for the cultural context in which definitions of comfort are created. Heather Chappells and Elizabeth Shove believe that comfort is not only decided by temperature, but also constructed by culture and convention, which is based on the report that people feel comfortable at temperatures range from 6 to 30 °C (Goldsmith, 1960; Nicol et al., 1999), as Cooper (1982a) indicates that comfort standards are '*social constructs which reflect the beliefs, values, expectations and aspirations of who construct them*'. Heather Chappells and Elizabeth Shove point to the difference between two theoretical positions of thermal comfort-one that comfort is an universally definable state of affairs, the other that it is a socio-cultural achievement-have quite different consequences for energy and environmental policy (Table 3.3).

They interviewed 13 architects, building services engineers, property developers, manufactures and regulators, and further discussed with 17 participants at a specially convened workshop to provide some insight into the ways in which comfort is currently conceptualized. The aim of this interview is to monitor thinking, identify and review ideas currently held by those actively involved in debating, shaping and making the meaning and reality of future comfort. The research suggests that the future of comfort remains fluid, contested and controversial. Heather Chappells and Elizabeth Shove believes that the range of possible responses is much wider than that currently contemplated by environmental and energy policy-makers whose first reaction when faced with the uncertainties of climate change is to probe into find the most efficiently ways to maintain of the current thermal standards.

Table 3.3 Contrasting concepts of comfort and what they mean for policy and practice (source: Heather Chappells and Elizabeth Shove).

	Comfort as a universally definable state of affairs	Comfort as a socio-cultural achievement
Theory of comfort	Heat balance model	Historically and culturally specific experience
Characteristics of comfort	Definable universal condition	Social phenomenon
How to provide comfort	Deliver specified comfort conditions	Provide opportunities in which people make themselves comfortable, whatever that means
Policy response to the challenges of climate change	Develop and promote technical fixes and so increase the efficiency with which comfortable conditions are provided	Debate and explore diverse meanings of comfort; construct new and varied infrastructures, contexts and experiences of comfort

3.7. Thermal comfort standards

The standards for thermal comfort are regularly reviewed on a basis by organizations. In European countries the current standard for evaluating thermal comfort is ISO 7730 together with EN 15251, which covers thermal comfort as well as other indoor environmental parameters (ISO 7730 2005; EN 15251 2007). CR 1752 is a technical report on ventilation that deals with the quality of the indoor climate too (CR 1752 1998). ANSI/ASHRAE Standard 55 is the standard in North America that deals with thermal comfort (ANSI/ASHRAE Standard55 2004). CIBSE is a UK standard for building's environment comfort criteria, it has developed different sorts standards and guides to determine governmental regulations and legislation. These documents appoint comfort zones in which a major percentage of occupants with given individual parameters to think the thermal environment as acceptable. Besides, the special standards of adaptive thermal comfort are introduced in this chapter. Such adaptive models have been introduced in ANSI/ASHRAE Standard 55-2010 for the evaluation of the indoor environment in naturally conditioned (free running) buildings as well as in EN 15251.

3.7.1. European Standards ISO 7730

The European standard ISO 7730 is an international standard, which has been established to access thermal comfort of indoor environment. This standard provides methods for predicting the general thermal comfort and degree of thermal discomfort or dissatisfaction of people in moderate thermal environment. In the design of new building or the existing buildings, ISO 7730 enables the determination of thermal comfort for occupants by using calculation of PMV, PPD and local thermal discomfort. It also provides methods for accessing local discomfort that caused by draught, asymmetric radiation and temperature gradients (Parsons 2001).

ISO 7730 species three different levels of acceptable classes for general thermal comfort and local thermal discomfort parameters in compliance with CR 1752 (Table 3.4), and ANSI/ASHRAE Standard 55 has proposed a similar scheme. According to the table, the different targets of thermal satisfaction are established: category A for 90% acceptability, category B for 80% and category C for 70%. These categories are an evaluator indicator of how close the indoor environment is controlled concerning to a certain set point. It regards the close control as "*denoting a superior building*" (Nicol 2009).

Table 3.4 Categories of thermal environment based on ISO 7730(2005).

Category	**General comfort**		**Operative temperature**	
	PPD (%)	PMV	Winter (1.0 clo and 1.3 met)	Summer (0.5 clo and 1.2 met)
A	<6	-0.2<PMV<+0.2	21.0-23.0	23.5-25.5
B	<10	-0.5<PMV<+0.5	20.0-14.0	23.0-26.0-
C	<15	-0.7<PMV<+0.7	19.0-25.0	22.0-27.0
Category	**Local discomfort**			
	Vertical air temperature difference		Caused by warm or cold floor	Radiant asymmetry
A	<3		<10	<5
B	<5		<10	<5
C	<10		<15	<10

3.7.2. ASHRAE Standards 55

American society of heating, refrigerating, and air conditioning engineers (ASHRAE) standard 55 is developed for thermal environmental conditions for human occupancy. The main purpose of the ASHRAE-55 standard is to specify the combinations of four indoor thermal environmental parameters (temperature, thermal radiation, humidity, and air speed) and two personal parameters (metabolism rate and clothing insulation) that will produce the acceptable thermal environmental conditions to a majority of the subjects. This standard has a close agreement with ISO 7730 Standard 2005, in which the PMV/PPD calculation and adaptation criteria have been developed in this standard. The revised version of this standard defines the acceptable range of indoor thermal environmental conditions for a majority of occupants, but accommodates an ever incremental variety of design solutions intended both to provide comfort and to respect the current essential for sustainable buildings (ANSI/ASHRAE Standard 55-2010).

In the 1990s, ASHRAE asked deDear and Brager (1997) to conduct a specific research project to collect information from many different field studies performed in several countries: Thailand, Singapore, Indonesia, Pakistan, Greece, Canada, Australia, UK and USA. This study showed that subjects' thermal responses in free running spaces majorly depend on the outdoor air temperature, which may different with the thermal responses of subjects in HVAC buildings. This difference occurred by the different thermal experiences, changes in clothing, control availability, and transfers in occupant expectations. Therefore, ASHRAE suggested a selectable method for deciding acceptable thermal conditions in naturally conditioned (free running) spaces. These spaces must have no mechanical cooling system and equipped with operable windows. This method introduces the equation as follows, which resulted from more than 21,000 measurements taken around the world, largely in office buildings:

$$\mathbf{T_{CO} = 0.31T_{ref} + 17.8\ ^{\circ}C} \qquad \textbf{(1)}$$

where T_{ref} is the prevailing mean outdoor air temperature (it is for a time period between last 7 and 30 days before the day in question) (ASHRAE 2010). This equation is only used for summer when the outdoor temperatures is ranged from 5 °C to 32 °C.

Figure 3.3 shows the relevant comfort bandwidths based on equation above, it includes 80% and 90% acceptability comfort ranges of occupants. Typical application is the 80% acceptability limits when a higher standard of thermal comfort is desired is 90% acceptable limits. Moreover, the activity level is determined as normally sedentary activities which being less than 1.3 met.

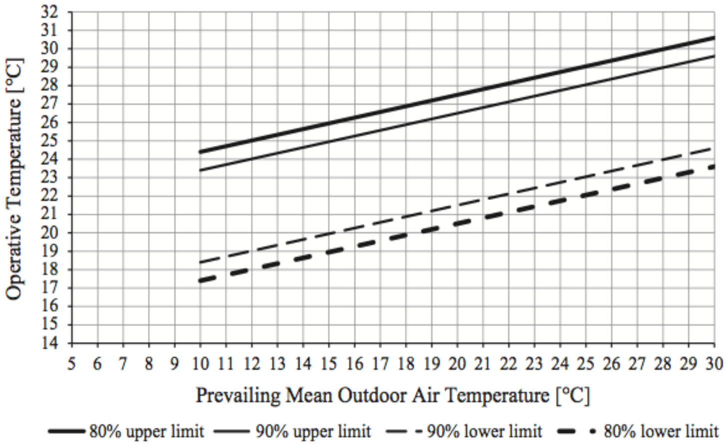

Figure 3.3 Comfort bandwidths of ASHRAE 55-2010.

3.7.3. Chartered Institution of Building Services Engineers (CIBSE, UK Guideline)

CIBSE was founded in 1985 and the aim of its standards is to promote the art, science and practice of building services engineering for the benefit of all, and the promotion of education and research in building services engineering (CIBSE website). CIBSE has developed different sorts standards and guides to determine UK's governmental regulations and legislation. CIBSE Guide A is edited not only to improve the design of building environment but also provides the recommendation for building's environment comfort criteria (Nasrollahi 2007). It is a reference source for designers of low energy sustainable buildings (CIBSE Guide A 2006). At the point of defining acceptable thermal comfort criteria, the CIBSE Guide A (2006) is in agreement with ASHRAE Standard 55 (2004) and ISO 7730 Standard (2005). Both thermal comfort models; heat balance model and adaptive model are covered in this standard. Besides, CIBSE also give more space type's reference criteria of comfort temperature range than ASHRAE and ISO 7730 standards.

3.7.4. EN15251

The European Standards EN 15251 and its contents are described by Olesen et al. (2006) and Olesen (2007). The majority content of this standard is overlap with the above standards for thermal comfort. This standard specifies the way of establish environmental input parameters for the non-industrial buildings (i.e. single family houses, apartment buildings, educational buildings, offices, etc.) for design and energy performance calculations (CEN 2007). The guidelines of thermal comfort from this standard are based on the Smart Control and Thermal Comfort project (SCATs), which is commissioned by the European Commission. In this project, there are 26 European buildings in France, Sweden, Greece, Portugal and the UK was surveyed. The survey was last for three years and covered free running, conditioned and mixed-mode buildings (McCartney 2002). Table 3.5 shows the developed adaptive algorithms for each country participated in the survey.

Table 3.5 Adaptive comfort algorithms for individual countries (Source: McCartney 2002).

	Adaptive control algorithm	
Country	T_{rm}≤mu °C	T_{rm} >10 °C
All	22.88	0.302*T_{rm}+19.39
France	0.049*T_{rm}+22.85	0.206*T_{rm}+21.42
Greece	NA	0.205*T_{rm}+21.69
Portugal	0.381*T_{rm}+18.12	0.381*T_{rm}+18.12
Sweden	0.051*T_{rm}+22.83	0.051*T_{rm}+22.83
UK	0.104*T_{rm}+22.85	0.168*T_{rm} +21.63

Based on SCATs project, the European Committee for Standardization (CEN) issued EN15251 in 2007, and the following equation is for naturally ventilated buildings:

$$\mathbf{T_{CO} = 0.33T_{rm7} + 18.8\ °C} \qquad \mathbf{(2)}$$

where T_{co} is comfort temperature, and $T_{rm}{}^{7}$ is the exponentially weighted running mean of the daily outdoor temperature of the previous seven days based on the equation proposed in 1978 by Nicol, Humphreys and McCartney (2002). It showed a more accurate prediction given by considering the exponentially weighted running mean outdoor temperature:

$$\boldsymbol{\theta = (1-\alpha)(\theta_{ed}-1 + \alpha\theta_{ed}-2 + \alpha^2\theta_{ed}-3 \cdots)} \qquad \mathbf{(3)}$$

0.8 for the constant α in Eq. (3) is recommended and leads to:

$$\mathbf{T_{rm}{}^{7} = (T-1 + 0.8T-2 + 0.6T-3 + 0.5T-4 + 0.4T-5 + 0.3T-6 + 0.2T-7)/3.8} \qquad \mathbf{(4)}$$

In this standard, the accepted deviation of the indoor operative temperature from the comfort temperature is divided into four categories (Table 3.6). Figure 3.4 presents the comfort bandwidths based on the comfort algorithm and the range permitted for different percentages of acceptability.

Table 3.6 Suggested applicability for the categories and their associated acceptable temperature ranges (Source: CEN 2007).

Category	Explanation	Limit of deviation (°C)	Range of acceptability (%)
I	High level of expectation for very sensitive and fragile users (hospitals)	±2	90
II	Normal expectation for new buildings	±3	80
III	Moderate expectation (existing buildings)	±4	65
IV	Values outside the criteria for the above categories (only in a limited period)	>±4	<65

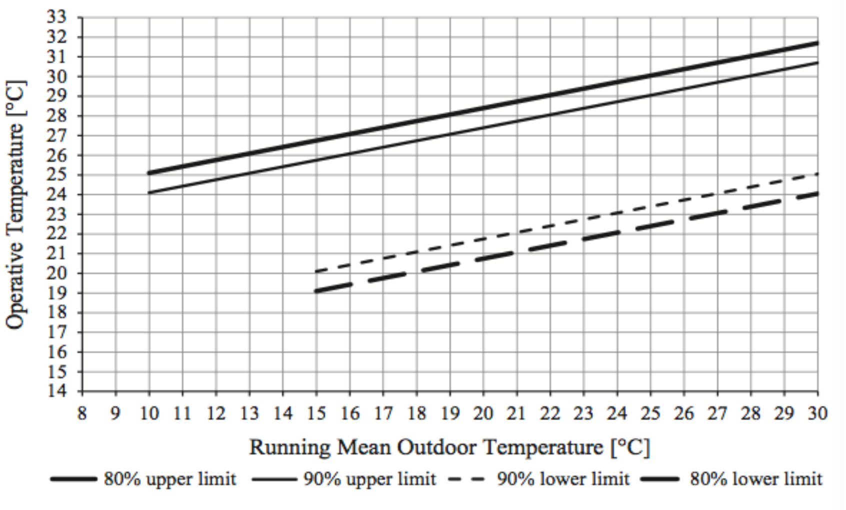

Figure 3.4 Comfort bandwidths of EN15251 (Source: CEN 2007).

3.8. Thermal comfort in transitional spaces

The rapid development of buildings with integrated functions improves the development of transitional space, as the imitation of modern architecture style with widely used glass, especially in office and commercial buildings. However, the extensive use of glass with less consideration for the climate has created the fully artificial indoor environment. Transitional spaces in these buildings are generally located in front of the building and with a large façade of glass. The artificial indoor environment use of electrically driven ventilation and heating systems, this can result in the excessive unnecessary energy consumption for heating and cooling the buildings. To investigate the problem of how to improve the comfort and energy consumption condition in transitional spaces, thermal comfort level of the occupants is an important factor that needs to be considered. This section gives a review of key studies dealing with the comfort research in different type of transitional spaces. It also covers the influence of physical environment on thermal comfort and main studies dedicated to the behavior aspects of transitional spaces' thermal comfort in other climates.

From the literature review, it was found that compared to full continually occupied indoor environment, transitional environment has received little research attention in the field of thermal comfort. There appears to be three main reasons as follows: 1) people in developed countries where most research has been conducted heretofore, spend a larger proportion of their life indoor rather than outdoor. 2) in the work environments, thermal comfort is assumed to related to productivity directly, and so it is assumed to be economically important for employers to define and provide preferred thermal condition for employees. 3) the outdoor and semi-outdoor thermal environment is considerably more difficult to engineer and control than its indoor counterparts (Spagnolo, 2003). However, despite these obstacles there are many reasons to further the understanding of thermal comfort in transitional space. Firstly, many recreational activities of important commercial value are conducted in transitional spaces (e.g. cultural events, exhibitions, leisure activities). Secondly, increasingly more weather-sensitive business in the service sector, such as restaurant and cafes, are expending their operating space to transitional spaces. Thirdly, improve energy saving of transitional space and other components of the building.

According to pervious studies (de Dear 1993, Nagano 2005), to adjust sensation steady state and accommodate the environment change, the least time period of occupants stay in the same environment is 20 minutes. It means that people whose just stay in transitional spaces for a short time would not achieve a thermally steady state. The regular thermal comfort standards, such as the ISO 7730 and ASHRAE Standard 55, have not been applied to transitional spaces. However, a number of people stay longer than 20 minutes in some kind transitional spaces like indoor transitional spaces with a close relationship with fully occupied spaces, which are researched in this study. Beside, it is accepted that thermal comfort in transitional spaces need to be investigated due to such spaces are commonly encountered in daily life.

The literature review mainly includes four methods of researching thermal environment, thermal comfort and energy saving in transitional space: measurements, field study, laboratory study and simulation. Measurement is always uses for survey the thermal environment of transitional space to improve the physical environment of it. Field study is a common approach used by the scholars to investigate thermal comfort and people's thermal perception in the "*real*" world. Another approach for studying thermal comfort in transitional spaces can be laboratorial aiming to study people's thermal comfort by collecting data of the environment variables (air temperature, mean radiate temperature, humidity, air movement speed) and to statistically correlate the space environment conditions to the subjective thermal sensation of the people for a given clothing design. Due to empirical approach has an applicable limitation to the climatic conditions of the experiment and the clothing of participants and cannot be extended over the range of these experimental parameters. So some scholars choose a theoretical modeling and simulation approach because its advantages in that the model can be applied for a variety of active human and transitional conditions.

3.8.1. The physical measurement approach

Tsujihara (1998a, 1998b, 2004) investigated air temperature distribution inside an enclosed arcade located at the mild and sunny climate area. It indicates that air temperature in the arcade was a little higher than the outdoor temperature and vertical temperature showed a temperature slope from the upper part to the lower part of the arcade space due to solar radiation and ventilation rate. Beside, the thermal environment inside the arcade is influenced by the solar radiation.

Chun et al. (2004) conducted a research to investigate the thermal comfort in the space in between outdoor and indoor. This research combine the measurements and experiment approach, it revealed that transitional spaces' physical environments varied according to the space types and architectural characteristics. The typical behaviors in transitional spaces are different with the sedentary behavior in offices and homes as observed were walking, standing, and sitting. This study also verified that the most efficient architectural shape of transitional spaces is related to the regional climatic conditions, and PMV cannot be used for predicting thermal comfort in transitional space because of the unstable physical environment in transitional space and dynamic MET value.

Kaynakli (2005) suggests that thermal comfort conditions are very difficult to control in the certain volumes, especially in the transitional spaces like lobbies and corridors that receive direct sunlight. This difficulty increases especially in warm or hot seasons, when these volumes reach to a higher temperature than the smaller controlled volumes.

Kim et al. (2006) claimed that thermal discomfort and poor indoor air quality could arise from certain physical characteristic of arcades. The comparison in this study is among the indoor environments of three Korea transitional markets after the streets of these markets have been transformed into arcades to finds the design elements affecting indoor environment that includes actual temperature, humidity, air velocity, CO/CO_2 and etc. The results show that the indoor environment of the arcade wad greatly influenced by the factors such as shape and size, roof materials and ventilate opening.

Lin et al. (2006) evaluated the effects of passive thermal strategies on bus stations by field of measurement in Taiwan. It was founded the Sky View Factor (SVF) has the significance influence on human thermal comfort. As a consequence, it was strongly emphasized taking into account the better-shaded spaces at semi-outdoor spaced in sub-equatorial climate.

3.8.2. The field study approach

Jitkhajornwanich et al. (1998) conducted a field study that investigated transitional spaces in buildings in Bangkok, Thailand. This study compared thermal comfort conditions among four groups of people: two groups moving from outside environments into air-conditioned and naturally ventilated transitional spaces separately, and another two groups going outdoors from air-conditioned and naturally ventilated transitional spaces separately. By reference to the whole sample group, they informed that the neutral temperature in cool season is 27.1 °C, and in the warm season is 26.5 °C; and the preferred temperature in the cool season is 21.6 °C.

Potvin (2000) conducted a survey work in arcades and proposed a theoretical quantification of environmental transitions possible for occur when varying solar radiation and wind exposures. It indicates that of the three examples of urban elements as passages, courtyard and arcades, the arcade is the most preformat in terms of the difference of temperature between the ambient conditions and the interior. This survey indicates that the arcade allows for a progressive increase or decrease in temperature when enter or exit it, which is contrary to the passage or courtyard elements. This particular thermal behavior that is due to the spatial configuration and degree of opening of the arcade to the ambient environment. The arcade favors the subconscious environmental adaptation, which decrease the discomfort of pedestrian results from the abrupt environmental changes. Therefore the arcade encourages environmental diversity in a way without impede the comfort of the user. However, thermal behavior of arcade is determined by the spatial configuration, orientation, and balance between opaque and transparent surfaces.

Jitkhajornwanich and Pitts (2002) conducted an another similar field study in Bangkok, four groups of building occupants were identified moving either inwards or outwards between the outdoors and the indoor environments that either air-conditioned or naturally ventilated. The results of the analysis the thermal rating response for expectation, sensation and preference subjects indicated that: 1) the thermal conditions in the cool season proved more comfortable than those subjects in the warm seasons; 2) The effect of air-conditioning on the groups of "*from outdoors to air conditioning environment*" and "*from air conditioning environment to outdoors*" appears to lead to acclimatization and a fondness for a controlled cooler environment and the expectation of an discomfort warm sensation when encountering the outdoor environment; 3) The neutrality thermal temperature of the subjects should be between 26.1 °C and 27.6 °C in spite of the preferred temperature is lower than 25.0 °C; 4) The Pearson's Correlation Coefficients indicate that positive correlations is occurred between expectation and sensation responses and the negative correlation is occurred between preference and sensation responses. The highest positive correlation of expectation and sensation are occurred when subjects stay in the naturally ventilated environments, and the high negative correlation of sensation and preference are occurred when subjects stay in the sheltered indoors; 5) A proposed method of adding values of standardized mean thermal responses is explaining the subjects' past and present thermal experience (using thermal expectation and thermal sensation votes), as well as the possibility for compensation in the thermal environments between neutrality and preference (using thermal sensation and thermal preference votes); 6) This study verified the exists of potential to improve occupant comfort by using transition zones to alleviate reaction to changes in environmental conditions. There are two benefits of this potential: reducing energy needs of a transition space to conditioned itself and the potential of reducing energy use to condition the main internal occupied spaces of a building.

Spagnolo and de Dear (2003) conducted a field study of thermal comfort in outdoor and semi-outdoor (exposed to the outdoor environment in most respects but included man-made structures that moderate the influences of the outdoor conditions) environment in subtropical Sydney Australia, subjects' thermal comfort in outdoor and semi-outdoor were investigated by a questionnaire and a comprehensive package of micro-meteorological instruments. They found that thermal neutrality in terms of thermal comfort index OUT_SET of 26.2 °C was significantly higher than the indoor SET counterpart of 24 °C.

Nakano (2003) conducted field and laboratory experiments in semi-outdoor space and office to investigate the influence of environment conditions on thermal comfort. It is confirmed that thermal conditions of semi-outdoor environment were cast a significant influence on physiological parameters of a person passing through. However, in the succeeding environment, the psychological effects were negligible 30 minutes after transition. In additionaly, occupants in semi-outdoor environments designed for arbitrary occupancy were able to achieve comfort in the range 2 to 3.5 times wider than that predicted by the thermal comfort index. The office environment was limited with the adaptive opportunity, therefore occupants in it were mainly relying on the adjustment of thermal environment to achieve comfort, and they were found to rate the comfort conditions more severely than the comfort range predicted by the thermal comfort index.

Chun and Tamura (2005) conducted a laboratory and a field study to investigates people's thermal comfort during walking activities through urban corridors, shopping streets and open-ended passageway. They set 20 designated points in the field and in specific rooms in the control chamber. The results revealed that the previously experienced temperatures always determined thermal comfort at the following point in sequence; thermal comfort in transitional spaces can be adapted quite widely compared to comfort inside of buildings. Thermal comfort along with the experimental courses was assessed by averaging the temperature of a course.

Nakano et al. (2006) were carried out a filed study at Station T which is a large station in Tokyo to investigate thermal environment of it. It appeared that the thermal environment in concourse is closely related to passenger's comfort. The results indicate that the thermal environment in the concourse was not acceptable enough for passengers. At most place and time, thermal environment in concourse was easily over the upper limit of acceptable range for passengers as 32°C in SET*. Besides, although thermal environment in the concourse was widely distributed, passengers stayed in the place relatively uncomfortable for the reasons of meeting people. To improving thermal environment and comfort in the station, the detail of thermal environment and occupancy characteristic of passengers should be considered.

Hwang and Lin (2007) conducted field survey of thermal environment in outdoor and semi-outdoor space, because providing thermally comfortable is essential to multi-functional public spaces such as museums, cultural centers and university campuses. They suggested individuals may have reduced expectations regarding the thermal comfort of outdoor environments because the difficulty of controlling the thermal conditions. The results show that people in semi-outdoor and outdoor environments have a higher toleration of thermal comfort than people in naturally ventilated indoor environments. Also it was demonstrated solar radiation has the most influential effect on subjective thermal sensation than air movement have.

Hwang et al. (2008) conducted a field study in a transitional space to investigate the different thermal response of guests who experiencing step changes in temperature when entering the space from outdoors. Besides, it also studies the thermal response of staff present in the thermally steady state and providing a thermal comfort range for the transitional space. The results of comparing the thermal response between guests and staff revealed that experiencing a sudden air temperature change led to a enhancement in guest aspirations as a way of treating with thermally uncomfortable conditions rather than an accommodation in the requirements for thermally comfortable conditions. Its also found guests and staff have similar requirements for a neutral thermal temperature, preferred thermal temperature and comfortable temperature range. Otherwise, in this and previous study conducted in Bangkok, Thailand, it notably showed that the thermal requirements for transitional spaces were similar to the thermal requirements for office environments.

Kim et al. (2008) carried out s field study in four Korea traditional markets with different market structure and arcade form, 156 market occupants were surveyed when air temperature and humidity levels were measured simultaneously, then numerical simulations were performed in order to evaluate 18 different design approaches related to the enclosed arcade market. The results from measurements revealed that the indoor temperature was significantly affected by roof transmittance while the results of simulation showed that the transmittance of the roof material was the major design element that thermally affected indoor climate, followed by the ventilation opening and the roof height and type. It also found that the impact of ventilation opening on the indoor thermal environment increased as the increasing of the roof transmittance, and that created a greater difference of temperature between the interior and exterior climates on sunny summer days.

Pitts et al. (2008) indicates that the difference actually exist between occupants' reaction of thermal stimuli and thermal prediction (PMV) in transition spaces. Significant proportions of occupants appear a higher acceptation level of the thermal environment than the thermal prediction rate. This further evident that PMV limits for transition spaces can be expanded beyond the conventional indoor limit of ±0.5, which would contribute on the reductions of heating and cooling demand in winter and summer. This is coincidence with the truth that transition spaces using more energy per unit area or volume than many other rooms in a building. This study also suggested that to make use of the benefit, more buildings could designate as transition spaces or buffer areas.

Kwong and Adam (2009) conducted a field study in the enclosed lift lobby of an educational institution in Malaysia. The aim of this study is to identify the thermal environment of a totally enclosed transitional space in an educational institution and occupants' perceptions on thermal comfort in a tropical climate. This field study covered objective subjective assessment and measurement and Computational Fluid Dynamics (CFD) simulation. The results of comparing empirical and predicted outcomes showed a higher thermal satisfactory rate, it means that most of the subjects were satisfied with the thermal environment in the enclosed lift lobby. In terms of thermal preference, it was directed towards a cooler environment. The predicted results showed impartial agreement with the empirical results that with minor differences between the two results for the thermal and air movement conditions. Besides, a lower thermal expectation factor in PMV index is required for transitional spaces' thermal environment.

Kwong and Adam (2011) conducted another field study in the enclosed lift lobby of a Malaysia educational institution. A comparison was made on the percentage of thermal sensation, thermal preference, thermal acceptability and general comfort votes obtained under the 26 °C air-conditioner temperature setting. The results indicates that the human thermal perception in the enclosed lift lobby of tropical climate would be directly relative to the level of human occupancy, in addition, any sudden temperature change could lead to thermal discomfort of occupants. It also found that the respondents generally preferred to have cooler environment rather than have warmer environment, and comfortable temperature can be obtained even with a higher air conditioner thermostat setting.

Pagliarini and Rainieri (2011) explored the thermal comfort condition of occupants in the semi-outdoor space covered by glass in Italy. It indicates that people seated and stand evaluates their thermal condition in a same way. However, comparing to the stand people, seated people are more sensitive tot the solar radiation and insensitive to the air movement speed.

Hui and Jiang (2014) conducted a filed survey to investigate the thermal performance of semi-opened and fully enclosed transitional spaces in HKU and subjective seasonal variable responses. This study provided the basic knowledge of transitional spaces and evaluates the current thermal comfort theories. The results reveal that semi-opened spaces are more easily influenced by variable weather station than fully enclosed transitional spaces. It was found that the current comfort standards and criteria are not designed for transitional spaces, which evident by the results that people can accept wider thermal environment in transitional spaces. The research proposed using a modified adaptive comfort model to examined thermal comfort ranges for transitional spaces and this would contribute to the possible changes to the current design guidelines and standards. Several energy saving strategies such as passive design, hybrid ventilation and flexible HVAC controls were proposed in this study to achieve more energy efficient and healthy buildings in the future.

Kotopouleas and Nikolopoulou (2014) conducted a survey work in airport terminals to evaluate thermal perception of passengers and staff. The difference of dressing code and activity, along with dwell time and overall expectations between this two group of people are significantly and reinforced by the diversity of spaces and the heterogeneous functions across the different terminal zones, which results in thermal comfort conflicts and often in energy wastage. The result clearly reveals a significant difference of thermal requirement between passengers and staff, as passengers prefer cooler temperature than staff. It was found that passengers have a higher tolerance of the thermal environment when employees' thermal tolerance is lower due to their limited adaptive capacity. This research highlight the complex nature of thermal comfort in airport terminals where significant proportions of occupants state that their desired thermal state is other than neutral, and it also highlight the multitude of design and operational characteristics in airport terminals influence the indoor environment of them.

Gloria Vargas (2016) explores a dynamic and transient condition repeated in people’s daily routines to evaluate their short-term thermal history and thermal comfort perception in the real condition by the field of questionnaire surveys and simultaneous climatic measurements in a moderate climate. The lobby areas were investigated as a space modifies people’s thermal perception when they move from the outdoor to the indoor environment. It was found that a seasonal thermal adaptation affecting occupants’ short-term thermal perception and change their thermal comfort perception and preferences rapidly when they moving from one space to another. This research was also found that there are three thermal patters as flat, sudden and irregular that work together with the temperature differences to change people’s short-term thermal history.

3.8.3. The laboratory approach

Nagano et al. (2005) through their laboratory experiments in Japan informed that there were differences in the neutral temperature even at 50 minutes after step changes in air temperature, due to the thermal environments before the temperature changes.

Zhao (2007) performed experiments in the controlled chambers in Beijing, China, to investigate the transient thermal environment, and certificated that during the accommodation period, occupants would be over-sensitive to thermal sensation when the different of air temperature between two chambers is exceeded 5.0 °C.

Wu and Mahdavi (2014) investigated thermal comfort assessments under transitional states in the laboratory building. The thermal sensation and comfort evaluations of responses were assessed before transition and that is immediately after the spatial transition and after a short period of adaptation. The results indicates that changes in subjects’ thermal sensation vote subsequent to a thermally concerned transition from one room to another room, are consistent with the temperature difference between the two rooms. But the transition-related changes in thermal comfort vote are more consistent with a proposed new measure of the “*thermal distance*” between these two rooms, namely the effective temperature difference.

3.8.4. The simulation approach

Kaynakli and Kilic (2005) established a thermal interaction mathematical model between human body and environment, and under the transient conditions, the effect of clothing and air velocity was examined. The developed model has separated human body to 16 segments and took into considering the local discomforts. Using the model, thermal comfort indices were calculated such as changes in the sensible and latent heat losses, skin temperature and wittedness. In a hot environment potential heat loss increases by the way of sweating. Because of comfort sense goes worse when skin wetted over. Especially, wettedness reaches maximum level at feet and pelvis skin. Sensible and potential heat losses rise and the skin temperature and wettedness decrease with increasing air velocity.

Bouyer et al. (2007) conducted a study to address thermal assessment of outdoor and semi-outdoor environments by using the thermal index PET (physiological equivalent temperature). They use the case of a semi-outdoor stadium to assume on the thermo-physical phenomena as well as geometric computations. PET is used to show the thermal comfort condition caused by wind velocity directly as a chart of different cases. PET maps show a lot of information but they should not be regarded as ’’absolute’’ results.

Pitts and Bin Saleh (2007) test four basic building layout of transitional space to investigated energy saving potential by study if more flexible defining approaches of thermal comfort in transition spaces suit to the building design. The results shows an extensive opportunity for energy saving and which can be quantified as 6% correspond to the variation of control temperatures set point by ±3 °C and 10% if a ±5 °C variation is permitted. This study considering the potential practical significance to the building industry, especially in the current climate of energy uncertainties, which is significant at the stage of making the irreversible decisions about basic layout and circulation with considerable implications for future operational costs.

Ghaddar et al. (2011) suggested that the requirement of modeling approach including the change of clothing insulation due to air movement and ventilation, and requires the determination of the amount of microclimate air recovery for various clothed body segments as function of external body movement and air velocity. He further explained that modeling approach for extending current knowledge of human thermal comfort response in transitional spaces is insufficient in literature, which is result from the complication of the interaction among the clothed human and environment and the large number of environmental, physical, physiological, clothing properties and the design factors affecting such interaction.

Taleghani et al. (2014) used modeling and simulation analyses the effects of transitional spaces' energy performance and indoor thermal comfort of low-rise dwellings in the Netherlands at present and projected in 2050. To investigate the need for innovative spaces that can provide thermal comfort and energy efficiency is also increasing. This analysis were used the four climate scenarios for 2050 from the Royal Dutch Meteorological Institute (KNMI). Including a courtyard within a Dutch terraced dwelling showed an increase in annual heating energy demand but a decrease in the number of summer discomfort times. An atrium integrated into a Dutch terraced dwelling decreased the heating demand but increased the number of discomfort hours in summer. Analyzing the monthly energy performance, comfort hours and the climate scenarios indicated that using an open courtyard from May through October. Besides, an atrium or a covered courtyard, in the rest of the year establishes an optimum balance between energy consumption and summer comfort for the severest climate scenario.

3.9. Summary

This chapter reviewed basic theory of thermal comfort and related research approaches, in addition to the related research of thermal comfort in transitional spaces. The literature has shown three different approaches to thermal comfort: the heat balance approach, adaptive approach, and social practices approach. The heat balance model is more accurate when predicting thermal comfort in air-conditioned building than naturally ventilated building. The adaptive model is more accurate in naturally ventilated buildings because it takes into account the effect of occupants' adaptive behavior to achieve thermal comfort. The heat balance approach and adaptive approach are commonly used in architectural science and the related standards for these two approaches were also introduced in this chapter. The studies driven by social practice are a reminder that findings provided through physical measurement based on accepted standards need to be considered in the social and cultural context in which they are carried out. They highlight the need to question accepted definitions to ensure they can explain how people actually feel and respond to thermal and other conditions in a given space. The relevant thermal comfort standards are listed in this chapter and the last section introduces the research on thermal comfort in transitional spaces and under transient environment.

Chapter 4 Methodology

4.1. Introduction

This chapter explains the methodology used in this research, which is based on field surveys. The methodology used for current study is the field study of thermal comfort of the significant advantage it offers for studying specific environments. It means that the results of the method can be directly applied to similar environments. Compared to other approaches, which depend on laboratory or climate chamber conditions, field surveys study the subjects in the "real world" that they can experience all of the full complex conditions. Two methods selected in this research to achieve the aims and objectives of this research are: questionnaires and physical measurements. The method of observation also plays a part in the filed study, but to avoid subjects feeling , confronted, it only works as an informal method to help the researcher get better quality data. For example, some subjects omitting garments like scarves when indicating their clothing insulation in a survey, can be added by the researcher if directly observed and to correct the questionnaire. Qualitative research involves a variety of quite different approach, it conducted to gain in-depth knowledge of underlying reasons and motivations. However, qualitative research also has limitations including the potential negative impacts of process of interaction of interviewer with interviewees. To avoid the research built-in bias and interviewees were leaded, researcher was used the neutral language with interviewees and avoided lead them towards providing specific choice.

The first part of this chapter provides a detailed introduction to the field study designed to measure thermal environmental parameters, the lighting environment and to collect occupant data using a questionnaire, focused on occupants' thermal perception. The measured environment and the equipment used are described. The second part gives a short introduction to the pilot study carried out before the actual study, and makes a detailed explanation of improvement from pilot study.

4.2. Design of field study

The previous review chapter of occupants' thermal sensation identified that in order to be able to explore the influence of personal preference on thermal environment and transient physical character on thermal environment, confounding factors need to be carefully considered in the analysis, and to this end a study exploring people's thermal perception is designed in this chapter. This field survey using thermal environment measurement synchronized with the questionnaire interview, which was curried out at three public buildings with indoor transitional spaces in Cardiff. These are three air-conditioned and natural ventilation transitional spaces in public buildings, two of them are educational institutions and another one is cultural institution. All of these three transitional spaces are connecting with the main doors of these buildings and always with a big façade of glazing, in addition to connecting or containing café, bars or store areas in them. These three transitional spaces are similar multiple-functioned as passing through, resting, eating and drinking, meeting, watching performance, study or working and so on. Each occupant in these three indoor transitional spaces has no control over the environmental condition in transitional spaces when they occupied. It means they have no adaptive opportunities on window and door position, and temperature control of heating and cooling system.

Surveys conducted during summer and winter separately, with a majority performed from January to February and July to August. To ensure that the visitors could experience an obvious temperature change when stay in indoor transitional spaces. Each set of measurements was carried out during the period of occupants' survey work to allow comparison between the two types of data. Measurement and questionnaire survey at each site lasts for 6-8 days in each season.

4.3. Physical measurements

4.3.1. Microclimate variables and equipment

Surveys of three transitional spaces are required so that the appropriate characteristic dependencies can be observed, recorded hence analyzed and evidenced. For a building this typically lasts one year to capture the effects of heating season and cooling season. In this study, a total of three transitional spaces and their associated 759 occupants were monitored and surveyed in two observation periods were classified by season as summer and winter.

Physical measurement is a traditional and necessary step for collecting climatic and internal environment data. Several spots measurement was conducted in the transitional spaces in public buildings. Thermal comfort is strongly related to the thermal balance of the body (Fanger 1972, McIntyre 1980, Gagge 1986). This balance is influenced by: 1) Environmental parameters like: air temperature (T_a) and mean radiant temperature (T_r), relative air velocity (v) and relative humidity (RH)； Personal parameters like: activity level or metabolic rate (M) (units: 1 met = 58 W/m^2) and clothing thermal resistance (clo) (units: 1 clo = 0.155 $m^2.K/W$). The physical measurement in transitional space mainly including those four environment parameters: air temperature, mean radiant temperature, relatively humidity and air speed.

Indoor air temperature (T_{ai}): The indoor air temperature was measured by AREXX TSN-TH70E - Wireless Temperature and Humidity Sensor temperature sensor (Figure 4.1 a), located in indoor transitional spaces at 1.0m-2.0m above the floor, avoiding direct sunlight. This temperature measurement at one height, instead of at three different heights (ISO 2001), was considered to be adequate, since a three different height experiment measured was did and the result of each height was quiet similar. To measure the air temperature influence participants' thermal comfort more accurately, a handhold Hot Wire Anemometer RS327-0640 is a used measuring air temperature closer participant than the sensor fixed on wall (Figure 4.1 b). It was hold about 1.0m above floor level, 0.5-1.0 meters away from the occupant, so as to avoid the effects from the heat generated from people's bodies and breathing. This measurement enabled a comparison between air temperature and mean radiant temperature for the monitored transitional space.

Mean radiant temperature (T_r): Mean radiant temperature was determined by conversion of the globe temperature data measured using a 150mm diameter globe thermometer. The indoor globe temperature was measured by a HOBO TMC1-HD temperature sensor surrounded by a blackened, 40mm table-tennis ball, and the measured data was recorded by a HOBO U12-012 data logger (Figure 4.1 c). This method has been recommended for assessing the warmth of a room with low air movement, due to the rapid response and convenient size of a table-tennis ball (Humphreys, 1977). In this study the globe temperature sensor was located in the main activity area of transitional spaces. Before being used for field measurement, all HOBO TMC1-HD probes had been calibrated at 20°C by the equipment supplier. In addition, the globe temperature sensors thus created were calibrated against a manufactured 40mm globe temperature sensor (of accuracy ±0.2°C) by the Grant Instruments, and were shown to give measurements within 0.2 °C.

Operative temperature (T_o): Operative temperature is the combined effect of the air and mean radiant temperatures, represented in a single value. It is a weighted average that depends on the heat transfer coefficients by convection and radiation at the clothed surface of individuals. Operative temperature can be calculated with sufficient approximation as the mean value of air temperature and mean radiant temperature when the relative air speed is small (<0.2 m/s, 40 fpm) or when the difference between mean radiant and air temperature is small (<4°C, 7 °F). For higher precision and other environments, operative temperature can be calculated by the equation (1):

$$\mathbf{T_{op}=\mathit{A}T_a+(1-\mathit{A})T_r} \qquad \textbf{(1)}$$

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 air speed (V_r) (Table 4.1).

Table 4.1 The value of A according to the different relative air speed value (Source: ASHRAE 55-2010)

Vr	<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

Indoor relative humidity (RH): According to the size of the candidate measure space, there are 2-4 sensors (Figure 4.1 a) used to measure the indoor thermal conditions. The air temperature and relative humidity is measured use a same sensor, this sensor is a solid-state device, which changes its electrical characteristics in response to extremely small changes in humidity. Air temperature determines heat flow between the body and air, it is measured as the internal temperature of a hollow sphere exposed to environment. The temperature and humidity values record is then transfer into the computer connect to the receiver.

Indoor air movement speed (AS): In the study, Hot Wire Anemometer RS327-0640 is used measuring indoor air movement speed around participants which effects on thermal environment around them (Figure 4.1 b). This equipment used to measure wind speed with the problem of directionality because a unidirectional instrument is not the best recommendation for this kind of field study. The omnidirectional hot-wire anemometer would be better for measuring wind speed (Hwang et al. 2008, Nikolopoulou and Lykoudis. 2006) and considering the equipment specifications described in the ISO 7726 standard. To avoid this defect, bubble and spray direction test were used in this research. Measurement devices used in this work were carefully positioned based on preliminary evaluation and observation of the bubble or spray flow direction, for example, adjust the equipment position according to the estimation that wind came from the narrow draught corridor caused by the main entrance doors, and spray test evident that. Nicol et al. (2012) suggest that different instruments to measure wind speed have different advantages and disadvantages, it is need to be selected very carefully based on the space that is being measured and available budget. EN ISO 7726 (2011) indicates that it is possible to use a hot-wire anemometer after a test of direction in the space when it is known that the wind speed is unidirectional.

Outdoor (thermal environment) air temperature (T_{air}): The outdoor air temperature was measured by a DELTA-T WS-GP1 weather station located on the roof of the building of Architecture School of Cardiff University. To minimize the effect from the heat extracted from the building on the temperature measurement, the weather station was mounted 3 meters higher than the roof level. Prior to the field measurement, the equipment manufacturer had calibrated the temperature sensor. Furthermore, its temperature measurement was compared annually with one calibrated DELTA-T WS-GP1 weather station, and 100% measurement variations were within ±0.2°C. In the case study buildings, survey works were occurred between 08:30 am and 19:00 pm, hence the outdoor air temperatures at these times were recorded. Averaging these values gave a good estimate of the external air temperature at the time when survey conducted and its influence on the interior temperature.

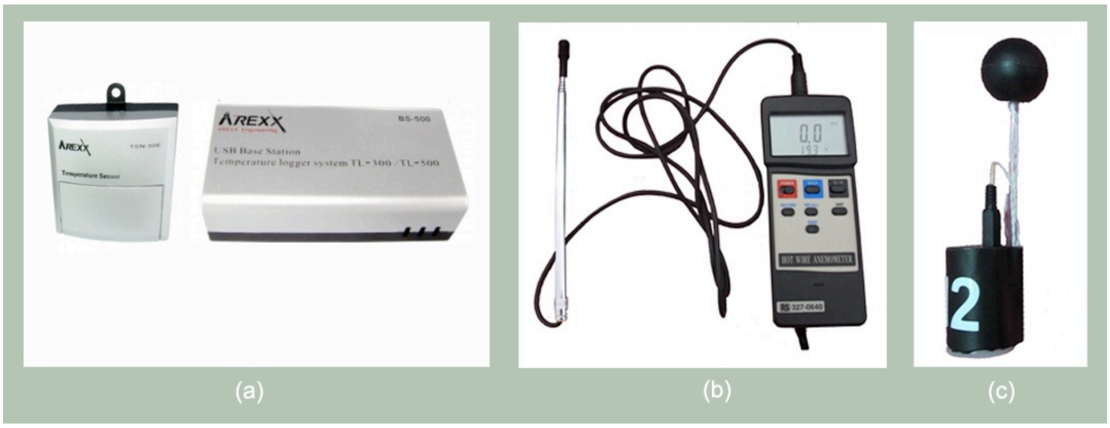

Figure 4.1 Measurement devices in the study

4.3.2. Activity level and clothing insulation

The metabolic rate was determined by observing participants' activity. This was predominantly reading and writing, social (meeting and talking) watching performance and working on computer (1.2 met) or sitting (1.0 met), but a small number of them were eating or drinking (1.5 met).

Clothing thermal resistance was estimated based on a clothing list provided by the participants, the dress of participants was converted to a numerical clo value according to CIBSE. In summer the transitional space occupants had very similar clothing insulation values, while in winter, the effect of outdoor weather resulted in distinct variations in clothing levels between the different individuals.

4.4. Human behavior monitoring

4.4.1. Questionnaire

Questionnaire is used in the field study for collecting data to survey people's perceptions of thermal comfort and mesh the results with prevailing environmental conditions. The questionnaire design was based on ASHRAE Standard 55. It began with a foreword explaining of its goals, followed by a major section that investigated the participants' thermal perception of the indoor thermal environment in transitional spaces. The content of the major section of questionnaire was divided into three sections:

- Section 1 is for collecting relevant personal information, including participants' gender, age, occupation and what they wore when they were participant the questionnaire survey.
- Section 2 is investigating participants' interaction history with the building and indoor transitional space they occupied.
- Section 3 is investigating participants' perception of thermal comfort in indoor transitional space.

The questionnaire (Appendix 2) includes three types of questions: individual information, fact allegation and satisfaction evaluation. The former using in section 1 and that main focus on participants' demographic features. The second one consists of 15 questions that construct a different aspects structure as Table 4.2. The latter consist 8 questions that construct a two level hierarchy structure: the first level is evaluates the overall thermal environment of transitional space, the second level is evaluates the thermal environment of specific area of transitional space.

Table 4.2 The aspects of section 2 of questionnaire investigated

Aspect	Index
Sensation of the outside climate	Living location and length
Interaction history with the transitional space	Reason and frequency of visiting the space, length of stay in this space, favorite area, stay reason
Personal sensitivity of thermal environment	Adaptation activity and drinking, temperature influence on choosing seating place

The second level of section 3 is the key content of the questionnaire, this section asks subjects to rate their current sensation about their thermal environment. Due to the variability of thermal condition in transitional space, thermal comfort will rated on a typical 7-point ASHRAE thermal sensation vote (TSV) scale, which range from -3 to 3 in response to a change from cold to hot, with 0 being the thermal neutral condition. The thermal acceptability (acceptable or unacceptable) question in the survey was assessed by the question of the occupant's evaluation of the thermal quality of the space. The records of the responses also need kept and catalogued according to time and date. All the other parts of this questionnaire are assistants to supplement, evident and correct the key content of it. Section 1 and section 2 are investigated participants' personality and their interaction with the indoor transitional space, which have the significant influence on the evaluation of their thermal perception.

The researcher's observation of participants combined with section 1, which including participants' sitting area, clothing, gender, activity, whether eating or drinking, and whether alone or with group of people. Detailed description of participants' clothing was noted in the questionnaire sheet.

The site map is attached on each questionnaire; it is use for participants point out their favorite area for staying and the reason of it in this space. It is also important so as to pinpoint the location in which each interview occurs. Interviews location is selected randomly within defined boundaries in each site so that it takes individuals' preferences into account.

4.4.2. Ethics risk and data protection

Ethical implications of the research need to be considered as the monitored subjects in this study are human participants. Generally, there are two main tasks need to be justified in the ethical process (KCL, 2008). At first, balance the benefit of the research to society and the risks concerned with participants. Secondly, in the process of research study and after it, treating the monitored data confidentially. To meet the requirement that an ethical approval was undertaken prior to starting this study, and approval was given both by the Welsh School of Architecture, and the Ethics Committee of Cardiff University. The ethical approval application carried out for this study has answered questions in the following aspects:

- Researchers' scientific quality on doing the study.
- Consent and deception of the study to the participants.
- How the data will be used and stored confidentially during and after the study.
- Will participants be provided with any incentives for the study？

When doing the ethical approval, in order not to influence occupants' judgment about their thermal perception, participants were told that all their information would be used anonymous. However, if they wanted to know some detailed information about the study or the results of the study, it can be provided to them after the study finished. The participants were chose at random and in this research they are entirely voluntary. All participants were over 16 years old.

As mentioned in the Data Collection section (Section 4.2), some measuring devices were used in the study for automated monitoring of important parameters. To ensure participants' safety during the measurement, a risk assessment of these devices was also completed, which resulted in a '*Low*' risk. This assessment has considered mainly the mechanical and electrical hazards; potential hazard of the workplace (both physical and environmental); potential hazard from substances; potential hazard of participants' work activity during the experiment; potential hazard of radiation. In addition, before being allocated into the monitored spaces, all the measurement devices had been tested carefully by professional electricity technicians in the School of Civil and Building Engineering, Cardiff University, making sure that they were in good working conditions.

4.5. The case study building

Nicol (1993) noted "we are interested in the relationship between the subjects and their environment. If the room is atypical, or the building of unusual design this may limit the applicability of your results". This study was looking for typical building with indoor transitional space in Cardiff, UK. The choice of the buildings to be used for survey was based on the following criteria: 1) located in Cardiff; 2) all buildings must be with a transitional space in it, and this transitional space provides function more than just passing through; 3) recently built building as contemporary buildings (no more than 20 years old); 4) typical in terms of design and material as far as possible; 5) the service system of indoor transitional space includes natural ventilated and air conditioning system; 6) the way of people using indoor transitional space is different.

The studies were carried out in three buildings' indoor transitional spaces: ATRiuM of Glamorgan University (AGU), Royer Welsh College of Music and Drama (RWCMD) and Welsh Millennium Center (WMC). All these three buildings are located at Cardiff, UK (51°29′0″N, 3°11′0″W, alt.65m). Figure 4.3, Figure 4.5 and Figure 4.7 depict the South, East and West façade separately of the three case study building and show transitional spaces in these buildings. Each building has big façade windows, but in WMC the window is not directly beside the main resting area of transitional space as in other two buildings. All the transitional spaces are having resting areas and connecting by corridor, all of these transitional spaces connect with some business spaces like café or store.

4.5.1. ATRiuM of Glamorgan University (AGU)

ATRiuM is a campus of University of Glamorgan, Cardiff, Wales. It is CCI (the Cardiff School of Creative & Cultural Industries), the home to one of the University's five faculties. This building is located on Adam Street, near Cardiff Queen Street railway station. The building includes a television studio, two tiered theatre, auditoriums, sound studios, learning resource center and gallery etc. It comprises a refurbished former BT office block and a newly-built extension, linked by a glass atrium. The transitional space of this building includes four parts: corridor split the office block, a café, rest area connect to the library and a small rest area close to north door (Figure 4.2 and Figure 4.3).

Figure 4.2 The case study building (ATU) and transitional space of ATU.

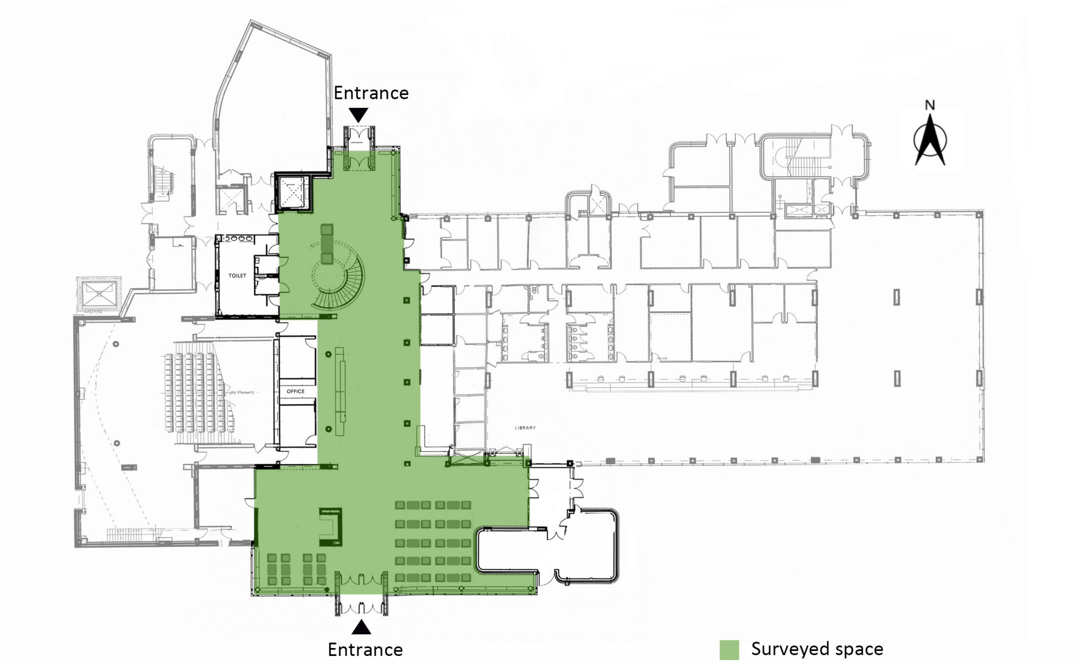

Figure 4.3 Floor plan of the case study building AGU's surveyed indoor transitional space.

4.5.2. Royal Welsh College of Music and Drama (RWCMD)

The area of RWCMD is an education institute, generally calculated, there are seven kinds blocks in this building: theater block, foyer block, corridor block, studio block, storage block, kitchen block and office block. Although the building appears to be a single structure it is in fact a renovated existing structure and three separate new buildings united under a single floating roof. The transitional space in this building is a foyer area in one of the new buildings. It includes café, resting area and reception area; sometimes resting area is using for assemblage or performance. There is a turnstile between double opened doors connected to the outside. On the other side, the foyer connects to a triple height arcade that forms a new spine between the new and old accommodation, that linking the constituent structures, functioning as exhibition space for the design and costume department, It also acting as air changing, creating a natural stack effect, which ventilates the public spaces. At the end of the arcade, its entrance to the college opens out on to Bute Park.

Three new build parts surround the candidate foyer, one is the biggest theater of RWCMD, and it is connect to a middle size theater of the building through an impending bridge. The third part is a semi-circulated construction with three floors, the first floor it is a café connect to refectory and foyer, the second and third floor are studios (Figure 4.4 and Figure 4.5).

Figure 4.4 The case study building (RWCMD) and transitional space of RWCMD.

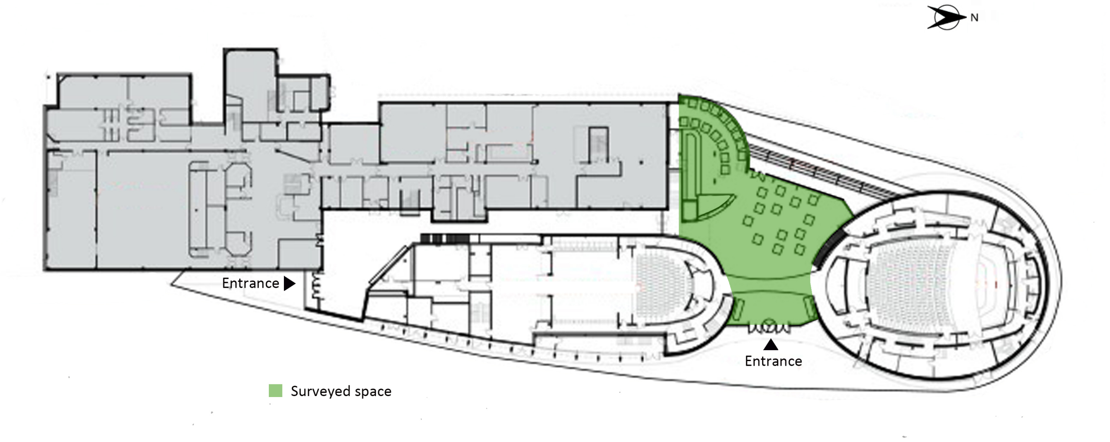

Figure 4.5 Floor plan of the case study building RWCMD's surveyed indoor transitional space.

4.5.3. Wales Millennium Centre (WMC)

WMC is an arts center located in the Cardiff Bay, Wales. The business of this center is covering art, cultural and tourist center. The Centre comprises one large theatre and two smaller halls with shops, bars and restaurants. The research candidate space in WMC includes two foyers beside the main corridor connecting them in front of the reception desk. There are shops and cafés besides two foyer areas; the corridor is connected to the outside with double glass automatic doors (Figure 4.6 and Figure 4.7).

Figure 4.6 The case study building (WMC) and transitional space of WMC.

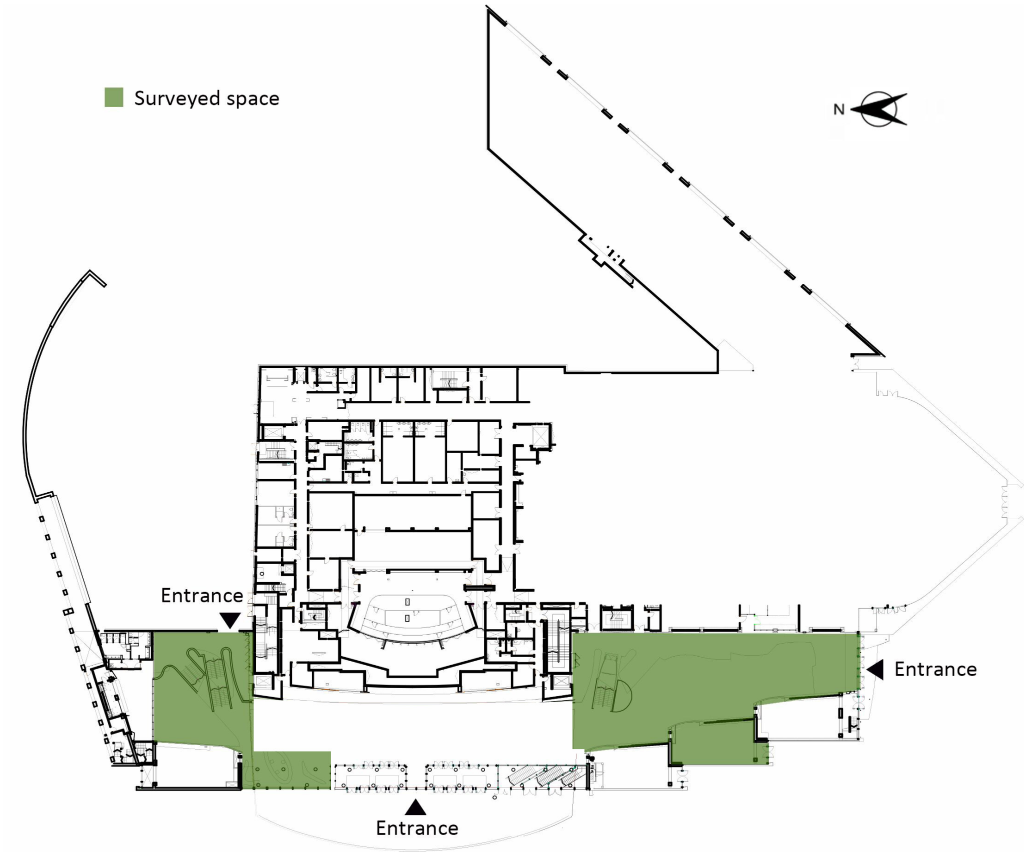

Figure 4.7 Floor plan of the case study building WMC's surveyed indoor transitional space.

4.6. The Pilot study

To test the validity of the methods of measurement and questionnaire in this research, a pilot study was carried out before the actual survey was conducted. This study is giving a more detailed definition of indoor transitional spaces based on the literature review by personally participants in the daily life of indoor transitional spaces. It shows that indoor transitional spaces are complex and diverse in design, and always serve multiple functions for participants. Transitional space can offer a wide range of adaptive opportunities (choice of sitting area, wider range of possible physical activities, greater tolerance of dress code etc.). When people stay in the indoor transitional spaces, they tend to experience a dynamic interaction with changes in temperatures. Due to the dynamic thermal condition in indoor transitional spaces, occupants experience at multi-sensory levels and tolerate greater temperature range than in fully occupied spaces, and in some transitional spaces the thermal environment is as dynamic as outside environment condition.

The definition of transitional space by scholars during recent decades is wide and imprecise, even though some scholar classified it by the location relation to the main building (Chun 2004). The transitional space researched in this study has a close and complex relationship with the main fully occupied space, but there is not a clear and precise definition of it from the literature review. The pilot study help to make the detailed definition of transitional spaces in public buildings: it is the large buffer space between outdoor and fully occupied indoor space, includes different function areas and provide multiple functions to occupants.

The measurement of pilot study showed that: 1) due to the rules given by the manager of the building, air temperature and relative humidity sensor must setting at covert place in case visitors saw them, it results in a bad signal of the receiver then lots of data just lost; 2) due to the relative big size of transitional space and owner asked no support for sensors appear in the public space, all of the sensors just can setting on wall or very close wall, it results in the sensor can not measure air temperature in an accurate way. 3) Some sensors' recording process is interrupted by temporary conditions (performance, exhibition) or the temporary movement of equipment even though the function and model of occupation in transitional space is well understands before the survey. To eliminate those interference during measurement progress in the formal survey, a negotiation with building managers about the setting location of sensors is necessarily, after did that work and increased the number of sensor, all the sensors were setting on the place covered by the receiver equipment's signal but still close to or on wall. To measure the thermal environment around participants more accurately, a handhold Hot Wire Anemometer RS327-0640 is used measuring air temperature around participants.

The pilot study highlighted some improvements of questionnaire survey to benefit the formal study as follows: 1) improve the design of the questionnaire (content, format and layout); 2) changes to the method of recruiting participant to get more reliable and trustable responses; 3) adoption a more flexible timetable to apply questionnaires to cover a wide temperature range; 4) improving the method of combining questionnaires with physical measurements to get a more reliable results; 5) adding more data for comparing and validate the results of formal study.

According to the data collection experience in pilot study, some new questions were added to the questionnaire used in the formal study, e.g. the question of: '*how often do you visit this space*?' '*how long do you stay in this space*?'. The new questions were added because observing and communicating with occupants in the pilot study found that the duration of the visit and frequency might influence people's thermal perception in indoor transitional space.

The way of recruiting participant also changed, for example, some occupants used the transitional space just to passing through and some of them walking hastily, which always influence their attitude to filling the questionnaire and their metabolic rate might influence the results of thermal perception analysis. So these occupants were excluded in the formal survey when recruiting participants for the questionnaire survey. The time for applying questionnaires was also adjusted in the formal study according to the observation of the occupants' activity routines in the pilot study.

The pilot study was conducted to test and develop the methodology of this study. The measurement method and the place of equipment were improved and adjusted. The pilot questionnaire survey showed that participants could understand well what they asked by each question. As a result of the pilot work, it has been found that the interview time has to be shortened. The time take for each participant to fill in the questionnaire is 5-10 minute it was within a reasonable scale. Moreover, some questions were omitted, others were added, and the wording of some questions were revised either to use simpler language and or to give more specific meaning. Finally, answers of the closed questions were confirmed. Moreover a coding for expected answers of the open questions was developed.

4.7. Statistic Analysis plan

There is two statistics approaches were adopted for data analysis of the questionnaire: descriptive statistics and inferential statistics. Descriptive statistics focus on distribution of participants' demographic features and participants' evaluation of their thermal environments. Inferential statistics are used to investigate the important theoretical issues on thermal evaluation and the effect of thermal comfort on using of indoor transitional spaces. It includes: 1) correlation analysis between participants' demographic features, thermal environmental features, and thermal comfort evaluation to examine the relation among them; 2) analysis of Variance (ANOVA) of the satisfaction level to compare the mean values of thermal sensation in indoor transitional space; 3) regression analysis of the actual mean vote (AMV) and PMV of thermal sensation; 4) principle component analysis of the environment and participants features elements to extract the main impact dimensions on thermal sensation evaluate in indoor transitional space.

4.7.1. Chi-square

Chi-square (χ^2) test of independence is a statistical method based on a cross tabulation table to test whether two (or more) category of variables are independent or homogeneous by the way of comparing the observed occurring rate of cases each of the categories, with the values that would be expected if there was no association between the variables being measured conducted to compare the actual thermal sensation vote (AMV) of three indoor transitional spaces' participants. First, the assumption of Chi-square must be checked, so that the minimum expected cell frequency should be 5 or greater, or at least 80% of cells have expected frequencies of 5 or more. If the assumption has been violated then the Fisher Exact test should be considered, and the next step is the interpretation of Chi-square output. The main value to be checked in this test is Pearson Chi-square. If the associated significance level of Pearson Chi-square values is equal or smaller than 0.5, the result of this test shows a significant association between the tested variables, yet the strength of this association needs to be examined.

The level of association between the variables can be found by the effect size (strength of association). Having two categorical variables in this test (AMV and the three indoor transitional space groups), the recommended effect size is Somers' d (Pallant 2010). Somers'd affect size enables choosing which variable is the dependent one, in this case AMV is the dependent variable. Table 4.3 shows the criteria to decide the effect size depending on the value of Somers' d, taking into account the number of categories in the variables tested where R is the number of rows and C is the number of columns, the smallest value between (R-1) or (C-1) to be considered for choosing the criteria in

Table 4.3, in this case C=2. Therefore, the first row should be applied in this case.

Table 4.3 The criteria of deciding the effect size of the Chi-square test.

	Somers' d value		
(R-1) or (C-1) = 1	Weak= .01	Moderate= .30	Strong=.50
(R-1) or (C-1) = 2	Weak = .07	Moderate = .21	Strong =.35
(R-1) or (C-1) = 3	Weak = .06	Moderate = .17	Strong =.29

4.7.2. One way ANOVA

The one-way analysis of variance (ANOVA) is used to determine whether there are any significant differences between the means of three or more independent (unrelated) groups. To check whether the data can be analyzed by using the one-way ANOVA test, three assumptions should be filled:

- The one-way ANOVA is considered a robust test that against the normality assumption. This means that it tolerate violations to its normality assumption quite well. In the case of the normality of group data, the one-way ANOVA can tolerate data that is non-normal (kurtotic or skewed distributions) with only a small effect on the Type I error rate. However, platy kurtosis can have a profound impact when the sizes of group are small. This leaves with two options: 1) transform data using various algorithms so that the shape of distributions become normally distributed or 2) choose the non-parametric Kruskal-Wallis H Test that does not have a requirement of the normality assumption.

- There are two tests can run that are applicable when the assumption of variances' homogeneity has been violated: Welch test, or Brown and Forsythe test. Alternatively, a Kruskal-Wallis H Test. Welch test has been shown is best for the most situations.

- The cases lack of independence has been stated as the most significant assumptions to fail.

The above three sections are the normal procedures should carried out in a ANOVA test, but a Welch F test need to run if the assumption was violated. The ANOVA test only test whether an overall difference occurred between different groups but not test which specific groups differed. Therefore, the post hoc tests do need to run to confirm where the differences occurred between groups, they should only be run when an entire important difference happed in group means (i.e., a significant one-way ANOVA result). Post-hoc test offers to control the experiment wise error rate (the alpha value is 0.05) in the same way that the one-way ANOVA is used, instead of multiple t-tests.

4.7.3. Pearson's correlation coefficients

Parametric (Pearson's) correlations are used to confirm the strength and direction of the linear relationship between two numerical variables (Pallant 2010). In this study, correlations are used to compare results from physical variables measured in the different indoor transitional spaces and their participants' evaluation of their actual thermal sensation.

4.7.4. The ordinal regressions

The ordinal regression analysis (McCullagh 1980) allows to modeling the dependence of a polytomous ordinal response on a set of predictors, which can be covariates or factors. The ordinal regression analysis was carried out to examine how the environmental variables (explanatory variables or predictors) related to the actual thermal sensation votes of participants (criterion or dependent variable). The procedure used in ordinal regression is the logistic regression that is similar to a linear regression model, but it is suited to the models where the dependent variable is dichotomous or branched. The regression coefficients can be used to estimate effect size for each of the predictors (Pallant 2010). The Wald statistic is calculated for the variables in the model to confirm whether a variable should be removed.

Wald statistic results show the major factors that influence the thermal sensation vote. Variables with significant Wald values contribute significantly to the predictive ability of the model. The Beta value (B) in the table is similar to that used in multiple regression analysis, and it is used in the equation to calculate the AMV. The negative or positive B shows the direction of the relationship between the relevant predictor and the dependent variable, AMV in this case.

4.7.5. The probit analysis

Ballantyne et al. (1977) suggested that the neutral temperature can be determined from probit analysis and is represented as the temperature at which the maximum number of participants would change their thermal assessment between two levels of response to a variable. As an example of this, suppose P1, P2, P3, P4, P5, P6 and P7 are the percentages of assessments for thermal sensations 1, 2, 3, 4, 5, 6 and 7 (seven point scale 1= cold and 7= hot) at a fixed condition of parameters affecting thermal sensation. Then the probit analysis could be applied to the variation of these assessments with change in one of the parameters (such as operative temperature T_o). The probit analysis only deals with two levels of response. Therefore, the thermal sensations should be split into two groups in any of following ways:

1. P1 and P2+P3+ P4+P5+p6+p7
2. P1+P2 and P3+P4+P5+p6+p7
3. P1+P2+P3 and P4+P5+p6+p7
4. P1+P2+P3+P4 and P5+p6+p7
5. P1+P2+P3+P4+P5 and P6+p7
6. P1+P2+P3+P4+P5+P6 and P7

The preferred thermal sensation and temperature would be defined as the intersection temperature at which the maximum number of people would change their assessment from the votes "*neutral*" to "*cooler than neutral*" or "*warmer than neutral*". In other words, the votes can be split into "*cooler than neutral*" by splitting votes between the two groups as follows (P1+P2+P3) and (P4+P5+P6+P7), and "*warmer than neutral*" can be split as (P1+P2+P3+P4) and (P5+P6+P7). Therefore, the preferred temperature should be defined as the interaction temperature of "*cooler than neutral*" and "*warmer than neutral*" while the preferred thermal sensation should be defied in the same way.

4.8. Summary

This chapter systematically explained the methodology adapted in this research. Firstly, it proposed the research aims and objectives: analysis of thermal environment features in indoor transitional space, analysis participants' actual thermal sensation in indoor transitional space and the effect of thermal comfort on people's using of indoor transitional space. Based on research questions, research strategy was established and methods are adapted as combing physical measurement with face-to-face questionnaire. The central part of this chapter gives a detail introduction of these two methods. The later part is introduces the related information about pilot study, including the aims and lessons to carry out the pilot study, and the last part is introduce the analysis methods.

Field surveys are central in the research of thermal comfort in indoor transitional spaces because field surveys enable studying the complex relation between both physical and subjective variables. Therefore, a causal comparative design based on field surveys has been chosen for this study. A combination of physical and human measurements was used to collect environmental data and to measure human attitudes. The physical measurements consist of measuring the thermal environmental variables in each space and estimating activity level and clothing insulation of the investigated subjects. In addition, the questionnaire method of monitoring human attitude was conducted during the same time.

Pre-field work preparations were made to select suitable sites for this research. Research materials were also arranged and tested and a pilot study was conducted. After initial analysis of each one of the selected sites and improve the defects of the pilot study, the formal fieldwork was started. Data collection included both physical measurements and human behavior monitoring. The collected data were sorted and were prepared for analyses. Results will be presented and discussed in the following chapters.

Chapter 5 Descriptive Analysis

5.1. Introduction

This chapter is the part of the results obtained from the field surveys. The purpose of this chapter is to evaluate the physical factors that influence thermal comfort in actual indoor transitional spaces, based on two seasons of data collected from the case study buildings. It relates to the previous chapter by analyzing the collected data through physical measurement and questionnaire. It has the following objectives:

1. to evaluating the thermal environment of each field study case in both seasons;
2. to investigating occupants' thermal perception in each studied indoor transitional space case;
3. to evaluating the relationship of thermal environment and actual thermal sensation in indoor transitional spaces.

This chapter starts with the description of field study cases and sample profile. It then analyses the results of field studies for each case and compares the results of three different cases. By the end of this chapter, the reader should have learned about the thermal environment in indoor transitional spaces, and about the influence of thermal environment condition on actual thermal sensation of people occupied in indoor transitional spaces in Cardiff, UK. As explained in Chapter 4, environmental data were collected with the completion of questionnaires by the occupants of the study, the data of questionnaire were concerning to subjective perceptions of the environment and personal information.

5.2. Description of the survey sample demographic

A total of 759 interviews were carried out, 375 in the winter and 394 in the summer, including 362 females and 397 males. Demographic data were collected in the questionnaire relating to the respondents' age, gender, occupation, clothing insulation and activity level, and frequency of visiting and duration of occupation. The analysis presented below includes the data collected in winter and summer.

The Atrium Building of Glamorgan University (AGU): The total sample population in AGU consists of 245 people, with 123 sampled in winter and 122 in summer. **Royal Welsh College of Music & Drama (RWCMD):** The total sample population in RWCMD transitional space consists of 265 people with 132 in winter and 133 in summer. It shows in winter the sample female-male ration is 54:46 when in summer it is 42:58. The main age range of participants in RWCMD is from 16-64 while in winter much of the sample's age is range 16-24 (46%). In RWCMD the majority of interviewees in winter are students and people living on skills with degree when in summer most are students and people living without degree. 43% participants in winter and only 24% in summer visit this space frequently. Even though the visit frequency to this space is not very often by most participants, most of them stay in it more than 20 minutes.

Table 5.1 shows the collected demographic data relating to the respondents' age, gender, occupation, living location, and frequency of visiting and duration of occupation. The female: male ratio in winter is 54:46, while in summer it is 42:58. Most participants in AGU are in the age range 16-34 (94% in winter and 60% in summer), and the average age of participants in AGU displays a median age of 25-34. The occupations of participants are divided according to what they do for living, as skilled without degree, skilled with degree and student. In AGU the majority of interviewees are students (65%), 84% in winter and 51% in summer separately. The skilled without degree people occupied 24% of all participants, but in winter they occupied a quite big percentage at 40% of the participants. In terms the visit frequency, it shows that in summer most participants (75%) visit AGU frequently, but in winter just half of them visit it frequently. When they visiting AGU, most of them stay in it more than 20 minutes both in winter and summer.

Royal Welsh College of Music & Drama (RWCMD): The total sample population in RWCMD transitional space consists of 265 people with 132 in winter and 133 in summer. It shows in winter the sample female-male ration is 54:46 when in summer it is 42:58. The main age range of participants in RWCMD is from 16-64 while in winter much of the sample's age is range 16-24 (46%). In RWCMD the majority of interviewees in winter are students and people living on skills with degree when in summer most are students and people living without degree. 43% participants in winter and only 24% in summer visit this space frequently. Even though the visit frequency to this space is not very often by most participants, most of them stay in it more than 20 minutes.

Table 5.1 Demographic information of field study in three indoor transitional spaces

		AGU		RWCMD		WMC	
Elements	Category	Winter (%)	Summer (%)	Winter (%)	Summer (%)	Winter (%)	Summer (%)
Gender	Female	54	42	61	51	53	52
	Male	46	58	39	49	47	48
Age	16-24	80	35	46	21	18	12
	25-34	14	25	11	23	18	19
	35-44	2	17	8	18	20	26
	45-54	2	16	20	18	18	24
	55-64	2	6	12	10	9	5
	65-74	0	1	2	5	13	12
	74over	0	0	1	5	3	2
Occupantion	Student	84	51	39	67	15	7
	Skilled without degree	8	40	13	24	21	38
	Skilled with degree	8	9	48	9	64	55
Frequency of visit	Almost everyday	18	22	13	9	5	5
	Several times per week	57	19	29	14	41	7
	A few times per month	9	12	8	39	15	41
	Rarely	11	26	18	22	16	31
	None	5	21	32	16	23	16
Dwell time	Less than 20 minutes	1	7	1	8	9	14
	More than 20 minutes	99	93	99	92	91	86

Welsh Millennium Center (WMC): The total sample population in WMC consists of 249 people with 120 in winter and 129 in summer separately. It shows the demographic data was collected by the questionnaire relating to the respondents' age, gender, occupation, frequency of visiting and duration of occupied. In the winter survey, the female-male ration is 53:47 when in summer it is 42:58. The participants in WMC are at a relatively average age range, most of them are at the age range between 16-54. In winter WMC the majority of interviewees are people living on skills with degree (65%) when in summer most are skilled with degree (55%). In terms the visit frequency, it shows that both in winter and summer most participants (61% and 57%) visit WMC frequently. When they visiting WMC, most of them stay in it more than 20 minutes both in winter and summer.

The comparison of these collected data of three indoor transitional spaces showed that the gender ratio is almost even between female and male. In terms of the age range, the overall participants' age in AGU was younger than in the other two transitional spaces. In AGU, participants' aged 34 or younger accounts for 94% in winter and 60% in summer. But in RWCMD and WMC they were more evenly dispersed across the age groups. Especially in WMC, the participants younger than 34 accounted for 36% and 31% in winter and summer respectively, while in RWCMD the ratio were 57% and 44%. According to the observation, even though both AGU and RWCMD are educational institution, the visitors of indoor transitional spaces of these two building are different, in AGU most occupants are students when in RWCMD a important part of occupants are staff in this building and the building nearby of Cardiff University Welsh School of Architecture. The occupation ration in these three spaces is well evident this phenomenon: there are a quite big part of participants in AGU (84% in winter and 51% in summer) and RWCMD (39% in winter and 67% in summer) are student when only 15% and 7% participants in WMC are student. This is decided by the main function of three buildings, the age of dominate participants in educational building AGU and RWCMD are younger than in the commercial and cultural building WMC.

Among these three indoor transitional spaces, AGU's participants are visit the indoor transitional space most frequently as 75% in winter and 41% in summer, while in RWCMD (42% and 23%) and WMC (45% and 12%) the visit frequency is less. It also clearly suggests that people visit indoor transitional spaces more frequently in winter than in summer. The duration of visits in WMC is a little different with in other two indoor transitional spaces: the percentage of people stay in this space less than 20 minutes is higher than other two. It is due to the more complicated constitution of visitors in WMC than the main body of it in AGU and RWCMD is student and they stay longer in indoor transitional spaces, quite a lot of people visit WMC transitional space for booking the tickets of performances, visiting tourist guidance center and passing through, so they just use this indoor transitional space as a short time buffer space.

5.3. Overview of the three field study cases

There are three buildings with indoor transitional spaces chosen for the field studies. These three buildings were chosen because they offered good examples of indoor transitional spaces as following reasons: 1) they are non-domestically buildings, indoor transitional space is used widely in non-domestically buildings in recent decades, the research of thermal comfort in these spaces will improve the design, the way of using these spaces and the potential energy saving opportunity for these spaces and the connected spaces; 2) all these transitional spaces are located in the buildings, they are in front of the building and connecting indoor and outdoor spaces; 3) all these indoor transitional spaces provide rest facilities, which significantly influence the time people spend in these spaces and their activity level; 4) according to the classification by Pitts (2013), all the indoor transitional spaces are long term occupancy spaces. Table 5.2 shows the key information of these three cases of indoor transitional spaces.

These three indoor transitional spaces are located in the building with different functions: two of them are located in educational institutes: the indoor transitional space of the Atrium Building of Glamorgan University and Royal Welsh College of Music & Drama; the another one is located in a commercial and cultural building: the indoor transitional space of Welsh Millennium Center.

The Atrium Building of Glamorgan University (AGU): The AGU transitional space includes four parts: a corridor split the office blocks, two rest areas in north and south transitional space separately. The small north rest area is close to north door while the south rest area is close to south entrance and connects to the library, and it is opposite to a café across the corridor (Figure 5.1). Including of the café rest area, there are three main rest areas in this space; the south one is the biggest one and with most facilities, people use it for working, studying, meeting, resting and waiting etc.. The café rest area always use for have lunch and breakfast, and the north smallest rest area always use for wait or take a break by occupants.

Table 5.2 The key characteristics and survey time of case study building.

Name of Case study Building		Atrium of Glamorgan University (AGU)	Royal Welsh College of Music and Drama (RWCMD)	Welsh Millennium Centre (WMC)
Date of building		2007	2011 (Refurbished)	2004
Business type		Academic	Academic	Cultural-business
Building area		2490 m²	4400 m²	19020 m²
Transitional Space area		810 m²	1129 m²	2198 m²
External façade orientation		North	East	West
Type of windows		Double glazing	Double glazing	Double glazing
Open windows		No	Automatically depends on temperature inside	No
Type of building service	Winter	Electrical under floor heater	Electrical under floor heater	Air conditioning
	Summer	Air cooling mechanism	Natural ventilation	Air conditioning
Number of inward opens		7	4	7
Number of and outward opens		3	3	3
Surveyed period	Winter	09:00-17:00	09:00-17:00	09:00-19:00
	Summer	09:00-17:30	09:00-17:30	08:30-19:00
Number of questionnaires	Winter	123	132	120
	Summer	122	133	129
Dates of studies	Winter	24,25,27,28,29,30, 31 January 2013	05,06,07,08,09,10, 11 February 2013	12,13,14,15,16,19 ,20 February 2013
	Summer	29,30,31 July, 01,02,05,06,07 August	08,12,15,16,17,18, 19 July	12,13,14,15,16,17 August

Royal Welsh College of Music & Drama (RWCMD): Indoor transitional space in RWCMD is a foyer connecting to a café and a triple height arcade (Figure 5.2). People mainly use foyer and café area in this transitional space for studying, working, meeting, waiting, drinking and eating, watching performance and attending activities. But the other areas in this transitional space is rarely occupied, most time they are used as passageway.

Welsh Millennium Center (WMC): The transitional space in WMC building includes two foyers and a corridor with seating areas, and several cafés and shops. There are a café and a tourist center (shop) connecting to the north foyer, and there are sitting facilities set in the foyer. The south foyer is bigger than the north one and there is a small stage in there for some free performance, some chairs setting around the stage (Figure 5.3). Three cafes and a small shop are connecting to this area.

All of these three buildings are new modern building with multiple function indoor transitional space. The size of the indoor transitional space in Atrium of Glamorgan University (AGU) and Royal Welsh College of Music and Drama (RWCMD) are smaller than in Welsh Millennium Centre (WMC). AGU and RWCMD mainly function as academic institutes while WMC serves multiple functions. The layout of these three buildings is totally different, which contributes to differences when they receive solar radiation. The building services systems in these three buildings are also different and create different thermal environments in each building.

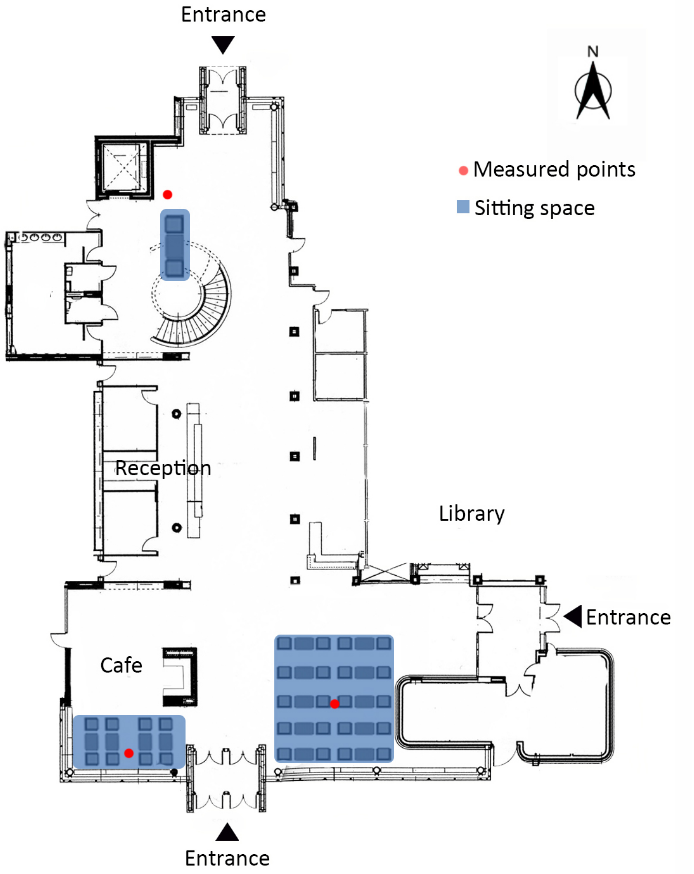

Figure 5.1 Plan of surveyed AGU transitional space.

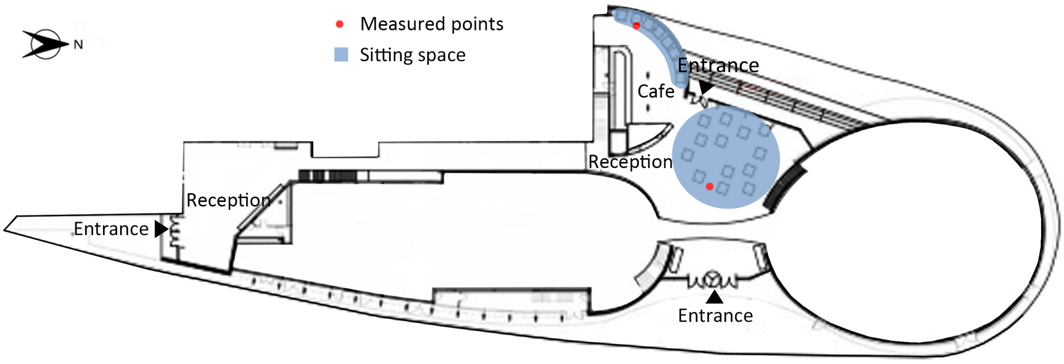

Figure 5.2 Plan of surveyed RWCMD transitional space.

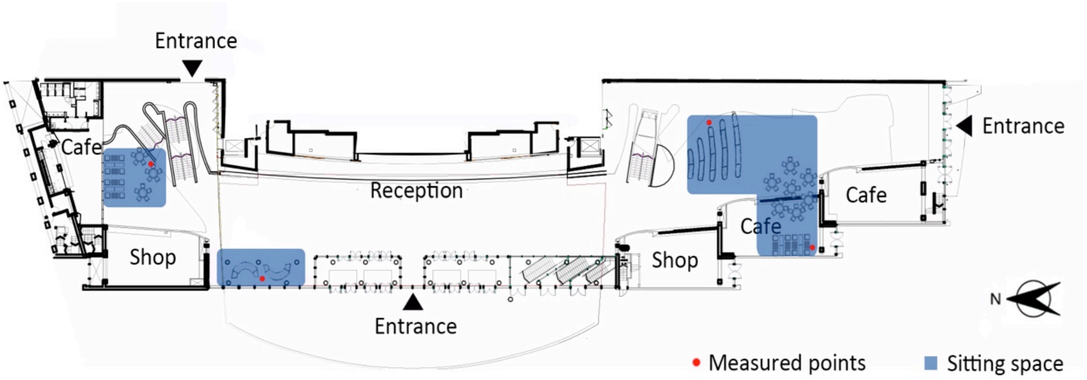

Figure 5.3 Layout plan of surveyed WMC transitional space.

5.4. Description of the space-conditioning plant of the field study buildings

The space-conditioning plant decides the thermal environment of indoor transitional space and influences the way people use the space (for example, the outlines of heating and cooling system in WMC around the sitting areas are produce gentle breeze that results to some people sitting close or avoid this area to adjust their comfort conditions). The service systems in these three cases are different and which contribute to the different thermal environment characteristics.

The Atrium Building of Glamorgan University (AGU): In AGU, the heat is delivered to the space from boilers from the plant room. This is pumped through to under floor heating. Trench Heater is located across the window areas at the front and rear (Figure 5.4 and Figure 5.5). Under floor heating runs the whole length of the foyer from the front doors past reception to the rear doors. The space is ventilated via high-level ventilation fans located in the roof that will only operate if the trench heater is not running. There are ventilation ducts on the lift lobby areas also. Both Heating and Ventilation is controlled via BMS located in the administration office, which uses time schedules and temperature set points. Few thermostats located around the ground floor.

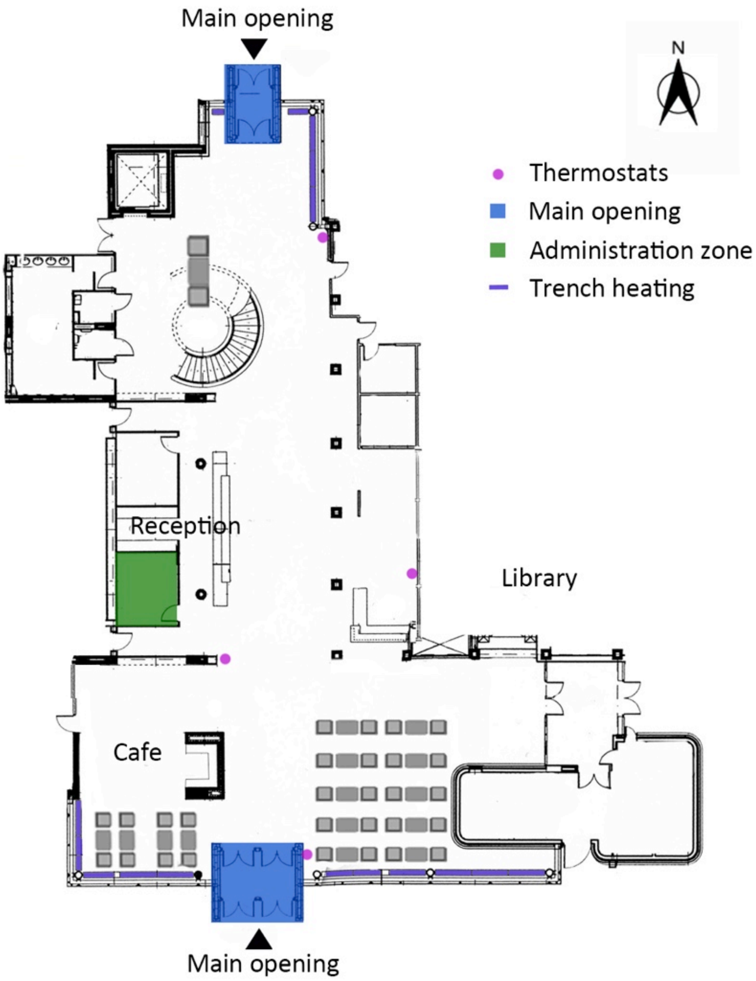

Figure 5.4 Space-conditioning plant of AGU transitional space.

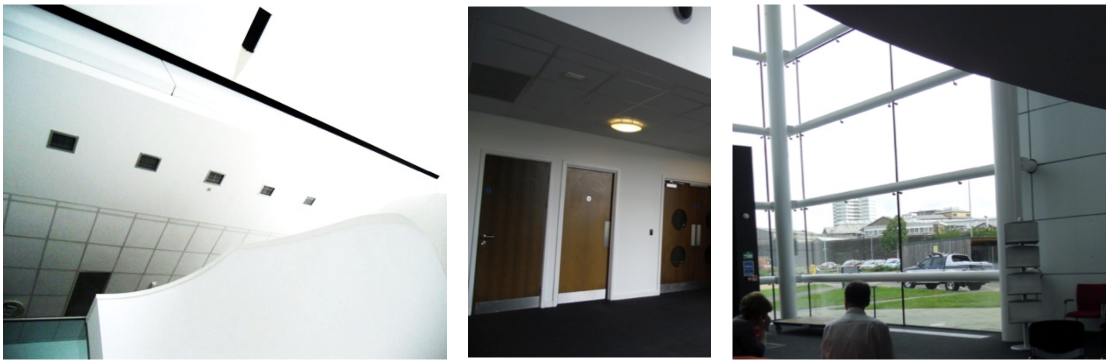

Figure 5.5 Heating and Ventilation facilities in AGU transitional space.

Royal Welsh College of Music & Drama (RWCMD): RWCMD has multiple heating systems, in the foyer area there are couple of trench heater on the floor; in the café area there are heater outlets on the wall; and in the corridor area there are several groups of radiant heaters near the wall (Figure 5.6 and

Figure 5.7). In summer the RWCMD space is naturally ventilated through the main openings: doors and windows.

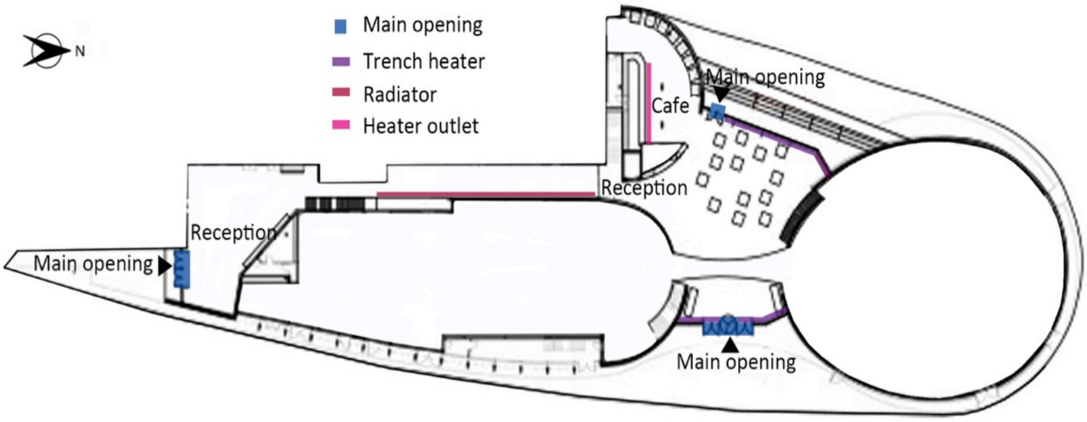

Figure 5.6 The space conditioning plant of RWCMD transitional space.

Figure 5.7 Heating facilities in RWCMD transitional space.

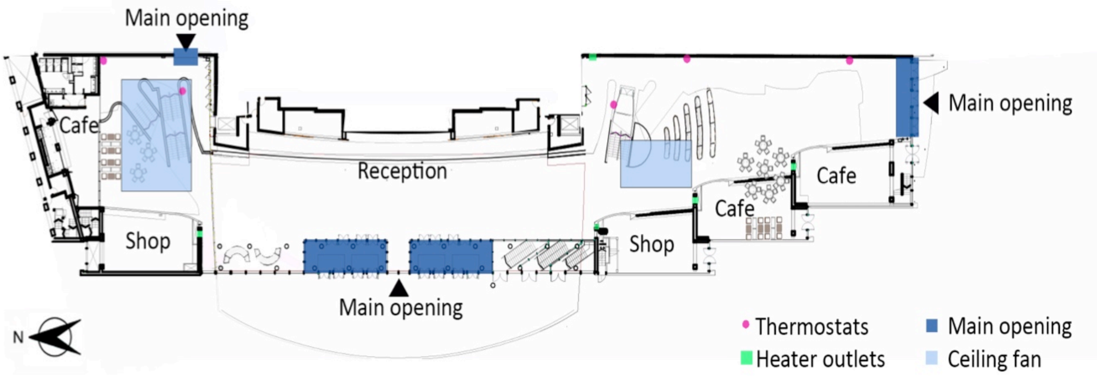

Figure 5.8 The space conditioning plant of WMC transitional space.

Figure 5.9 Celing fans (left) and heat and cool wind outlets (right) in WMC transitional space.

Figure 5.10 Therometer sensors in WMC transitional space.

Welsh Millennium Center (WMC): In WMC, heat is derived from centralized boilers supplying low temperature hot water at 73 °C (LTHW), this water is circulated through insulated pipework to heater coils located within various air conditioning equipment located around the site, the four outlets are located within the north and south foyer areas and are identified through the Aluminium Louvre design (sliver dragon). Both the north and south concourse areas are ventilated by a ceiling mounted extract fan (1 in each concourse area) and of course natural ventilation through the many entrance and exit doors around the concourse – these fans only provide extract duty once the internal temperature reaches 22.5 °C (measured towards ceiling level – they wish to maintain heat within concourse and not ventilate to outside until this temperature is reached as this would be wasteful of energy). There is a Honeywell Building Management System (BMS) which controls the air conditioning equipment – the BMS also schedules the 'on' and 'off' times. Building Management System controls the 'on' and 'off' times for the air conditioning – these times are adjusted to suit their business needs but typically would be as follows for a 'performance day' (show on stage):on at 07:00 and off at 23:00. If there were no show then the times would typically be on at

07:00 and off at 19:00. Equipment and monitors various sensors to feedback and adjust final delivered temperature through 2 and 3 port valve control for the LTHW. There are five sensors on the ground floor locations (Figure 5.8, Figure 5.9 and Figure 5.10).

Although all of these three cases have the same indoor transitional spaces' characteristics. The different conditions in these three transitional spaces results in the different thermal environments condition, which might affecting people's thermal comfort perception and influencing the way of people use indoor transitional spaces. Difference in the building conditions includes their physical character and the heating/cooling systems. The layout of all of these three building is different: the layout of AGU is North-South when RWCMD is West-East and WMC is East-West. Commonly, a North-South orientated building can get more radiant heat from the sun. In this research, the highest temperature truly measured at AGU both in winter and summer, when the lower temperature measured at RWCMD and lowest is at WMC. In terms of heating and cooling condition, AGU uses electrical floor heating in winter and mechanical ventilation in summer, while RWCMD has a similar type of electrical floor heater in winter but natural ventilation in summer. But WMC is different to both of them: it has natural plus water-heating mechanism in winter and natural plus water-cooling mechanism in summer.

5.5. External climatic conditions during the surveys

The external climate was measured by a meteorological station that is located on the roof of Bute Building, King Edward VII Avenue, Cardiff. Figure 5.11 shows the marked location of weather station as well as the three case buildings.

Figure 5.11 The locations of weather station and case buildings.

Ten climate conditions were monitored by the weather station: air temperature and humidity, global and diffuse horizontal solar radiation, global and diffuse horizontal illumination, wind speed and direction, rainfall and barometric pressure. Depends on the literature review, among these factors, air temperature was the most important factor to influence the internal thermal environment and the crucial factor of adaptive model, and relative humidity and air movement speed are the important factors to decide thermal environment. Therefore the following analysis of measuring results about outdoor climatic parameters is mainly focus on the outdoor temperature, relative humidity and air movement speed. The detail data of relevant environment parameters in every survey day are listed in Appendix 4.

The outdoor climatic profile during AGU survey: During the winter survey the outdoor 24 hours mean temperature ranged between 0.94-10.74 °C and in summer it was 16.88-21.81 °C. Figure 5.12 and Figure 5.13 show the overall variation of outdoor air temperature during the survey days. The mean outdoor monthly air temperature during the survey is 5.2 °C in winter and 18.6 °C. In winter the mean air temperature during survey time range from 1.9 to 12.2 °C, when the mean relative humidity range from 63.9 to 82.8 % and air speed range from 1.78 to 5.90 m/s. In summer the mean air temperature during survey time range from 18.8 to 26.9 °C, when the mean relative humidity range from 42.3 to 74.0% and air speed range from 1.52 to 3.98 m/s.

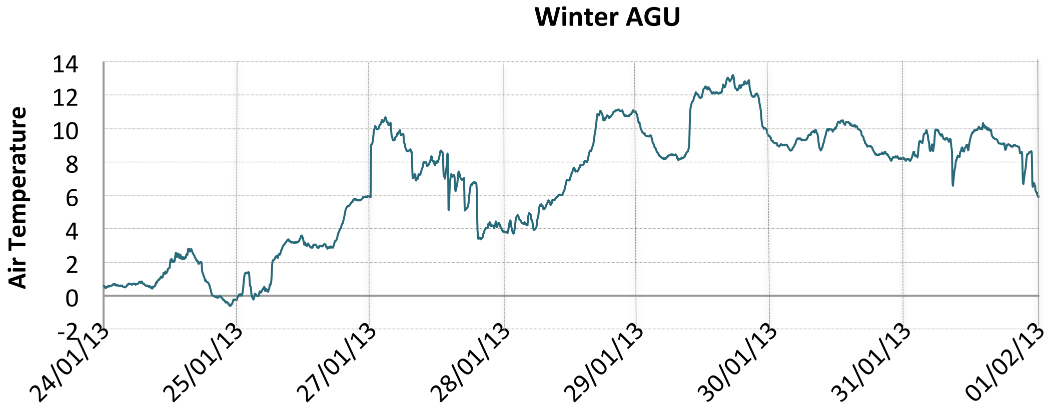

Figure 5.12 External air temperatures in winter during the field study of AGU.

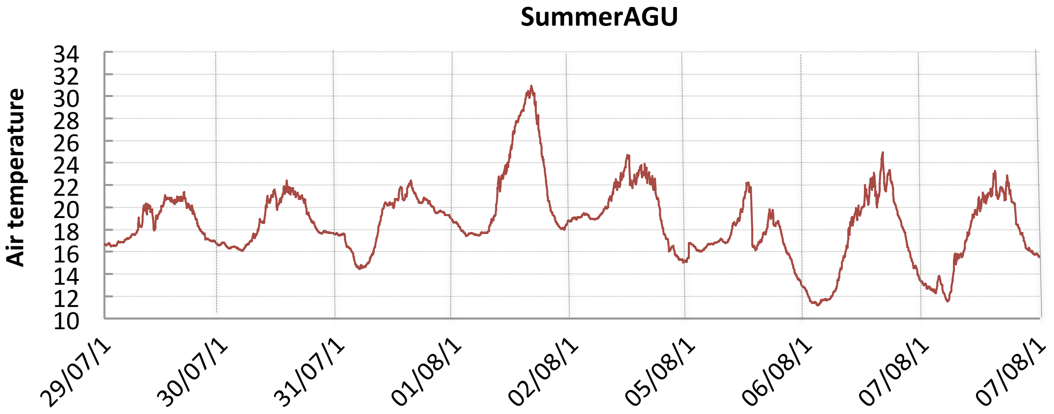

Figure 5.13 External air temperatures in summer during the field study of AGU.

The outdoor climatic profile during RWCMD survey: The outdoor 24 hours mean temperature during the winter survey ranged 2.7-6.0°C and in summer it was 19.8-24.3°C, the overall outside air temperature variation is shows in Figure 5.14 and Figure 5.15. In winter, the mean air temperature during the survey time was varied markedly especially the last day. The mean air movement speed varied obviously in each day, it ranges from 1.46 to 5.02 m/s during the survey time. Under the same situation, relative humidity variation ranges from 48.3 to 84.7%. In summer the mean air temperature ranged from 23.9 to 27.7 °C while the mean relative humidity ranged from 35.3 to 49.2% and the mean air movement speed from 1.46 to 4.22 m/s during the surveyed days. The mean outdoor monthly air temperature during the survey is 4.3 °C in winter and 19.8 °C in summer.

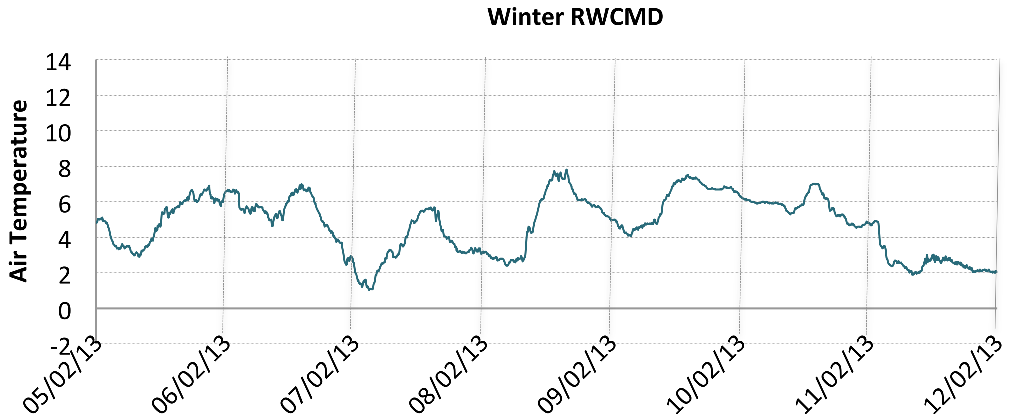

Figure 5.14 Outdoor air temperature in winter during the field study of RWCMD.

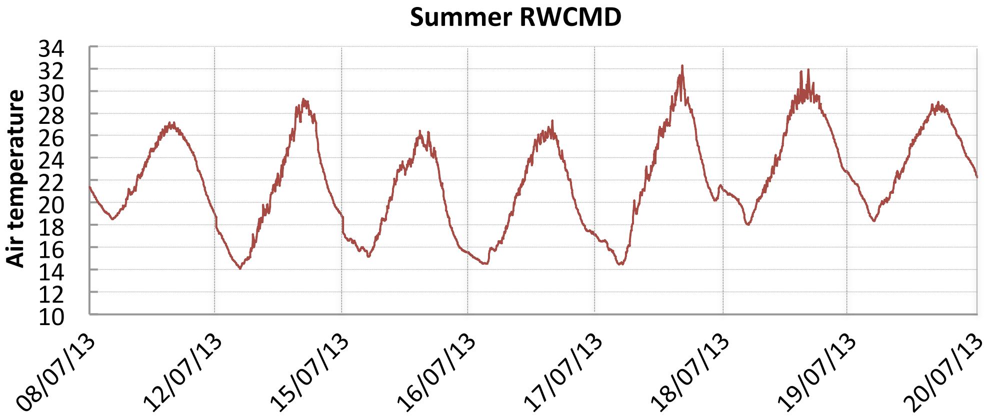

Figure 5.15 Outdoor air temperature in summer during the field study of RWCMD.

The outdoor climatic profile during WMC survey: During the winter survey in WMC the outdoor 24 hours mean temperature ranged from 2.1-7.7 °C and in summer it ranged from 15.1-19.0 °C, Figure 5.16 and Figure 5.17 show the overall outside air temperature variation situation. The mean outdoor air temperature during those survey days is range from 2.3 to 8.4 °C when in summer it shows a narrower range from 17.4 to 20.1 °C. The winter outside relative humidity is change gently than in summer as 59.4 to 80.0% and 49.1 to 81.4%. The air move speed is changed obviously in winter outside as from 1.12 to 3.82 m/s while in summer it is more moderated as from 2.27 to 3.30 m/s. The mean outdoor monthly air temperature during the survey is 4.3 °C in winter and 17.4 °C in summer.

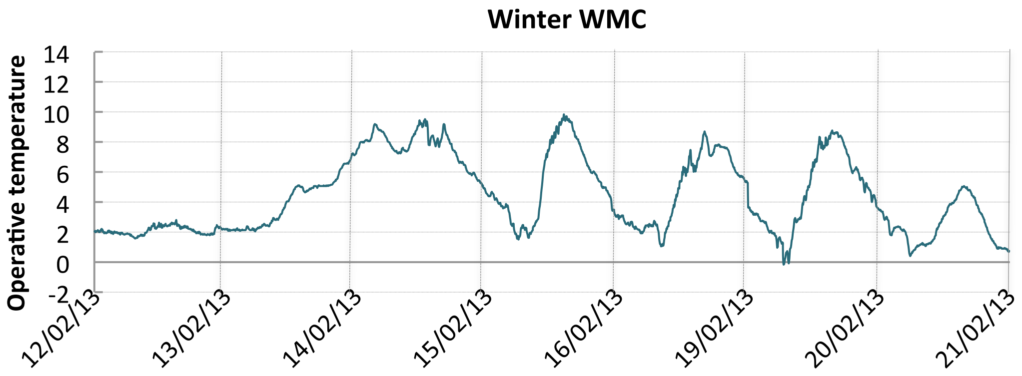

Figure 5.16 Outdoor air temperature in winter during the field study of WMC.

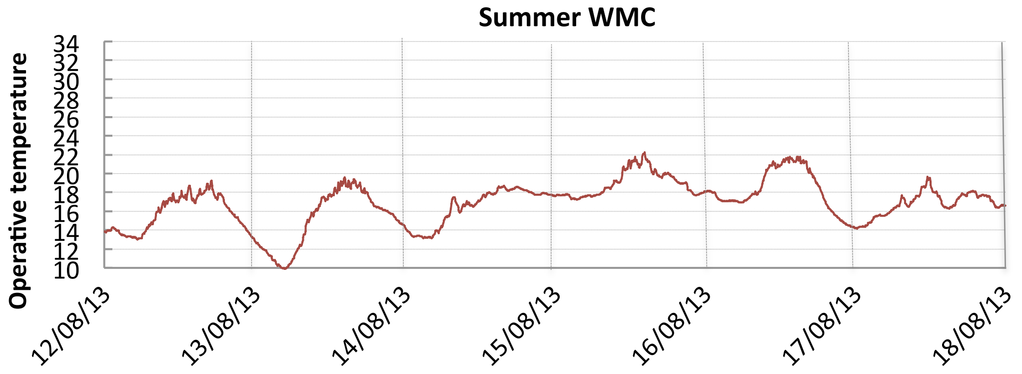

Figure 5.17 Outdoor air temperature in winter during the field study of WMC.

Comparison of the outside climatic profile during the surveys: During the winter surveys, the outdoor 24h-mean temperature of every survey day was ranged between 0.94-10.74 °C of AGU, 2.5-6.7 °C of RWCMD and 2.3-8.4 °C of WMC. In summer the mean outdoor temperature of every survey day ranged from 16.88-21.81 °C of AGU, 23.9-27.7 °C of RWCMD and 17.4-20.1 °C of WMC. Pitts (2013) pointed out that transitional spaces have a stronger thermal connection with the exterior environment compared to the interior. Table 5.3 shows the related outdoor environment parameters during field surveys, it indicated that in winter, the mean outdoor temperature of AGU was about 2 °C higher than other two cases when in summer the mean outdoor temperature of RWCMD was far higher than AGU and WMC (about 5 °C and 8°C separately). The outdoor air move speed was highest during the AGU field survey in winter and during RWCMD field survey in summer. The highest relative humidity in winter is at RWCMD and in summer is at WMC, the lowest relative humidity in summer is also measured at RWCMD. The relevant affects of outdoor environment parameters on indoor environmental condition of indoor transitional spaces will be introduced in the following section.

Table 5.3 Descriptive values of outdoor physical quantities monitored in winter and summer in three cases.

		Winter			Summer		
		AGU	RWCMD	WMC	AGU	RWCMD	WMC
Air temperature (°C)	Mean	7.4	5.3	5.6	21.5	25.6	18.4
	Max	13.2	7.8	9.9	31.0	32.3	22.2
	Min	0.5	1.9	1.2	16.2	18.9	13.6
	SD	0.7	0.8	1.2	1.3	2.0	1.1
Humidity (%)	Mean	70.7	68.2	71.5	56.4	41.6	66.5
	Max	87.7	86.8	89.0	83.7	65.5	84.9
	Min	53.2	36.3	48.0	33.0	18.5	38.6
	SD	4.3	3.5	5.5	6.3	4.8	5.7
Air speed (m/s)	Mean	4.39	2.99	2.43	2.38	2.34	2.75
	Max	8.82	7.88	5.4	6.31	5.58	5.27
	Min	0.13	0.08	0.28	0.15	0.56	0.85
	SD	0.98	0.88	0.65	0.73	0.64	0.68

5.6. Internal thermal environmental and individual parameters from surveys

5.6.1. Internal thermal environmental of AGU

An overview of the factors decides indoor environmental conditions for the AGU transitional space is provided in Table 5.4. In AGU transitional space the operative temperature (T_o) presented a wide range as 13.8 °C in winter and 10.9 °C in summer. The lowest and highest temperatures were measured during the low and occupancy peaks respectively. The highest temperature in winter AGU transitional space is 26.9 °C, just 4.3 °C lower than in summer, when the average temperature in winter is 20.1 °C and 5.5 °C lower than in summer. The average air movement peed is less than 0.2 m/s even some times it is quite high, as 0.70 in winter and 0.96 in summer. The mean relative humidity in summer AGU transitional space is 11% higher than in winter, and the max and min value of summer are both higher than in winter.

Table 5.4 Descriptive values of physical quantities monitored in winter and summer in AGU.

		Winter			Summer		
		T_o (°C)	AS(m/s)	RH(%)	T_o (°C)	AS(m/s)	RH(%)
AGU	Mean	20.1	0.12	45.0	25.6	0.19	56.0
	SD	3.3	0.13	8.4	2.1	0.18	8.20
	Max	26.9	0.70	61.9	31.4	0.96	76.7
	Min	13.1	0.00	27.3	20.5	0.00	33.2

Figure 5.18 illustrates the distribution of indoor operative temperature recorded during the winter and summer survey period in AGU transitional space. Each bar shows the number and percentage of survey samples falling within each operative temperature bin. Approximately 98% of observed operative temperature measurements fell within the range of 14 to 25 °C in winter and approximately 85% fell within 24 to 29 °C in summer.

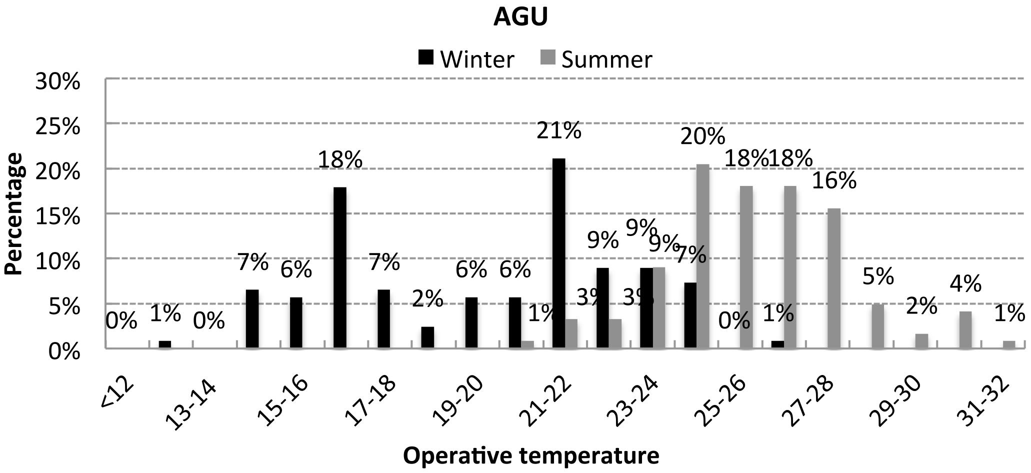

Figure 5.18 Histogram of indoor temperature binned at 1°C intervals in AGU.

To further investigate the thermal environment in transitional space and how the environment condition influence the way people use this space. The basic information of operative temperature in each area is showed as Table 5.5. In winter AGU, the lowest mean operative temperature was at Corridor area (CO) as 17.7 °C when the highest mean operative temperature was 20.6 °C at Cafe sitting area (CS). In summer AGU, the lowest mean temperature is at North sitting area (NS) as 24.4°C when the highest mean temperature is at CO and CS as 27.6 °C and 26.1 °C separately.

The mean operative temperatures in AGU (20.1 °C in winter and 25.6 °C in summer) are close to the uniform temperature environment in winter across all the areas except CO, and in summer close to the temperature in the south areas as CS and SS. The higher operative temperature in CS and SS results from the big façade of glazing, north-south layout and the relatively enclosed environment. It can be seen that comparing to winter outdoor air temperature, summer outdoor temperature influence the indoor temperature more significantly. In summer the indoor temperature of all areas are 2.9-6.1 °C higher than outdoor temperature, this caused by the strong solar radiation and low air movement speed of the interior environment. The lowest temperature of NS produced by no direct sunlight and higher air movement speed caused by the door close it with no revolving door.

Table 5.5 Operative temperature in each area of AGU indoor transitional space and outdoor temperature.

	Winter				Summer			
Area	Mean	Max	Min	SD	Mean	Max	Min	SD
South sitting area (SS)	20.4	26.9	14.2	3.3	25.6	31.4	21.0	2.1
Café sitting area (CS)	20.6	25.6	13.1	3.8	26.1	30.3	22.8	1.9
Corridor area (CO)	17.7	24.9	15.1	3.1	27.6	29.1	26.5	1.0
North sitting area (NS)	19.7	24.2	14.3	3.2	24.4	26.9	20.5	1.9
Outdoor air temperature	7.4	8.6	5.7	0.7	21.5	24.1	18.6	1.3

Design is a very important parameter that influencing the thermal environment of transitional space. Due to the compact nature and North-South layout, AGU presents a uniform thermal environment throughout. The indoor conditions are greatly influenced by the layout, especially the thermal condition at South seating area (SS) and Café seating area (CS). The layout of AGU was a contributing factor to the higher temperature in the majority of the space in AGU transitional space in summer, although the most important factor appears to the extensive use of glazing. The high mean temperatures in the SS (25.6 °C), CS (26.1 °C) and Corridor (CO) (27.6 °C) are representative of the effect of the external heat gains on the indoor environment in summer.

5.6.2. Internal thermal environmental of RWCMD

In the RWCMD transitional space the indoor operative temperature ranged between 17.3-24.9 °C in winter and 22.4-28.8 °C in summer. The mean indoor operative temperature is 21.6 °C in winter and 25.6 °C in summer. Because the main occupied area of RWCMD transitional space is opposite the main entrance of the space, the air movement speed in transitional space has a significant relationship to the outside air movement speed and door's open-close frequency. The indoor air movement speed is varied widely as 0.00 to 0.60 m/s in winter and 0.00 to 2.14 m/s in summer. The difference in winter is obviously smaller than in summer, it is because in winter the automatic door is used rarely and people use the turnstile frequently. The building manager put a sign in front of the automatic door to reminder occupants that open this door will cause cold draughty. The mean relativity humidity in this space shows a small difference as 36.1% in winter and 56.0% in summer (Figure 5.6).

Table 5.6 Descriptive values of physical quantities monitored in winter and summer in RWCMD.

		Winter			Summer		
		T_o (°C)	AS(m/s)	RH (%)	T_o (°C)	AS(m/s)	RH (%)
RWCMD	Mean	21.2	0.16	36.1	25.0	0.30	56.0
	SD	1.3	0.13	5.3	1.3	0.35	4.7
	Max	24.9	0.60	49.3	28.8	2.14	66.0
	Min	17.3	0.00	26.8	22.4	0.00	44.2

Figure 5.19 illustrates that approximately 95% of observed operative temperature measurements fell within the range from 19 to 24 °C in winter and approximately 90% fell within 22-27 °C in summer. It indicates evidently that the indoor operative temperature range in winter is wider than in summer.

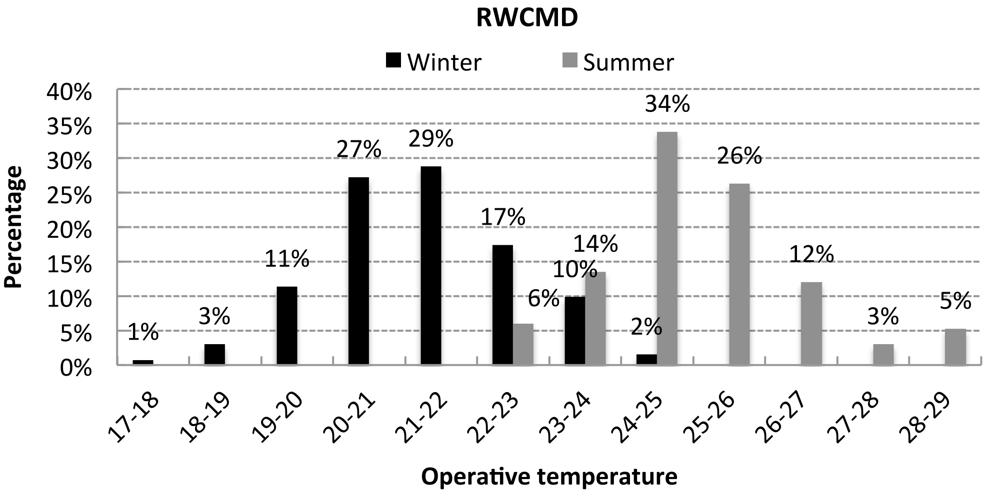

Figure 5.19 Histogram of indoor temperature binned at 1°C intervals in RWCMD.

To further investigate the thermal environment in RWCMD transitional space and how the environment condition of it influences the way people use this space, the environment of different areas of transitional space in RWCMD is measured. The basic information of operative temperature in each area is showed as Table 5.7. In RWCMD indoor transitional space, the mean operative temperature in Café seating area (CS) is always higher than the Foyer seating area (FS). Both in winter and summer, the lowest temperature is happen at FS rather than CS. The higher operative temperature in CS results from the relatively enclosed environment that no gate of CS connects to the outdoor directly, and the heat dissipating from machines in café. The mean temperature in FS is more close to the mean temperature of RWCMD transitional space. It can be seen that in winter outdoor temperature hardly impact on the indoor temperature environment when in summer it impacting significantly as only 0.1-1.5°C difference between outdoor and indoor temperature.

Table 5.7 Describes of operative temperature in each area of RWCMD indoor transitional space and outdoor temperature.

	Winter				Summer			
Area	Mean	Max	Min	SD	Mean	Max	Min	SD
Foyer sitting area (FS)	20.9	23.3	17.3	1.1	24.8	28.8	22.4	1.1
Café sitting area (CS)	22.8	24.9	21.0	1.0	26.2	28.3	23.9	1.7
Outdoor air temperature	5.3	6.4	3.6	0.8	26.3	29	22.1	2.0

Compared to other two cases, the composition survey area of RWCMD transitional space is simpler, just a foyer sitting area (FS) and a café sitting area (CS). Even though there is a corridor connecting the foyer with a reception area, and it is just open to the student and staff. In most time it is used as passing through and people's activity is always walk hastily, and it is rarely occupied by people stay more than 5 minutes. So this area is excluded from this study that mainly focus on the long-term occupied indoor transitional spaces. But the thermal environment of these areas are also put an influence on the main occupied areas of indoor transitional space, especially the foyer area. The designer BFLS describes the RWCMD transitional space as: *"The focus of the scheme is a public foyer with views west into Bute Park and into the Exhibition Gallery in the arcade." "The building's arcade operates as the building's 'lungs,' circulating warm and cool air through its natural stack chimney effect."* It indicated that the thermal environment in FS of RWCMD transitional space not only effected by the outdoor climate it connected directly, but also effected by the corridor (arcade) connect with it.

5.6.3. Internal thermal environmental of WMC

In WMC the in door operative temperature ranged from 19.9-23.9 °C in winter and 20-30 °C in summer. The mean indoor temperature is 19.6 °C in winter and 22.5 °C in summer. The air movement speed in transitional space is varied widely as 0.00 to 0.80 m/s in winter and 0.00 to 1.63 m/s in summer. The mean relativity humidity in this space shows a small difference as 40.8 % in winter and 64.1 % in summer as Table 5.8 shows.

The indoor operative temperature during survey time binned at 1 °C is shows as Figure 5.20. It illustrates that approximately 90% of observed operative temperature measurements fell within the range of 16 to 21 °C in winter and approximately 90% fell within 20-24 °C in summer. The basic information of operative temperature in each area is showed as Table 5.9. In WMC transitional space, the mean operative temperature in Café outside area (CO) and Café inside area (CI) is always higher than the other areas both in winter and summer. In winter the South Foyer area (SF) is slightly warmer than North Foyer area (NF) and Corridor sitting area (CS) as 0.6 and 0.4 °C, While in summer the CS is 0.6 °C warmer than SF and 1.2 °C warmer than NF.

Table 5.8 Descriptive values of physical quantities monitored in winter and summer in WMC

		Winter			Summer		
		T_o(°C)	AS(m/s)	RH(%)	T_o(°C)	AS(m/s)	RH(%)
WMC	Mean	19.4	0.20	41.0	22.1	0.15	64.1
	SD	1.4	0.10	5.6	1.3	0.22	8.9
	Max	22.0	0.80	58.2	26.4	1.63	78.6
	Min	14.5	0.00	30.0	20.0	0.00	47.1

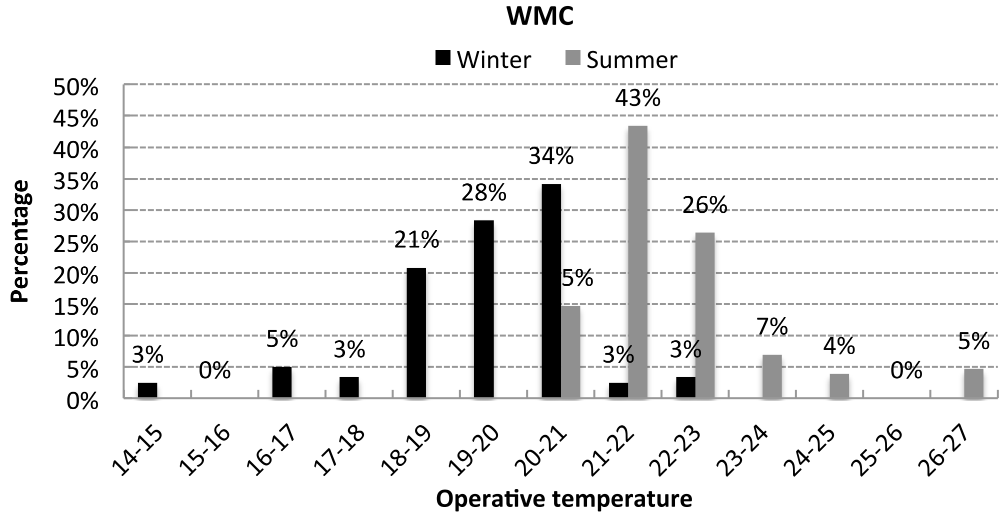

Figure 5.20 Histogram of indoor temperature binned at 1°C intervals in WMC.

Table 5.9 Describes of operative temperature in each area of WMC indoor transitional space and outdoor temperature.

	Winter				Summer			
Area	Mean	Max	Min	SD	Mean	Max	Min	SD
North Foyer area (NF)	18.9	20.0	16.8	1.0	21.3	22.5	20.2	0.7
Corridor sitting area (CS)	19.1	22.0	16.0	1.4	22.5	26.4	20.4	1.7
Café outside area (CO)	21.0	22	20.4	0.8	22.3	23.9	21.0	0.9
Café inside area (CI)	21.0	22.0	19.1	1.4	22.8	24.3	20.9	1.1
South Foyer area (SF)	19.5	21.4	14.5	1.4	21.9	23.7	20.0	0.8
Outdoor air temperature	5.6	7.1	3.0	1.2	18.4	20.2	15.9	1.1

WMC has the widest variety of spaces and respective temperature differences between the spaces in both seasons. WMC have the biggest transitional space among these three cases, each area of the space are relatively independently, especially the NS and SS. Each area in this transitional space has a special physical character and it result in the variety of temperature condition in each area. The café inside area (CI) has the highest mean temperature in winter and the temperature of seating area outside it (CO) also high due to it connect to the café area, which result from the direct sunlight radiation and the independent heating support in this café in winter. Both in winter and summer, the mean operative temperature in North Foyer area (NF) is lowest (18.9 °C in winter and 21.3 °C in summer) in this transitional space in both seasons as a result of its great exposure to the outdoor conditions and no direct sunlight. In winter, there is no heating outlet at this area and the east door of it always take draft for it. Both in winter and summer, there is no window in this area help to get sunlight, so this area is cooler than other areas. The corridor seating area (CS) is close to a heating outlet and near by the extensive glass and get the direct sunlight radiation in the afternoon time, so in winter it get the highest mean temperature (22.5 °C). The South Foyer (SF) is the biggest area in this transitional space and the thermal environment of it is most complex: there are several doors of it open to external climate, four heating outlets and one ceiling fan outlet in it, and the thermal environment of SF is also effected by the three bars' and shop's inside conditioner. Table 5.9 indicates that outdoor temperature in winter rarely impact on indoor temperature but in summer the impact is greater.

5.6.4. Discussion of design and thermal environment of three cases

An overview of the indoor environmental conditions for the three indoor transitional spaces is provided above. In AGU the operative temperature presented a widest range (13.8 °C in winter and 10.9 °C in summer) as a result of the specific construction character and uniform environment. In RWCMD the temperature ranged between 17.3-24.9 °C in winter and 22.4-28.8 °C in summer. As a result of its diverse space than other two spaces, WMC presented the temperature range not as wider as predicted in both seasons (7.5 °C in winter and 6.4 °C in summer). In AGU indoor transitional space, the operative temperature values in midday was significantly higher than other times. It is because the north-south layout of the building allows more solar radiation getting and operative temperature increased sharply in the noon, but which can lead to a more uncomfortable thermal condition (overheating) in summer than other two buildings that with a gently temperature difference.

The relative humidity in winter is lower than in summer in these three cases, and the mostly unstable level throughout one day is happen in AGU. Relative humidity range was sharing a same situation with operative temperature in these three indoor transitional spaces. The widest range is in AGU as the value of 27.3-61.9% in winter and 33.2-76.7% in summer, and narrowest in RWCMD (22.1% in winter and 21.8% in summer). The medium is show in WMC as 30-58.2% in winter and 47.1-78.6% in summer.

In terms of air movement speed in these indoor transitional spaces, the occasionally high air movement occurred in areas exposed to the outdoor wind through the openings, and the mean air movement speed was as low as 0.12-0.30 m/s. The range of air move speed value is wider in summer than in winter. The widest range was in summer RWCMD as 0.00-2.14 m/s while the narrowest range was in winter RWCMD as 0.00-0.60 m/s. This occurred because in summer RWCMD was naturally ventilated and the windows were opened to let more wind in, when in the most time of winter RWCMD, there was only one revolving door open to the outside, which contributes to the small change of air movement speed.

The measurement of external and internal thermal environment parameters indicates that the outdoor environment condition rarely affect the indoor transitional space's environment. Only outdoor air temperature in summer significantly impact the indoor operative temperature, especially in RWCMD indoor transitional space because it was naturally ventilated. It also indicates that solar radiation significantly impact the indoor temperature environment and which decided by the layout of the building, such as in AGU the north-south layout results in more solar radiation getting in the noon and operative temperature increased.

The measured environmental variables were tested to check if they are different or similar in three indoor transitional spaces in both winter and summer. This will help to understanding the difference of indoor transitional spaces' environmental variables and the reason why the different groups evaluated their thermal comfort differently. One way ANOVA analysis of difference was used for this purpose (Table 5.10). By comparing the means of operative temperature, wind speed, and the relative humidity, it can be seen that, neither in winter or summer, significant difference ($p<0.05$) were found among three cases. It can be concluded that significant difference were found among the measured environmental variables in AGU, RWCMD and WMC.

Table 5.10 The ANOVA analysis of environmental variables in three cases of indoor transitional spaces in winter (a) and summer (b).

a-In winter

	AGU		RWCMD		WMC		ANOVA
Variable	Mean	SD	Mean	SD	Mean	SD	
T_o (°C)	20.12	3.34	21.19	1.29	19.38	1.42	0.00
AS (m/s)	0.12	0.13	0.16	0.13	0.20	0.13	0.00
RH(%)	44.98	8.41	36.12	5.37	41.00	5.59	0.00

b-In summer

	AGU		RWCMD		WMC		ANOVA
Variable	Mean	SD	Mean	SD	Mean	SD	
T_o (°C)	25.74	2.07	24.99	1.30	22.09	1.29	0.00
AS (m/s)	0.18	0.18	0.30	0.34	0.15	0.22	0.00
RH(%)	56.04	8.23	56.02	4.71	64.09	8.90	0.00

5.7. Analysis of participants’ thermal response

In these three indoor transitional spaces, people cannot control any of their environment variables such as open/close windows or doors and turn on/off conditioners. People answered the questionnaire during the different time at three intervals (morning, noon and afternoon) of a day, which can help to understand people’s thermal perception and the using situation of the spaces in all the day. All the participants in this study are at the steady state and the results is based on this, which leading to the comparison with PMV model.

5.7.1. AGU participants’ thermal response

Statistical distributions of the survey participants’ perception of thermal environment are summarized in

Figure 5.21. Twenty nine percent of participants in winter expressed their thermal sensation as “neutral” while 34% in summer expressed as “neutral”. In winter almost

50% of the votes fell in the "warmer than neutral" region of the scale (i.e. including "slightly warm" 34%, "warm" 7% and "hot" 3%) and 50% of the votes "cooler than neutral" (i.e. including "slightly cool" 19%, "cool" 9% and "cold" 2%). In summer more than ten times as many votes fell in "warmer than neutral" region of the scale (i.e. including "slightly warm" 43%, "warm" 12% and "hot" 6%) compared to the votes "cooler than neutral" (i.e. including "slightly cool" 5%, "cool" 1% and "cold" 0%). The PPD thermal comfort index is based on the assumption that people voting in the middle three categories (i.e. "slightly cool" -1, "neutral" 0, and "slightly warm" +1) of the 7-point thermal sensation scale are satisfied with their thermal environment. Extending the assumption to the AMV in this survey, 82% of the participants in winter and summer were satisfied with their transitional space thermal conditions. By logical extension, votes on +2 (warm), +3(hot), -2(cool), -3(cold) can be regarded as an expression of thermal dissatisfaction, which in this survey amounted 18% both in winter and summer. This indicates that the AGU transitional space, in which the survey was conducted, successfully met the industry-accepted minimum standard of 80% acceptability, as recommended in regulatory documents such as ASHRAE Standard 55.

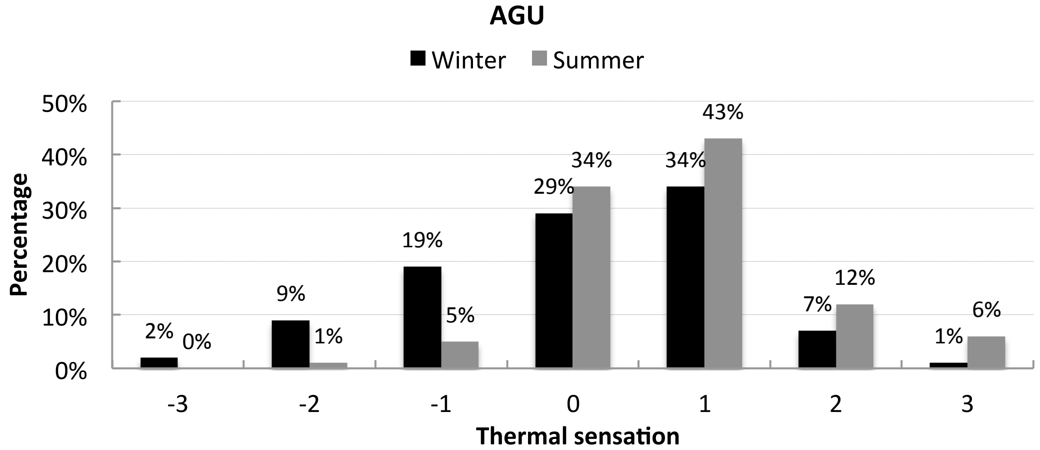

Figure 5.21 Distribution of thermal sensation in AGU transitional space.

Figure 5.22 shows a comparison of thermal satisfaction assessed using the following three methods: thermal acceptability, thermal sensation and thermal preference.

Whilst these three methods overlap, they offer slightly different perspectives on people's relationship with a given thermal environment. Thermal acceptability determines whether the current thermal conditions are considered to be acceptable (poor, neutral or good); thermal sensation assesses where the respondent's perception of current thermal conditions lies along an axis of Hot to Cold; and thermal preference is intended to determine if and how a subject would prefer the thermal conditions to change. It is worth noting that thermal comfort literature (Fox et al 1973, McIntyre 1980, de Dear and Brager 1997) shows that people can express satisfaction with current conditions, select a neutral sensation and yet counter-intuitively express a preference for a different set of conditions. For thermal acceptability, 89% participants in winter and 73% in summer found their thermal environment is neutral or good (acceptable). In terms of thermal sensation, 82% of the participants in both winter and summer were satisfied with the thermal conditions according to the ASHRAE scale (-1, 0, +1). In winter 11% of the participants found the environment is too cold (-2, -3) and 8% of them found the environment is too warm (+2, +3), when in summer only no more than 1% felt too cold and approximately 18% felt to warm. For thermal preference, 22% participants in winter indicated "no change" suggesting that they were satisfied with the present conditions, while 42% preferred warmer conditions and 36% preferred cooler conditions. In comparison, 20% participants in summer indicated "no change", whereas 8% preferred warmer temperatures and 72% preferred cooler temperatures.

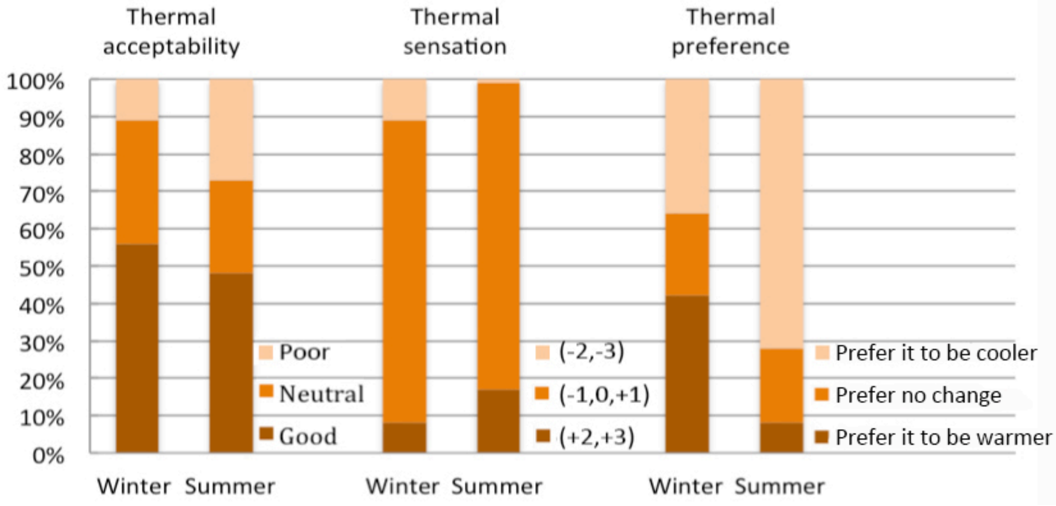

Figure 5.22 Comparisons of various subjective responses in AGU winter and summer.

The results show that thermal acceptability and thermal sensation indicate a high level of thermal satisfaction, higher or close to the ASHRAE Standard 55 recommended levels, while thermal preferences indicate a significantly lower level of thermal satisfaction — about 20% both in winter and summer.

5.7.2. RWCMD participants' thermal response

Figure 5. 23 shows that 52% and 51% of participants expressed their thermal sensation as "neutral" in winter and summer respectively. In winter, half of the votes fell in "warmer than neutral" region of the scale (i.e. including "slightly warm" 20%, "warm" 4%) and half of the votes were for "cooler than neutral" (i.e. including "slightly cool" 20%, "cool" 3% and "cold" 1%). In summer, it was almost the same situation: slightly more than half the votes fell in "warmer than neutral" region of the scale (i.e. including "slightly warm" 22%, "warm" 8%) compared to the votes for "cooler than neutral" (i.e. including "slightly cool" 20%). Extending the PPD thermal comfort index assumption (i.e. "slightly cool" -1, "neutral"0, and "slightly warm" +1) to the AMV vote in this survey, 92% of the participants in winter and 93% in summer were satisfied with their transitional space thermal condition. Similarly, the votes for +2 (warm), +3 (hot), -2 (cool), -3 (cold) can be seen as expressions of thermal dissatisfaction, which in this survey amounted 7% in winter and 8% summer. This indicates that the RWCMD transitional space, in which the survey was conducted, very successfully met the level of acceptability recommended in regulatory documents such as ASHRAE Standard 55.

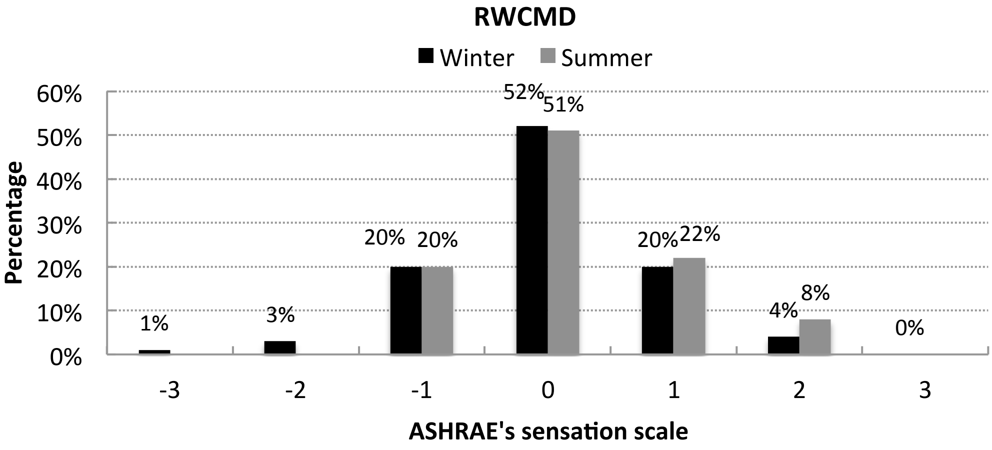

Figure 5. 23 Distribution of thermal sensation according to ASHRAE standards.

The levels of thermal satisfaction are illustrated in Figure 5.24 according to the three models introduced earlier: thermal acceptability, thermal sensation and thermal preference. For thermal acceptability, 89% participants in winter and 92% participants in summer found that the thermal environment condition is acceptable (neutral and good). In terms of thermal sensation, as mentioned above, 92% participants were satisfied with the thermal conditions in winter when 93% in summer were felt satisfied. For thermal preference, it is only 37% participants in winter and 44% in summer indicated "no change". Twenty two percent of participants like the environment "cooler" when 41% of them like the environment "warmer" in winter, when 44% participants prefer cooler temperatures and 17% prefer warmer temperatures in summer. The survey results also indicate that participants in RWCMD transitional pace have gauged their satisfaction of thermal acceptability, thermal sensation and preference different from the ASHRAE Standard 55 recommended as the result in AGU.

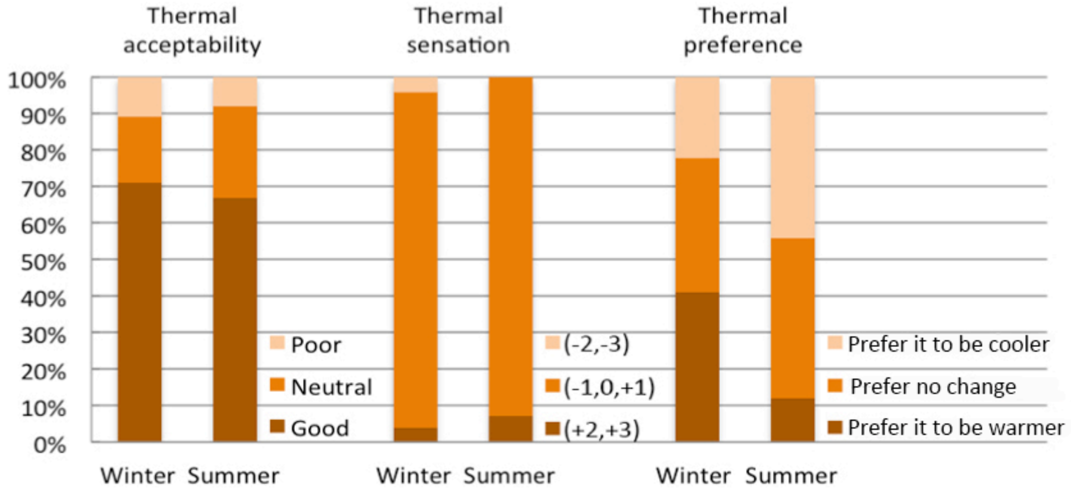

Figure 5.24 Comparisons of various subjective responses in RWCMD winter and summer.

5.7.3. WMC participants' thermal response

Statistical distributions of survey participants' perception of the thermal environment are summarized in Figure 5. 25. Fifty five percent and 54% of the subjects expressed their thermal sensation as "neutral" in winter and summer separately. In winter, less votes fell in "warmer than neutral" region of the scale (i.e. mainly at "slightly warm" 18% when other two choices are 0%) compared to the votes on "cooler than neutral" (i.e. "slightly cool" 26%, "cool" 1% and "cold" 0%). In summer, the votes fell in "warmer than neutral" and "cooler than neutral" are relatively equal as 24% and 23%

separately, even the votes on “slightly cool” are 2% higher than “slightly warm”. The middle central categories of the 7-point thermal sensation scale of Actual Mean Votes are as high as 99% in winter and 98% in summer. It indicates a quite high percentage of satisfaction of participants with their thermal environment compared to the industry-accepted minimum standard of 80% acceptability, as recommended in regulatory documents such as ASHRAE’S Standard 55 (ASHRAE 2013).

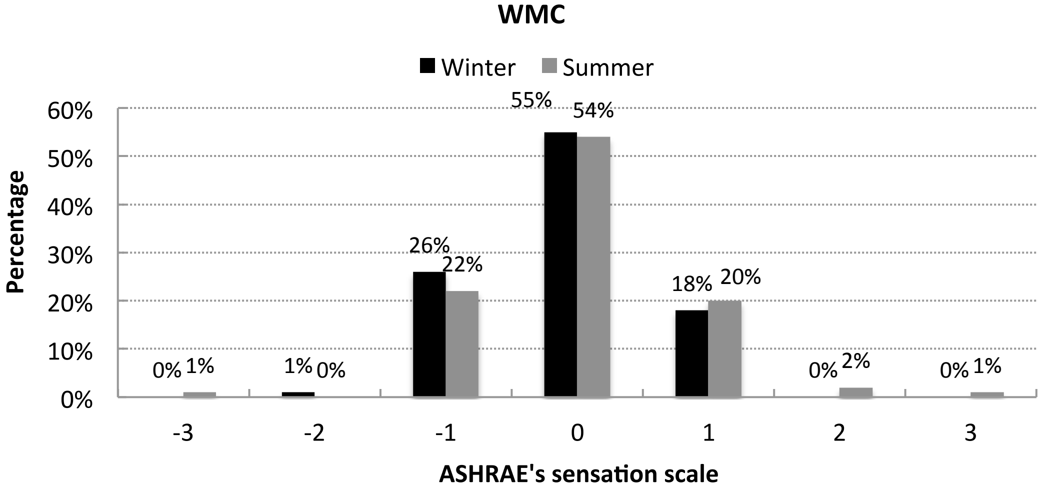

Figure 5. 25 Distributions of thermal sensation votes.

Figure 5. 26 illustrates participants’ satisfaction use three models as thermal acceptability, thermal sensation and thermal preference. For thermal acceptability, 96% of subjects in winter and 94% of subjects in summer were found the thermal environment is neutral and good (satisfied). By equating the central three categories (-1, 0, +1) of the ASHRAE scale with an expression satisfaction, as mentioned before, more than 95% subjects satisfied with the environment both in winter and summer. For thermal preference 43% and 50% of the participants in winter and summer indicated “no change”, suggesting that they were satisfied with the pre-set conditions. In winter 17% preferred cooler temperature and 41% prefer warmer temperature while in summer 24% prefer cooler thermal condition and 26% prefer warmer thermal condition.

The results show that thermal acceptability and thermal sensation indicate a high thermal satisfactory rate much higher than the ASHRAE Standard 55 recommended

(80%), when thermal preference indicate a quite lower thermal satisfactory rate no more than 50% both in winter and summer.

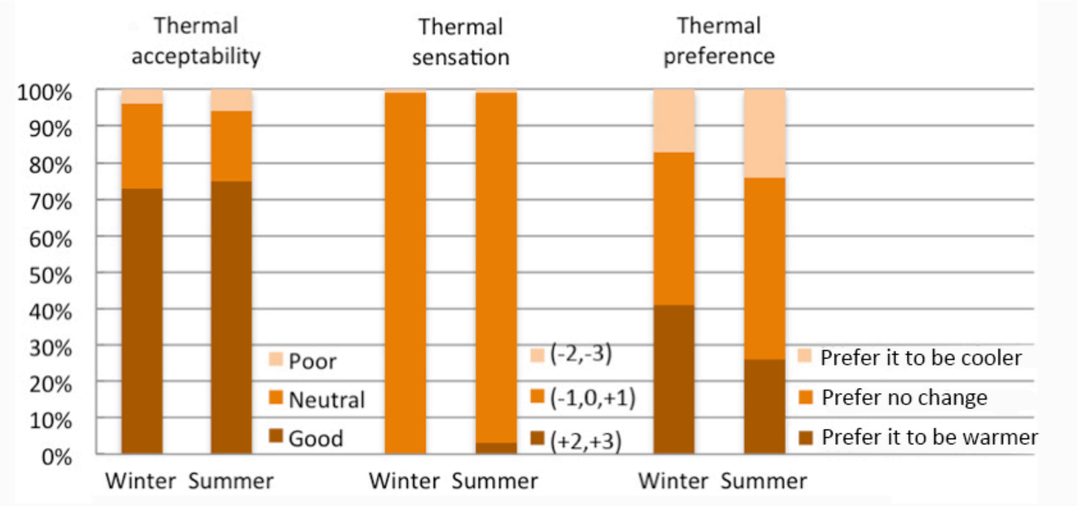

Figure 5. 26 Comparisons of various subjective responses in WMC winter and summer.

5.7.4. Discussion thermal satisfaction of the total indoor transitional space population

The above three sections show that among the three criteria for evaluating thermal satisfaction, both thermal acceptability (neutral and good) and thermal sensation levels (-1, 0, +1) indicate higher satisfaction than recommended by ASHRAE Standard 55 (80%) while the thermal preferences show a lower satisfaction rate — no more than 50% in all of three cases. Thus, Fanger's PPD model seems to overestimate the lack of thermal acceptability when compared to the judgments derived from thermal acceptability and thermal sensation methods, but underestimate dissatisfaction registered using the thermal preference method. This suggests that Fanger's PPD model is not useful in predicting people's thermal comfort in indoor transitional spaces.

Additionally, both in winter and summer, it can be seen that AGU participants express the highest levels of dissatisfaction with their thermal environment. Analysis of their reasons for dissatisfaction (open question on the questionnaire) as shown in Figure 5. 27, shows that the highest percentage of responses cite "too draughty" and "too cold" in winter, whilst in summer 26% of the respondents complain of being "too warm". The interesting thing is even in winter AGU, 7% people complains that it is too warm. Compared to the other two spaces, people in AGU complain more about it being "very bright", and coincides with the discussion in section 5.6 that a large glass façade in the south wall of the building lets too much direct sunlight into the space causing discomfort from glare. Figure 5. 27 also shows that in winter, a common reason for dissatisfaction over these three indoor transitional spaces is that they are "too draughty''. The draughts are caused by outdoor air movement, due to the indoor transitional spaces being located at the front of the building and which always close to the main entrance of the building, so people stay in the area of indoor transitional space where proximity to the entrance is often a source of discomfort due to draughts (some siting areas are set close to the entrance).

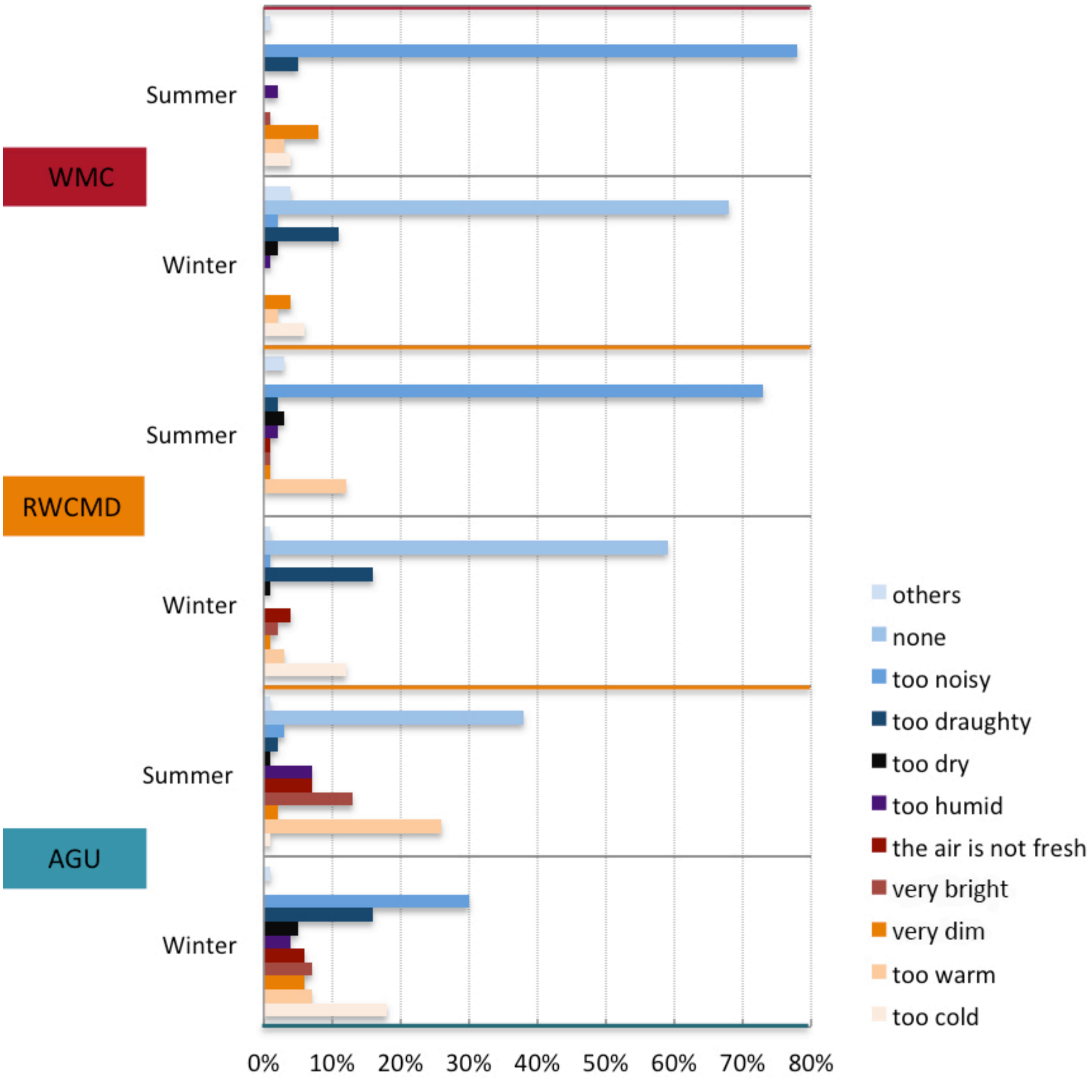

Figure 5. 27 Participants' dissatisfaction of the area they are staying.

Figure 5. 28 to Figure 5. 33 show the ranges for operative temperatures against the

80% and 90% acceptability levels. The acceptable temperature ranges were calculated according to the statistical assumptions underlying Fanger's PMV-PPD model. The 80% and 90% acceptability levels were correspond to a mean thermal sensation of ±0.85 and ±0.50 respectively. During the winter surveys the temperatures lie within 80% acceptability range for 100% of the time in the RWCMD and WMC, and 85% in the AGU. However, summer operative temperatures in all three cases were not 100% within the 80% acceptability range. Especially in AGU, operative temperatures remain within that range for only 73% of time, highlighting periods of overheating. Besides, the acceptable temperature range in winter WMC is far wider than the actual operative temperature range measured in the space, and so it illustrates a high thermal tolerance of the thermal environment by participants in WMC indoor transitional space.

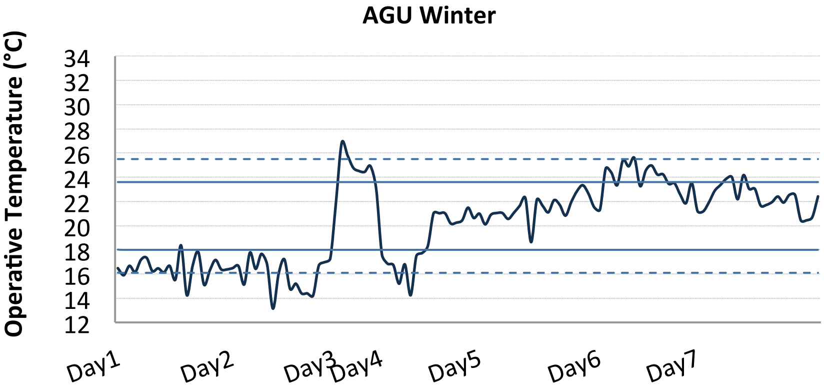

Figure 5. 28 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in summer of AGU.

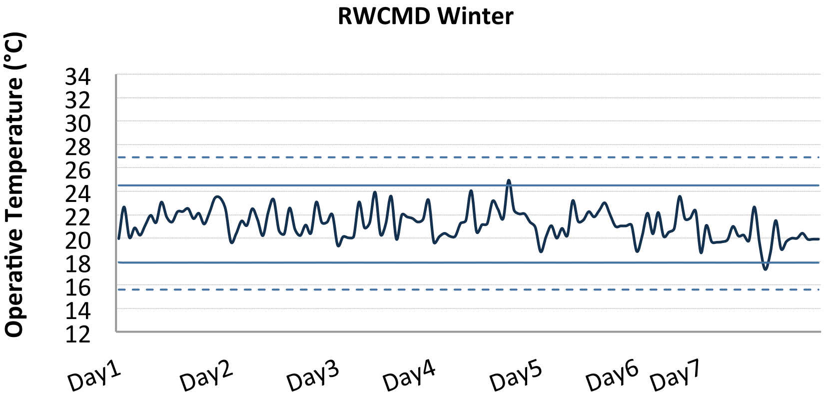

Figure 5. 29 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in winter of RWCMD.

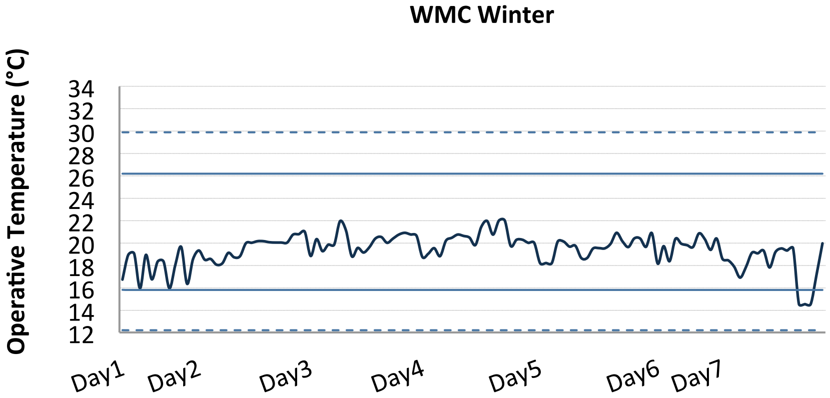

Figure 5. 30 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in winter of WMC.

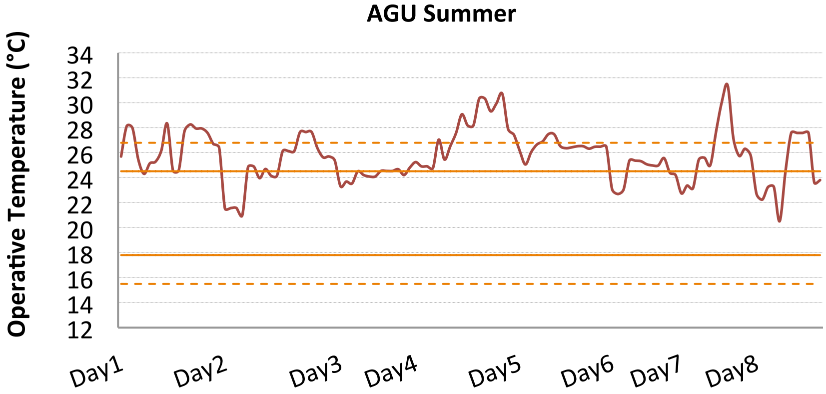

Figure 5. 31 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in summer of AGU.

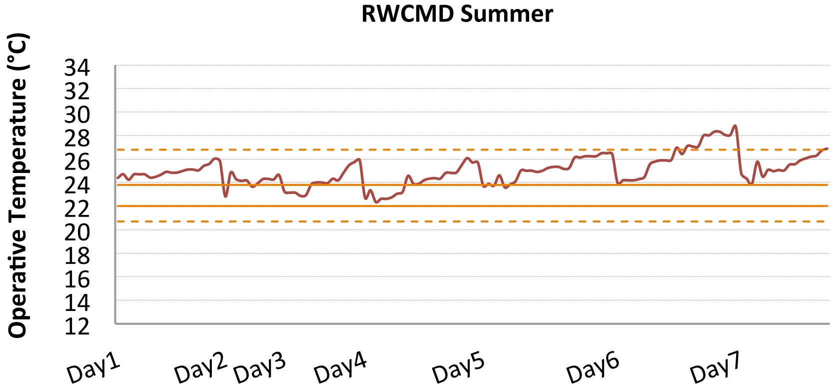

Figure 5. 32 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in summer of RWCMD.

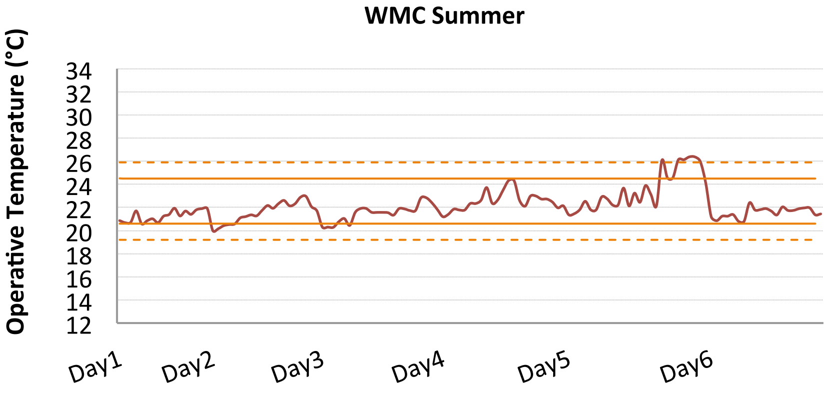

Figure 5. 33 Operative temperature, 80% (dotted lines) and 90% (continuous lines) acceptability temperature ranges in summer of WMC.

To examine how the thermal conditions are evaluated by people in three different indoor transitional spaces, the subjective thermal evaluations of three groups (in AGU, RWCMD and WMC), were compared against each other. The actual thermal sensation vote (AMV) was used as a dependent variable and the three groups as the independent variables as shown in Table 5.11. Chi-square (x^2) test of independence was conducted to compare the thermal sensation vote of AGU, RWCMD and WMC. Table 5.11 shows the results of Chi-square test of participants' AMV vote in AGU, RWCMD and WMC. Both in winter and summer, Fisher's Exact test was used to meet the Chi-square test assumption requirements. In winter the test results are x^2 =41.56, p<0.001 with the effect size -0.091; in summer the test results are x^2 =60.75, p<0.001 with the effect size -0.295. According to Table 5.11, the effect size of association between AMV and the participants in the three indoor transitional spaces was strong in both seasons. In other words, the Chi-square test shows a strong association among the actual thermal sensations of AGU, RWCMD and WMC. Therefore, based on these statistics, it can be concluded that people in the three indoor transitional spaces evaluate their thermal environment in a similar way. By considering the conclusion of the previous section — that significant differences were found among the main environmental variables measured in AGU, RWCMD and WMC —,it can be concluded that the reason people in the three indoor transitional spaces evaluated their thermal conditions differently is due to differences in the environmental variables across the three indoor transitional spaces.

The best that each space can realistically hope to achieve is a thermal environment that satisfies the majority of people in the space, or put more simply, ‘reasonable comfort’. Fanger (1970) claimed that, in general, a comfort zone is an environment situation in which 80% of the occupants feel satisfied with their environment, and the HSE (Health & Safety Executive) in the UK also considers 80% of occupants as a reasonable limit for the minimum number of people who should be thermally comfortable in an environment (Heath & Safety Executive 2007).

The data analysis indicates that the thermal conditions in the three surveyed transitional spaces in buildings regularly meet people’s thermal requirements. In all cases, satisfaction with the thermal environment according to the ASHRAE scale’s central three categories (-1,0,+1) meets the 80% required by that standard. Actually it is much more than 80% in RWCMD and WMC, especially in WMC, the satisfaction rate is close to 100% both in winter and summer. In terms of direct acceptability, the highest level also happens in the WMC with 96% in winter and 94 % in summer. The lowest occurs in the AGU, with 89% and 73% for winter and summer respectively. It indicates that regardless of whether thermal sensation scale or direct acceptability is used, people in all three indoor transitional spaces have a very high satisfaction level of their thermal environments, especially in RWCMD and WMC, even though the measured operative temperature in them is beyond the comfort temperature boundary. However, when using the thermal preference percentage to evaluate thermal satisfaction rate in indoor transitional spaces in these three building, it was found that participants prefer a thermal environment different to the one experienced. In most cases the percentage is no more than 50%, but in AGU summer, 72% participants expressed a preference for a cooler environment. Combining the results of the thermal sensation scale and acceptability shows a much higher satisfaction level than thermal preference results show. The high satisfaction rate and acceptability illustrates a higher thermal discomfort tolerance in indoor transitional spaces.

Table 5.11 Results of Chi Square test among three groups and AMV

Chi-square Test							Measurement of association (effect)			
	Number of cases	Pearson Chi-square (x^2)[a]			Fisher's Exact Test [b]		Cramer's V		Somers'd	
		Value	DF	Sig.	Value	Exact Sig.	Value	Sig.	Value	Sig.
Winter	375				41.557	0.000[b]	0.236	0.000	-0.091	0.045
Summer	384				60.754	0.000[b]	0.281	0.000	-0.295	0.000

a. 9 cells (42.9%) have expected count less than 5. The minimum expected count is .32.

b. Fisher's Exact test have been used only when the assumption of Chi-square is violated. Based on 10000 sampled tables with starting seed 1502173562 and 92208573.

5.8. The relationship between AMV and environment and personal parameters

This section aims to define the relative contribution of environmental and personal parameters (heat-balance parameters) to the thermal perception of subjects in indoor transitional spaces. To find which environmental parameters had strong influence on thermal comfort in three indoor transitional spaces, two steps of statistic analysis were conducted. Firstly, a correlation analysis was carried out between AMV and the environmental and personal parameters. Secondly, a further ordinal regression analysis carried out on the correlated environmental and personal parameters with AMV.

5.8.1. The correlation analysis

Table 5.12 shows the results of correlation analysis between AMV and environmental and personal parameters in AGU, RWCMD and WMC respectively. The results of correlation analysis indicate that AMV correlated with operative temperature than with any other of physical variables, with the associated coefficients being 0.492 for AGU, 0.264 for RWCMD and 0.256 for WMC (all significant at $p<0.01$). In terms of personal parameters, AMV correlated to clothing insulation rather than activity met as the results of -0.327 for AGU (significant at $p<0.01$), -0.155 for RWCMD (significant at $p<0.05$) and -0.019 for WMC (significant at $p>0.05$). Therefore, these variables analysed by using the ordinal regression analysis (because AMV value is ordinal variables).

Table 5.12 Correlation analysis between AMV and other environmental parameters.

a-AGU

	AGU					
	AMV	Top	AS	Rh	Clo	Met
Pearson Correlation		0.492**	0.069	0.067	-0.327**	0.076
Sig. (2-tailed)		0.000	0.279	0.296	0.000	0.235
N	245	245	245	245	245	245

***Correlation is significant at the 0.05 level (2-tailed).**
****Correlation is significant at the 0.01 level (2-tailed).**

b-RWCMD

	RWCMD

	AMV	Top	AS	Rh	Clo	Met
Pearson Correlation		0.264**	-0.021	0.054	-0.155*	0.059
Sig. (2-tailed)		0.000	0.735	0.384	0.011	0.339
N	265	265	265	265	265	265

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

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

c-WMC

	WMC					
	AMV	Top	AS	Rh	Clo	Met
Pearson Correlation		0.256**	0.008	0.050	0.010	-0.019
Sig. (2-tailed)		0.000	0.899	0.431	0.875	0.766
N	249	249	249	249	249	249

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

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

5.8.2. AMV model for indoor transitional spaces

Table 5.13 shows the results of the ordinal regression to predict the criterion variable (AMV), for data collected in AGU, from explanatory variables include operative temperature and clothing insulation that screen out from correlation analysis. As can be seen, operative temperature is the significant variable ($p<0.001$) and account for almost 24% (Cox and Snell $r^2=0.235$) of the variation in the actual sensation vote (AMV). However, $r^2=0.235$ indicates weakness in the ability of predicted model to fit that data. The Wald value also indicates that operative temperature (Wald=39.792 $p<0.001$) is the most important predictor that influences the actual thermal sensation votes of AGU participants. The outcome model is presented in equation (1).

$$\mathbf{AMV_{AGU}=0.281T_o \qquad r^2=0.235 \qquad (1)}$$

Table 5.13 Ordinal regression statistics and best fit model to predict AMV using environmental and personal data from AGU

a-Ordinal Regression (Logit)

Model Fitting				Goodness-of-Fit		
N	Chi-Square	df	Sig.	Chi-Square	df	Sig.
245	65.500	2	0.000	663.496	1432	1.000

b-Dependent variable: AMV

R squared		
Cox and Snell	Nagelkerke	McFadden
0.235	.247	.089

c-Ordinal Regression (Logit): Location

IV	Estimate	Wald	df	Sig.
T_o	0.281	39.792	1	0.000
Clo	0.196	0.306	1	0.580

d-Test of Parallel lines

Chi-Square	df	Sig.
15.974	10	0.100

Table 5. 14 shows the results of the ordinal regression to predict the criterion variable (AMV), for data collected in RWCMD, from explanatory variables include operative temperature and clothing insulation that screen out from correlation analysis. As can be seen, operative temperature is the significant variable ($p<0.001$) but only account for 6.4% of the variation in the actual sensation vote (AMV). Moreover, $r^2=0.064$ indicates weakness in the ability of predicted model to fit that data. The Wald value indicates that operative temperature is the most important predictor that influences the actual thermal sensation votes of RWCMD participants as the value of 12.664. The outcome model is presented in equation (2).

$$\mathbf{AMV_{RWCMD}=0.247T_o \qquad r^2=0.064 \qquad (2)}$$

Table 5. 14 Ordinal regression statistics and best fit model to predict AMV using environmental and personal data from RWCMD

a-Ordinal Regression (Logit)

Model Fitting				Goodness-of-Fit		
N	Chi-Square	df	Sig.	Chi-Square	df	Sig.
265	17.554	2	.000	617.073	1243	1.000

b-Dependent variable: AMV

R squared		
Cox and Snell	Nagelkerke	McFadden
.064	.070	.027

c-Ordinal Regression (Logit): Location

IV	Estimate	Wald	df	Sig.
T_o	.247	12.664	1	.000
Clo	.258	.375	1	.540

d-Test of Parallel lines

Chi-Square	df	Sig.
17.033	8	.030

Table 5. 15 shows the results of the ordinal regression to predict the criterion variable (AMV), for data collected in WMC, from explanatory variable of operative temperature screen out from correlation analysis and clothing insulation. As can be seen, operative temperature ($p<0.001$) and clothing insulation ($p=0.001$) are the significant variables and account for almost 10% of the variation in the actual sensation vote (AMV). However, $r^2=0.095$ indicates weakness in the ability of predicted model to fit that data. By comparing to clothing insulation, the Wald value also indicates that operative temperature (Wald=26.801 $p<0.001$) is the most important predictor that influences the actual thermal sensation votes of WMC participants. Clothing insulation for participants in WMC was found to be significant in predicting the AMV, however, it was less influence on AMV comparing to operative temperature, Wald value of clothing insulation is 10.715 and $p=0.001$. The outcome model is presented in equation (3).

$$\mathbf{AMV_{WMC}=0.442T_o+1.323Clo \qquad r^2=0.095 \qquad (3)}$$

Table 5. 15 Ordinal regression statistics and best fit model to predict AMV using environmental and personal data from WMC

a-Ordinal Regression (Logit)

Model Fitting				Goodness-of-Fit		
N	Chi-Square	df	Sig.	Chi-Square	df	Sig.
249	24.874	2	.000	509.756	1432	1.000

b-Dependent variable: AMV

R squared		
Cox and Snell	Nagelkerke	McFadden
.095	.107	.046

c-Ordinal Regression (Logit): Location

IV	Estimate	Wald	df	Sig.
T_o	.442	26.801	1	.000
Clo	1.323	10.715	1	.001

d-Test of Parallel lines

Chi-Square	df	Sig.
20.287	10	.027

Operative temperature is the most important predictor of thermal sensation in three indoor transitional spaces: $T_{o\ AGU}$ (Wald=39.792 p<0.001), $T_{o\ AGU}$ (Wald=12.664 p<0.001) and $T_{o\ WMC}$ (Wald=26.801 p<0.001). Since operative temperature combines the effect of both radiant and air temperature, its influence suggests the important of solar radiation intensity together with air temperature. Thus, the mitigated of solar and air temperature is significant for the design of indoor transitional spaces, and these two parameters could have great impact on the use of the indoor transitional spaces and may determine the number of people and activities in them.

5.9. Summary

This chapter primarily states the characteristics of three cases, which provide good examples of indoor transitional spaces in Cardiff. The sample profiles of participants as well as the climate environment profile in AGU, RWCMD and WMC were described.

Most visitors of indoor transitional space of educational institute (AGU and RWCMD) are student at the age range 16-24 while in the cultural institute (WMC) they are dispersed at each age range averagely. The building type also influence participant's visit frequency and dwell time in indoor transitional space of the building. The main activity in all of these three indoor transitional spaces is sitting and the sitting location is decided by the design and facility place in the indoor transitional space.

Three indoor transitional spaces have different physical characteristics (layout, size and external orientation etc.) and heating-cooling system, which results in a significantly different thermal environment among three indoor transitional spaces. This put a significant influence on the participants' evaluation of their thermal sensation.

The aim of this field experiment was to investigate the comfort perception of occupants in the air-conditioned and natural environment of indoor transitional spaces. Either by direct votes of acceptability or by indirect measures using central three categories of thermal sensation scales, it indicates a high satisfactory rate of thermal environment in all of these three indoor transitional spaces.

This investigation examined how people in different indoor transitional spaces evaluate thermal conditions. The finding suggests that people in three different indoor transitional spaces evaluate their thermal environment differently, and the reason is necessarily due to difference in the environmental variables among three indoor transitional spaces. However, other factors such as thermal adaptation may influence this relationship also. In fact, it was found that the percentage of participants who prefer to maintain their thermal conditions was lower than those who were feeling neutrally comfortable. In other words, some participants were unsatisfied with their thermal conditions even their feeling neutral, the contradiction between high acceptable and unsatisfied rate implies the occurrence of thermal adaptation.

The relationship between the environmental variables and the actual thermal sensation votes of participants was examined. Operative temperature T_{op} is appeared to be the most important predictor of thermal sensation in three indoor transitional spaces. This also suggests the importance of solar radiation intensity together with air temperature, which could have an excessive impact on the use of the indoor transitional spaces in UK climate, and may determine the number of people and activities in them. Both the design and management of indoor transitional spaces can influence mitigate of air temperature and solar radiation. For example, moderate the size of glass façade, change the seat area to avoid direct sun light; moderate heating-cooling system to mitigate air temperature in indoor transitional spaces. Besides, the cloth insulation also significantly affects subjects' evaluation of their thermal sensation.

Chapter 6 Thermal sensation and use of indoor transitional space

6.1 Introduction

This chapter presents and discusses how people from indoor transitional spaces evaluate their thermal environment and the indoor transitional spaces. Transitional spaces are a particularly complex building type where the needs of very different population groups are accommodated. The indoor microclimatic conditions are expected to provide a comfortable working environment to the small number staff and at the same time a comfortable transient environment to visitors. Besides, among the different group visitors, their thermal requirement of indoor transitional space are also differently depends on their way of using transitional space. Variations in activity level and clothing insulation, along with time spend in the zone and overall expectations are differentiating factors for variations in thermal requirements among different group of visitors. The diversity of spaces and the heterogeneous functions across the different transitional spaces zones further contribute to the thermal comfort conflicts. Understanding such conflicts can improve thermal environment conditions, while reducing the large amounts of energy consumed for conditioning of indoor transitional spaces.

This chapter firstly discussing the reasonability of heat balance model and thermal adaptive theory using for understand thermal perception in different indoor transitional space. Then discuss the thermal reception and thermal tolerance in indoor transitional spaces, the results comparing with thermal comfort standards, and a comparison between indoor transitional spaces and other type of transitional spaces should be discussed. Lastly, the relationship of thermal perception and using of transitional space is discussed. The results presented in this chapter explain the following:

- Investigate the evaluation of participants' thermal sensation in indoor transitional space.
- The thermal requirements in indoor transitional space, including neutral temperatures, preferred temperatures and comfort temperature range.
- Investigate the thermal adaptation of participants in indoor transitional spaces.
- Investigate the influence of thermal comfort on people's using indoor transitional spaces.

6.2 Thermal sensation in indoor transitional space

6.2.1 Evaluating the physiological approach

In order to find out if the thermal perception of subjects in indoor transitional spaces can be explained by physiological approach, subjective thermal sensations need to be compared with the heat-balance model. The thermal sensation in three indoor transitional spaces in Cardiff UK were examined. Participants were asked to evaluate their thermal sensation at the time of interview on ASHRAE scale. This was then compared to Fanger's model, the theoretical Predicted Mean Vote (PMV). The PMV model predicts thermal sensations as a function of six parameters: air temperature, mean radiant temperature, air velocity, humidity, clothing and activity. The results show a great inconsistency between AMV and PMV in AGU and WMC transitional space, and a little inconsistency in RWCMD transitional space.

The majority of occupants in each transitional space reported as acceptable AMV (middle three categories on the ASHRAE scale) in both seasons. In AGU, 82% of the participants both in winter and summer were satisfied with the thermal condition according to the ASHRAE scale central three categories (-1,0,+1), when in PWCMD it is 92% in winter and 93% in summer choose these three category and in WMC the percentage is 99% in winter and 96% in summer separately. Among these three transitional spaces, AGU participants were most dissatisfied with their thermal environment in both winter and summer when WMC participants were most satisfied with their thermal environment.

The percentage frequency distribution for PMV and AMV of the interviews has been calculated for all the indoor transitional spaces and the different seasons (Figure 6.1, Figure 6.2 and Figure 6.3). It is clear that there is a great inconsistency between the AMV and PMV. As a result of specific environment of AGU, “slightly warm” was the actual thermal sensation with highest percentage in winter and “neutral” in summer, when “neutral” was the sensation with the highest percentage in both winter and summer in RWCMD and WMC. Although PMV follows the seasonal shift of AMV it predicts cooler AMV in all three transitional spaces in winter and summer except in AGU summer. Besides, it shows that PMV matched to AMV in RWCMD in both season better than in other two indoor transitional spaces. In summer AGU, it predicts towards the warm side about 1 scale. The specific of AGU transitional space’s environment results to the opposite shifts AMV towards votes with PMV in cool season, in winter it towards warm votes obviously when in summer it towards warm side less obviously.

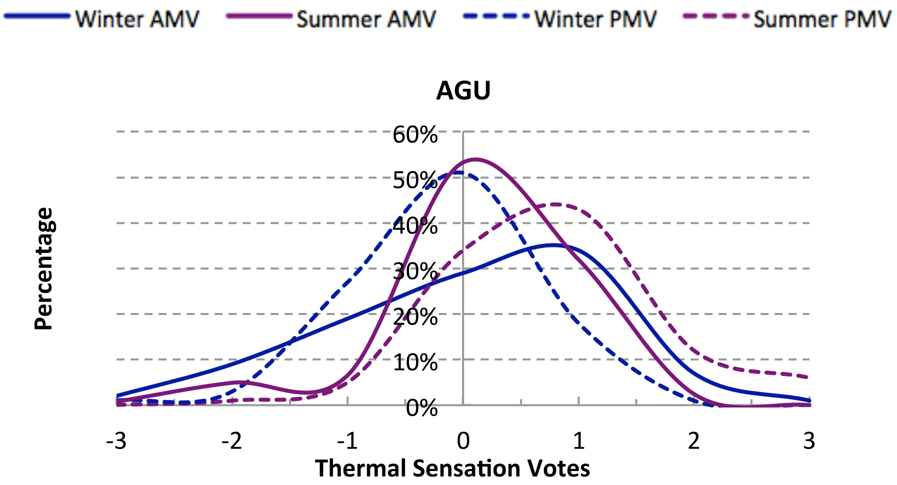

Figure 6.1 Percentage distribution of actual and predicted thermal sensation in AGU.

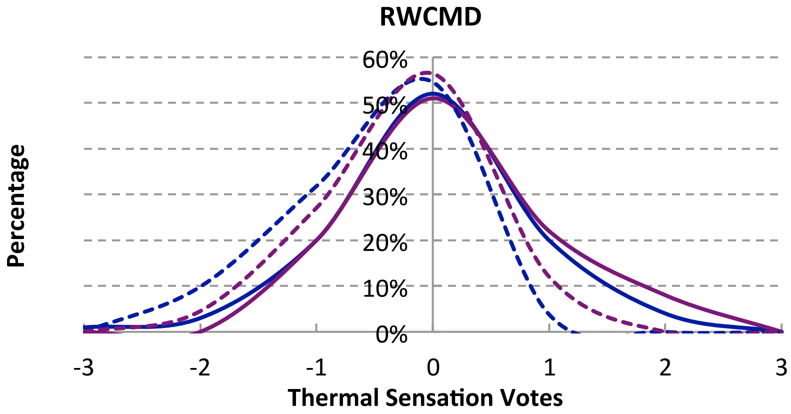

Figure 6.2 Percentage distribution of actual and predicted thermal sensation in RWCMD.

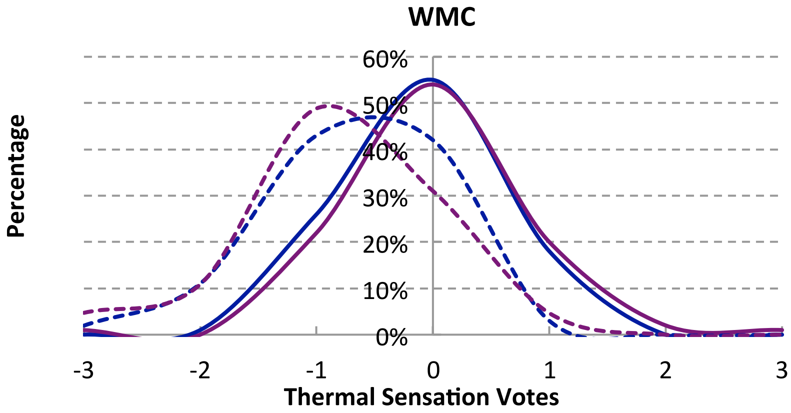

Figure 6.3 Percentage distribution of actual and predicted thermal sensation in WMC.

In AGU the Actual Mean Vote on thermal sensation scale is AMV=+0.08 in winter and AMV=+0.78 in summer for all participants samples fell between neutral (0) and slightly warm (+1). The mean of the predicted PMV (predicted sensation vote) index across this sample was -0.18 in winter and +0.18 in summer. The respondents' PMV was marginally colder than AMV by about -0.26 thermal sensation units in winter. In summer the respondents' PMV cooler than AMV by about 0.60 thermal sensation units.

In RWCMD the Actual Mean Vote on thermal sensation scale for all participants samples is AMV=+0.00 in winter and AMV=+0.17 in summer, felling the scale between neutral (0) and slightly warm (+1). The mean of the predicted PMV index across this sample was -0.42 in winter and -0.23 in summer. The respondents' PMV (predicted sensation vote) was marginally colder than AMV (actual sensation vote) by 0.42 thermal sensation units in winter and 0.40 units in summer.

In WMC the Actual Mean Vote on thermal sensation scale is AMV=-0.09 in winter and AMV=+0.01 in summer for all participants samples fell at and between slightly cool (-1) and slightly warm (+1). The mean of the predicted PMV index across this sample was -0.65 in winter and -0.86 in summer. The respondents' PMV (predicted sensation vote) was obviously colder than AMV (actual sensation vote) by 0.74 thermal sensation units in winter and -0.85 in summer.

The results are shows an apparently inconsistent between AMV and PMV, which evident that the thermal sensation of subjects in indoor transitional space of UK climate cannot be simply explained by heat-balance indices. Besides, the result indicates that neither in winter or summer, the actual thermal sensation of subjects in indoor transitional spaces was warmer than the predicted thermal sensation This is proves the conclusion of Chun's study of transitional space it claim that PMV cannot be used for transitional space thermal comfort predictions (Chun 2004). Chun pointed out that this is result from the unstable and dynamic physical and MET value of subjects in transitional space. Considering the steady state physical and MET value of subjects in indoor transitional space of this study, thermal experience and expectation should be considered as the main reason of the inapplicable of PMV.

6.2.2 Thermal sensation changing by operative temperature

The previous correlation analysis indicates that the evaluation of actual thermal sensation is significantly correlated to operative temperature in indoor transitional spaces. To investigate how the AMV change depending on the indoor operative temperature, the regression analysis is carried on the mean values and 95% confidence intervals for AMV and PMV categorized by indoor operative temperature binned by 1 °C intervals.

Although people stay in the same environment, thermal sensations among them are different. To reduce the individual's different individual differences, de Dear (1998) suggested that the bins' mean thermal sensation votes (MTSV), rather than the individual actual votes, be used in the analysis. Figure 6.4 and Figure 6.5 illustrate that the mean value and 95% confidence intervals for AMV categorized by indoor operative temperature binned by 1 °C intervals in winter and summer in AGU. These figures indicate how the actual (AMV) thermal sensations change depending on the indoor operative temperature. In winter, below 21 °C there seems to be a significant change in the subjects' actual thermal sensation, stay far from neutral except 16-17 °C. However, from 20 up to 23 °C, there seems no thermal sensation change and stay close to neutral. As indoor operative temperature from 22 up to 25 °C there is a steady increase in mean thermal sensation when from 25 to 27 °C the mean thermal sensation is steady decreasing. In summer, thermal sensation change steadily except during the temperature range from 20 to 23 °C and 31 to 32 °C.

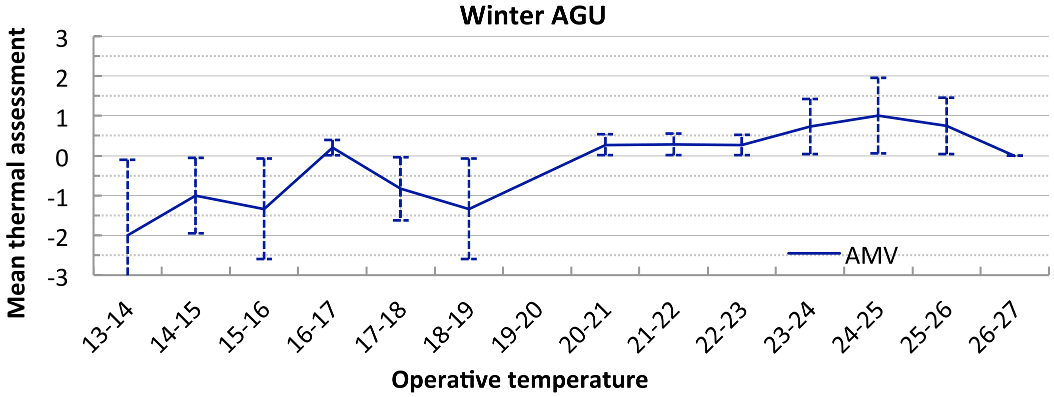

Figure 6.4 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in winter AGU. Error bars represent 95% confidence intervals.

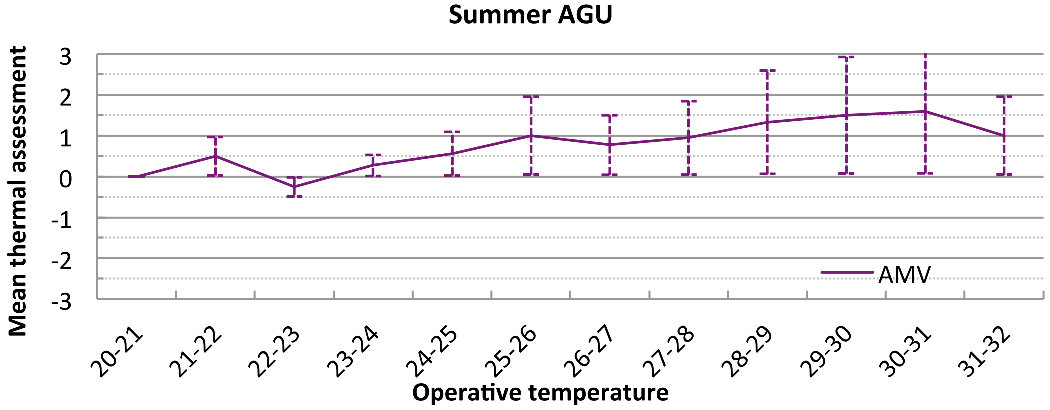

Figure 6.5 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in summer AGU. Error bars represent 95% confidence.

Figure 6.6 and Figure 6.7 show the mean value and 95% confidence intervals for AMV categorized by indoor operative temperature binned by 1 °C intervals in RWCMD. The change of actual thermal sensations (AMV) depending on the indoor operative temperature illustrated in these figures. Both in winter and summer, the thermal sensation shows an overall steady increasing with the increase of operative temperature. But in winter, from 19 to 25 °C, there seems to be no significant change in the subject's thermal sensation and staying close to neutral while in summer the increase tendency interrupted at 27 to 28 °C.

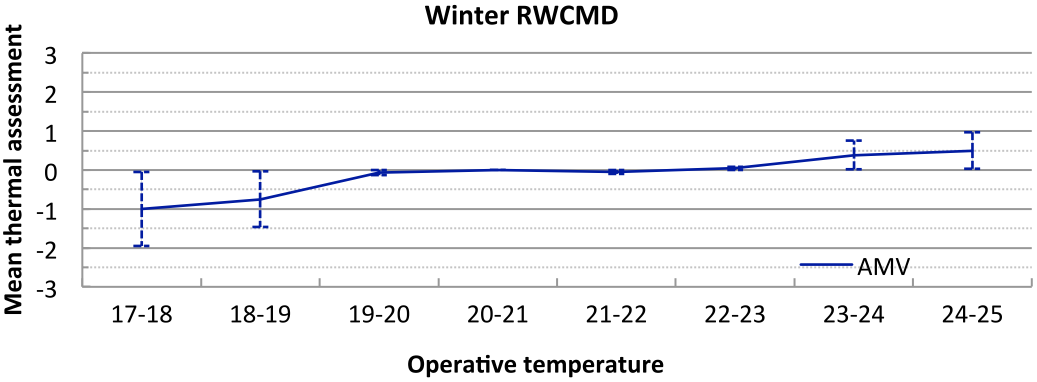

Figure 6.6 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in winter RWCMD. Error bars represent 95% confidence intervals.

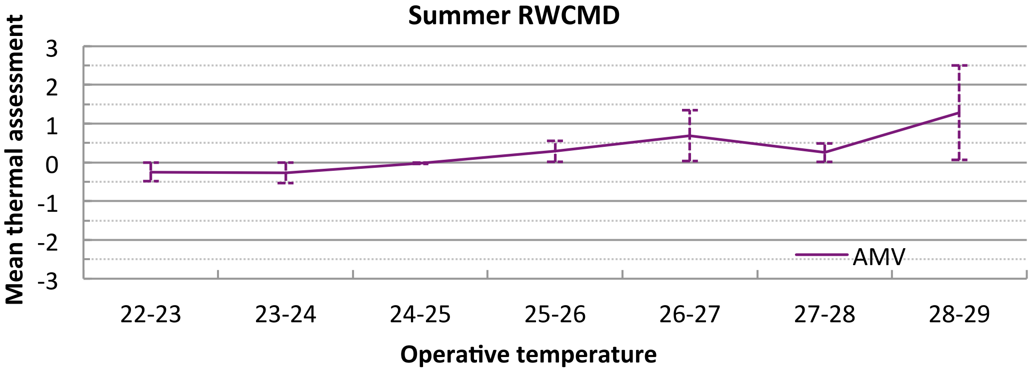

Figure 6.7 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in summer RWCMD. Error bars represent 95% confidence intervals.

Figure 6.8 and Figure 6.9 show the mean value and 95% confidence intervals for AMV categorized by indoor operative temperature binned by 1 °C intervals in WMC. The change of actual thermal sensations (AMV) depending on the indoor operative temperature illustrated in these two figures. In winter, during the range of indoor operative temperature from 14 to 18 °C there is a steady decrease in mean thermal sensation when from 18 to 23 °C there is a steady increase. In summer the steady increase is last during all the temperature range that from 20 to 27 °C.

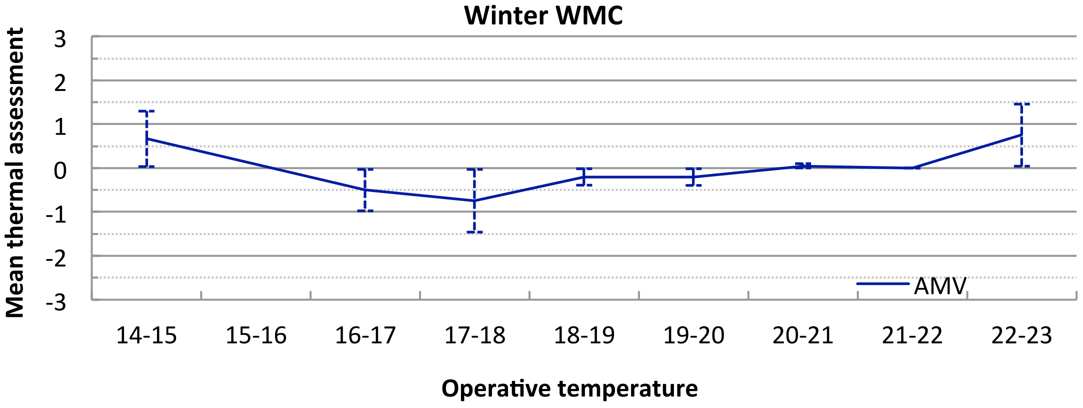

Figure 6.8 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in winter WMC. Error bars represent 95% confidence intervals.

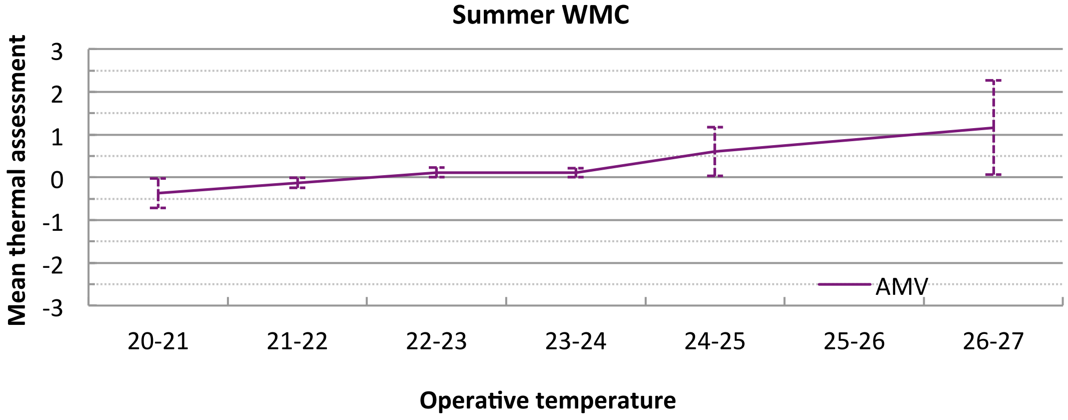

Figure 6.9 Actual mean thermal sensation (AMV) in relation to indoor operative temperature in summer WMC. Error bars represent 95% confidence intervals.

Figure 6.4 to Figure 6.9 show a significant change of thermal sensation vote depends on the increase of operative temperature. In additionally, this change is irregular in winter but increase steady in summer with the changing of operative temperature. It can be seen that in winter indoor transitional spaces, operative temperature not influence people's thermal sensation as significantly as in summer. Combing with the results of correlation analysis about thermal sensation and environmental and personal parameters, it means cloth insulation put a more significant influence on subjects' evaluation of their thermal sensation in winter indoor transitional spaces rather than in summer. Combing with the literature review, it also indicates that thermal expectation and thermal experience might be influence subjects' thermal sensation evaluation in indoor transitional spaces.

6.2.3 Comparison of thermal sensation to Humphrey's standardized equation

The mean sensation votes fro all the group of subjects in current study in the ASHRAE scale is +0.16, slightly warmer than neutral (mean air temperature is 22.5 °C). Thus there was a bias towards the warm side of the scale. Humphreys (1976) showed a highly significant correlation between mean responses versus mean air or globe temperature from more than 200,000 observations. The model of standardized mean sensation derived from the liner regression analysis as Equation (1):

$$\textbf{Standardized mean sensation} = -0.244 + 0.0166\, T_i \qquad (1)$$

Where T_i is mean indoor air temperature

Because of the different number of categories in various scales, Humphreys used a standardized form by dividing the absolute mean response by the number of positive categories on the scale. Figure 6.1 shows the mean thermal sensation votes of current study and the standardized sensation votes predicted by Humphrey's model. In winter all standardized sensation values of current subjects are lower than those predicted by Humphreys' model, when in summer the comparison value is varied in different building space. It implies that occupants in Cardiff UK are less adapted to cool condition than the means of world-wide subjects.

Table 6.1 Comparing mean thermal sensation votes of current study and the standardized sensation votes predicted by Humphrey's model.

	Winter			Summer		
	AGU	RWCMD	WMC	AGU	RWCMD	WMC
Mean operative temperature	20.3	21.3	19.5	26.2	25.1	22.5
Mean sensation vote	0.08	0.00	-0.09	0.78	0.17	0.01
Sensation predicted by Humphrey's model	0.09	0.11	0.08	0.19	0.17	0.13

6.3 Thermal comfort requirements

6.3.1 Neutral temperature

This study raised the question of how does the thermal comfort requirements in indoor transitional space in UK climate, such as how about the thermal sensitivity and what is the neutral temperature. Besides, if the thermal comfort requirement in different indoor transitional space is different depends on the way of subjects using it? The following step is to find and compare the thermal comfort requirement.

Thermal neutrality is the situation that the temperature people feel neither warm nor cool (neutral thermal sensation) in the environment (Humphreys 1975) or the thermal index value corresponding with a maximum number of building occupants voting neutral on a thermal sensation scale (Brager 1998). The average neutral temperature has been used in thermal comfort research to study the effects of experience on respondents' thermal perception (Lin 2009). Data collected from AGU, RWCMD and WMC was used to calculate the neutral temperatures to examine how people from different indoor transitional spaces adjust to their thermal perceptions. The "bin mean thermal sensation vote" rather than the individual actual votes was used to reduce individual difference (De Dear and Brager 2002) (Hwang and Lin 2007). This can be done by gathering several votes that correspond with half or more T_o degrees depending on the highest value of r^2 obtained.

Figure 6.10 to Figure 6.15 use mean thermal sensation responses of each half degree increment of operative temperature; other studies such as Hwang and Lin (2007) used a one-degree increment. The half-degree increment was selected because it better fits the number of participants in this study i.e. the value of r^2 associated with half-degree increment is higher than that when using one or two-degree increment.

a. Neutral temperature in AGU

Because of the significance of the operative temperature, as a predictor of the thermal sensation in the context of this study, it was therefore used as a thermal index to calculate the neutral temperature and examine the thermal sensitivity. The sensitivity of subjects' thermal sensation to operative temperature was evaluated by examining mean thermal sensation vote response for each half-degree interval. The plotted data is in Figure 6.10 and Figure 6.11. The fitted regression lines for subjects' sensation prediction versus operative temperature in winter and summer are:

Winter:

$AMV = 0.180\ T_o - 3.740 \quad r^2 = 0.600$ (2)

Summer:

$AMV = 0.150\ T_o - 3.173, \quad r^2 = 0.586$ (3)

The coefficient of determinant (r^2) between AMV and the operative temperature in winter is 0.600 for Equation. (2) and in summer is 0.586 for Equation (3).

The slopes of the regression lines represent the sensitivity of the subjects with respect to the operative temperature. It is approximately 5.5 °C per sensation unit for the AMV gradient in winter and 6.5 °C in summer. The neutral condition is derived by Equation (2) and (3) for a mean thermal sensation vote of zero. Regression analysis of average binned AMV gave a neutral temperature 20.8°C in winter and 21.2 °C in summer.

According to the equations, on average, 5.5 and 6.5 °C of operative temperature change shifts the occupant’s mean thermal sensation one point on the seven-point scale (one divided by the regression coefficient of 0.180 and 0.150 in Equation (2) and (3). In adaptive thermal comfort theory it regard the gradient of this regression equation as being inversely proportional to the adaptability of the building occupants under analysis; a very shallow gradient indicates the subjects were able to adapt very effectively to changes in temperature (instead of feeling over- or under-heated and shifting their thermal sensation accordingly), whereas a steep regression line suggests the subjects were not successful in adapting because they quickly felt warm (or cool) as the room temperature shifted away from their neutrality. At more than five and six degrees per thermal sensation unit, the regression equation shows this sample to be remarkably successful at adapting to changes in indoor temperature.

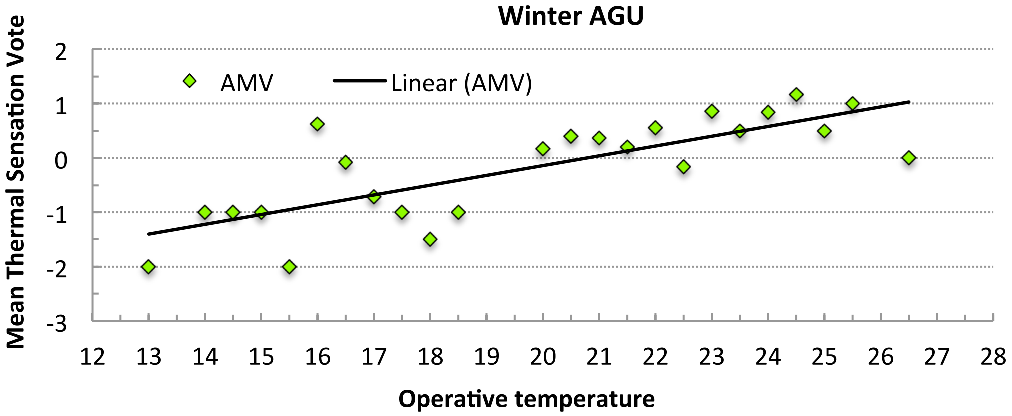

Figure 6.10 Mean observed sensation in winter AGU.

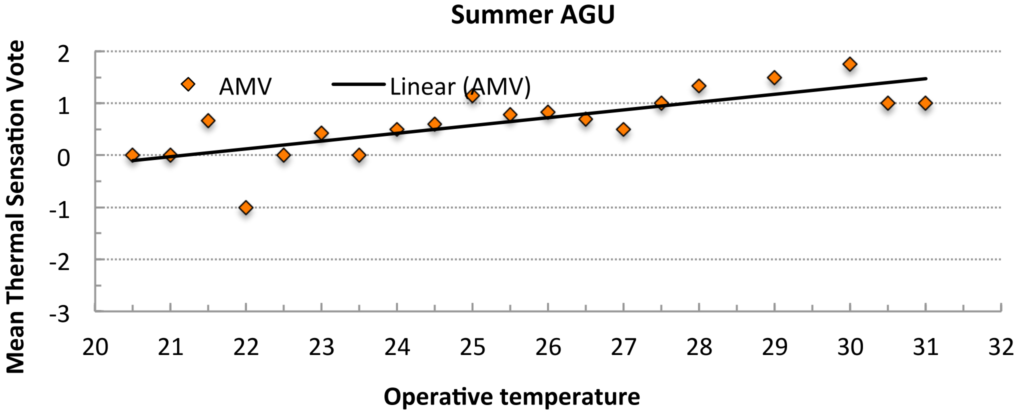

Figure 6.11 Mean observed sensation in summer AGU

b. Neutral temperature in RWCMD

The sensitivity of subjects' thermal sensation to indoor operative temperature in RWCMD was evaluated by examining mean thermal sensation vote response for each half-degree temperature interval. The plotted data is in Figure 6.12 and Figure 6.13 the fitted regression lines for subjects' sensation prediction versus operative temperature in winter and summer are:

Winter:

AMV = 0.184 T_o - 3.972, r^2 = 0.695 **(4)**

Summer:

AMV = 0.278 T_o - 6.613, r^2 = 0.754 **(5)**

The coefficient of determinant (r²) between AMV and the operative temperature in winter is 0.695 for Equation (4) and in summer is 0.754 for Equation (5).

The slopes of the regression lines represent the sensitivity of the subjects with respect to the operative temperature. It is 5.4 °C per sensation unit for the AMV gradient in winter and 3.6 °C in summer. Regression analysis of average binned AMV gave a neutral temperature 21.6 °C in winter and 23.8 °C in summer derived by Equation (4) and (5) for a mean thermal sensation vote of zero.

According to the equations, on average, 6.7 and 3.6 degrees of operative temperature change shifts the group's mean thermal sensation one point on the seven-point scale (one divided by the regression coefficient of 0.184 and 0.278 in Equation (4) and (5). The 5.4 and 3.6 degrees of per thermal sensation unit change indicated in adaptive thermal comfort theory, the regression equation shows this sample to be remarkably successful at adapting to changes in indoor temperature both in winter and summer.

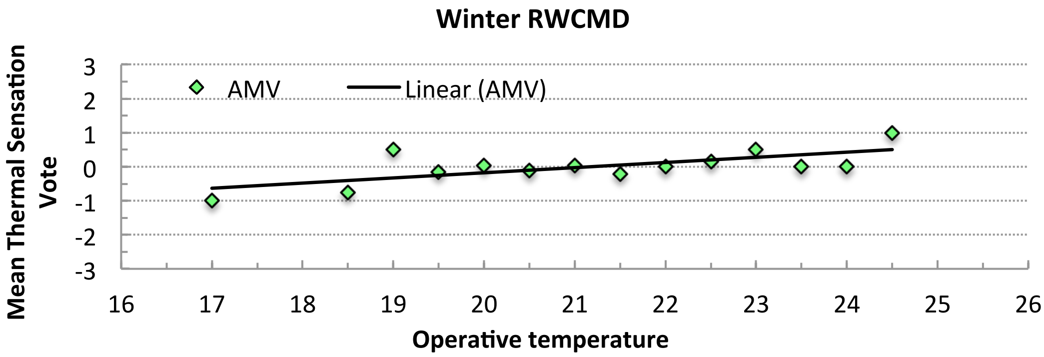

Figure 6.12 Mean observed sensation in winter RWCMD.

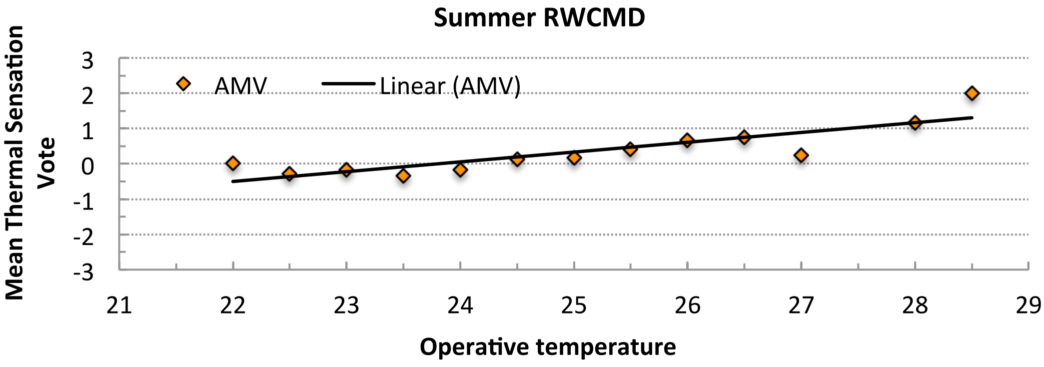

Figure 6.13 Mean observed sensation in summer RWCMD.

c. Neutral temperature in WMC

The plotted data is in Figure 6.14 and Figure 6.15, the fitted regression lines for subjects' sensation prediction versus operative temperature in winter and summer are:

Winter:

$$\mathbf{AMV = 0.162\ T_o – 3.264,\quad r^2 = 0.716} \qquad \mathbf{(6)}$$

Summer:

$$\mathbf{AMV = 0.254\ T_o - 5.730,\quad r^2 = 0.867} \qquad \mathbf{(7)}$$

The coefficient of determinant (r^2) between AMV and the operative temperature in winter is 0.716 for Equation (6) and in summer is 0.867 for Equation (7).

The slopes of the regression lines represent the sensitivity of the subjects with respect to the operative temperature. It is approximately 6.1 °C per sensation unit for the AMV gradient in winter and 3.9 °C in summer. Regression analysis of average binned AMV gave a neutral temperature 20.1 °C in winter and 22.6 °C in summer derived by Equation (6) and (7) for a mean thermal sensation vote of zero.

According to the equations, on average, 6.1 and 3.9 °C of operative temperature change shifts the group's mean thermal sensation one point on the seven-point scale (one divided by the regression coefficient of 0.162 and 0.254 in Equation (6) and (7). According to the adaptive thermal comfort theory, the regression equation shows this sample to be remarkably successful at adapting to changes in indoor temperature in winter, but the adaptability of participants in summer is a little weaker.

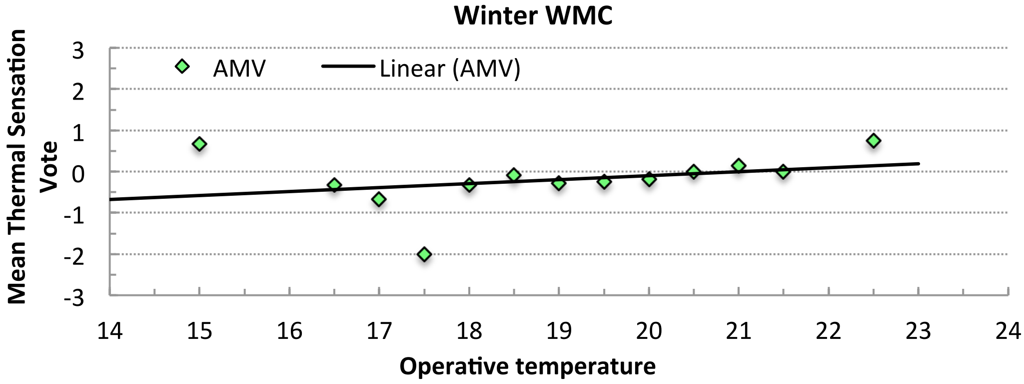

Figure 6.14 Mean observed sensation in winter WMC.

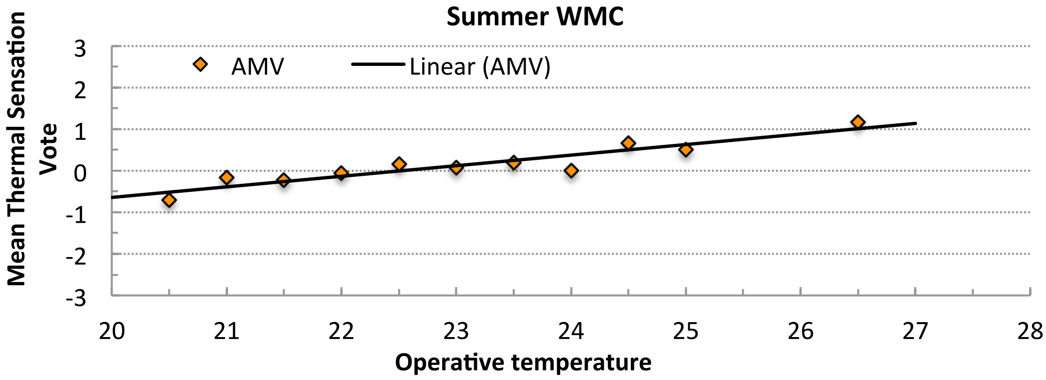

Figure 6.15 Mean observed sensation in summer WMC.

d. Comparison of thermal sensitivity and neutral temperature in three cases

The results shows in winter people in AGU and RWCMD were more thermal sensitive than people in WMC, as the slope value corresponds to 5.5 °C and 5.4 °C per sensation unit in AGU and RWCMD and 6.1 °C in WMC. However, in summer people in RWCMD and WMC were more thermal sensitive than people in AGU, the corresponding degree is 6.5 °C in AGU, 3.6 °C and 3.9 °C separately. This means that in winter people in WMC and in summer people in AGU were thermally comfortable at a wider range of operative temperature. In other words, the participants in winter in AGU and RWCMD were more sensitive to air temperature and mean radiant temperature than in WMC, but in summer participants in RWCMD and WMC were more sensitive than in AGU.

The survey of environment measurement shows the results that the mean operative temperature in winter WMC is lowest when in summer AGU has the highest mean operative temperature among this three indoor transitional spaces. A possible explanation of why people in winter WMC and summer AGU were found to be less thermal sensitive, might be likely due to the difference in clothing insulation and the way of people using indoor transitional spaces (stay area, visit frequency, visit time and stay time).

The neutral temperatures (T_n) can be calculated by using equations (2) to (7) when AMV = 0. The actual neutral temperature in winter is 20.8 °C, 21.6 °C and 20.1 °C in AGU, RWCMD and WMC; in summer is 21.1 °C, 23.8 °C and 22.6 °C respectively. As can be seen, the neutral temperature of AGU group is lowest among these three spaces neither in winter or summer. Meanwhile, neutral temperature of RWCMD participants is highest. The mean neutral temperature of indoor transitional space in this study is 20.8 °C in winter and 22.5 °C in summer.

The results above show differences in thermal sensitivity and neutrality among different groups in three indoor transitional spaces. This finding shows that the thermal requirements of people in three indoor transitional spaces must be considered separately. This is mainly due to the difference in the prevailing thermal environment in all of these three locations and the influence of thermal adaptive methods.

6.3.2 Preferred Sensation and Temperature

The preferred sensation and preferred temperature is the sensation and temperature people actually expected, compared to the neutral sensation and temperature in which people feel comfortable. The comparison of preferred sensation and temperature of different groups could help in exploring differences in their thermal perception or similarities. The smaller difference between the neutral and preferred sensation and temperature for a group of people relates to good adaptation they are to the thermal environment.

Probit analysis is employed for advanced analysis in thermal studies to survey thermal preference sensation and calculate the preferred temperature. This method is used for thermal sensation assessments by Ballantyne, Hill and Spencer (1977) were conducted separately on the preference of the participants in winter and summer for warmer and cooler conditions. The cumulative frequency distributions for the "*wanting warmer*" and "*wanting cooler*" inclinations were plotted against thermal sensation scale and operative temperature scale of environment separately. The point located at the intersection of the two cumulative curves corresponds to the subjects' preference. Probit regression used in this study for evaluating the preferred sensation and calculating preferred temperature.

a. Preferred Sensation and Temperature in AGU

Figure 6.16 shows the distribution of survey AGU participants' thermal preference votes in relation to their thermal sensation votes using Probit analysis. As shown in Figure 6.16, this preference did not coincide with the thermal neutral condition, but was shifted slightly toward a positive value in winter and a negative value in summer on the sensation scale. The optimal sensation occurred at levels of 0.21 and -0.18 in winter and summer respectively. As thermal sensation increased (i.e. from cold to hot), the percentage of subjects voting for '*want cooler*' generally increased. As one might expect, the percentage of those preferring to be warmer (i.e. '*want warmer*' responses) tended to increase as thermal sensation decreased from warm to cool. The analysis of preference votes demonstrated a symmetrical correlation between thermal sensation and thermal preference in winter, whereas thermal sensation and thermal preference were asymmetrically correlated in summer.

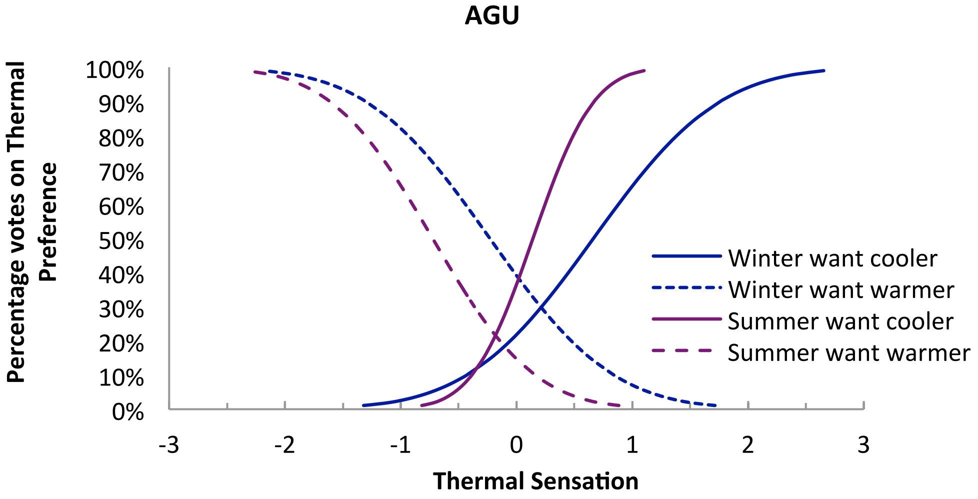

Figure 6.16 Percentage of thermal preference against thermal sensation in AGU.

In another Probit analysis, the cumulative frequency distributions for the "*wanting* warmer" and "wanting cooler" inclinations were plotted against operative temperature scale of environment in winter and summer (Figure 6.17 and Figure 6.18). The point located at intersection of the two cumulative curves corresponds to the participants' preference in terms of sensation. To investigate preferred temperature, participants' preference votes was binned into half degree intervals of indoor operative temperature. The point of intersection between "*want cooler*" and "*want warmer*" probit model is taken to represent the group's preferred temperature. According to the regression model, the preferred temperature in winter is 20.2 °C and in summer 21.5 °C.

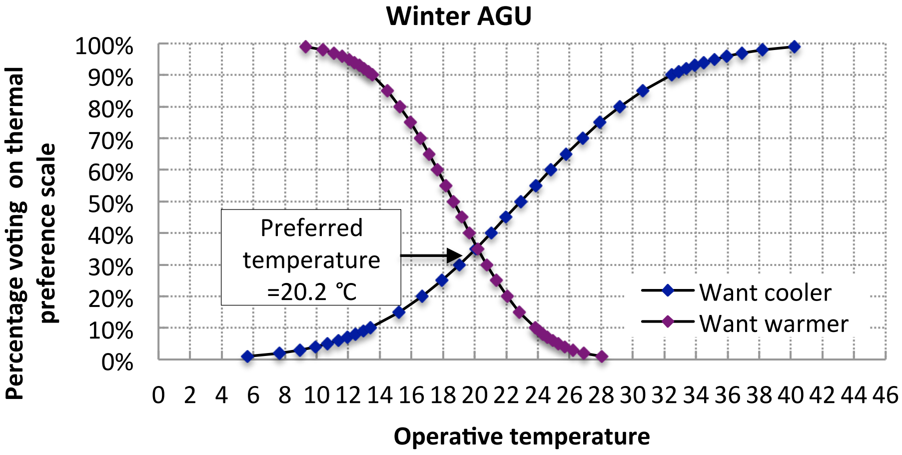

Figure 6.17 Probit regression models fitted to thermal preference percentages in winter in AGU.

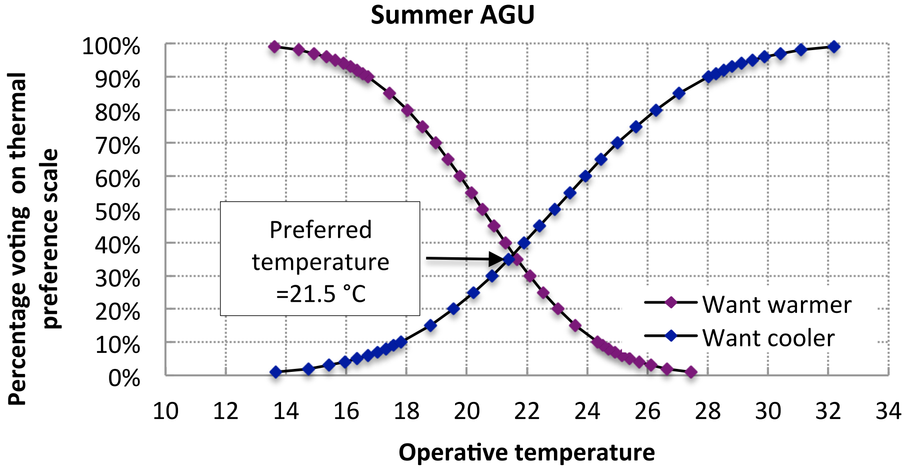

Figure 6.18 Probit regression models fitted to thermal preference percentages in summerin AGU.

b. Preferred sensation and temperature in RWCMD

Figure 6.19 shows that the probit analysis of thermal preference votes in relation to thermal sensation votes. It indicated that the preference did not coincide with the thermal neutral condition, but in winter it was shifted slightly toward a positive value while in summer it was shifted toward a negative value on the sensation scale. The optimal sensation occurred at levels of 0.35 and -0.59 in winter and summer respectively. As thermal sensation increased (i.e. from cold to hot), the percentage of subjects voting for '*want cooler*' generally increased. As one might expect, the percentage of those preferring to be warmer (i.e. '*want warmer*' responses) tended to increase as thermal sensation decreased from warm to cool. The analysis of preference votes demonstrated an asymmetrical correlation between thermal sensation and thermal preference both in winter and summer.

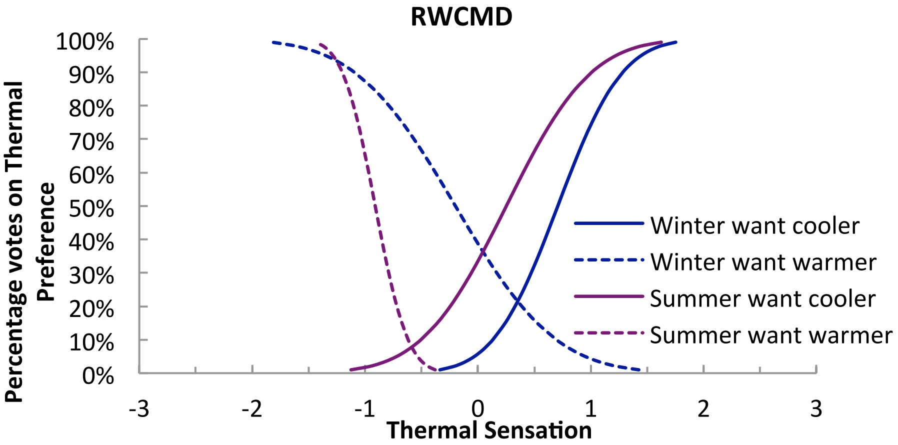

Figure 6.19 Percentage of thermal preference against thermal sensation in RWCMD.

To investigate preferred temperature of participants in RWCMD transitional space, participants' preference votes were binned into half-degree intervals of indoor operative temperature. Thermal preference votes within each half-degree of operative temperature became the basis of the probit regression models as Figure 6.20 and Figure 6.21. The point of intersection between "*want cooler*" and "*want warmer*" probit model is taken to represent the group's preferred temperature. According to the regression model, the preferred temperature is 22.5 °C in winter and 23.5 °C in summer.

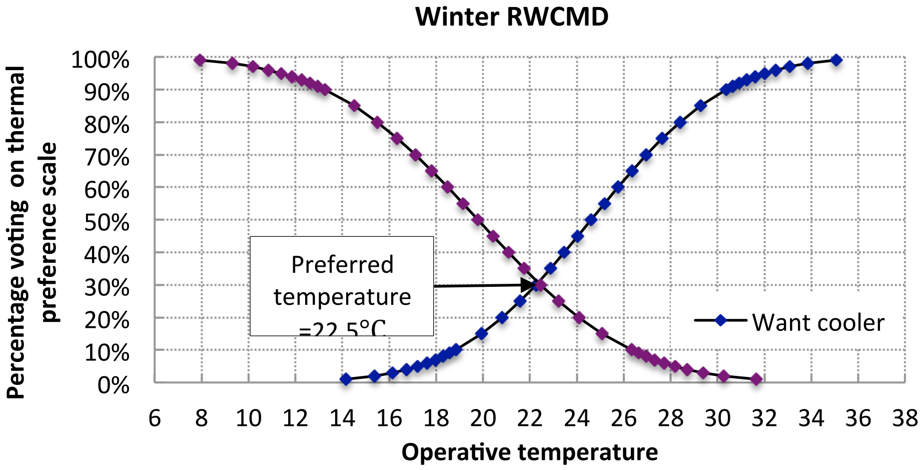

Figure 6.20 Probit regression models fitted to thermal preference percentages in winter in RWCMD.

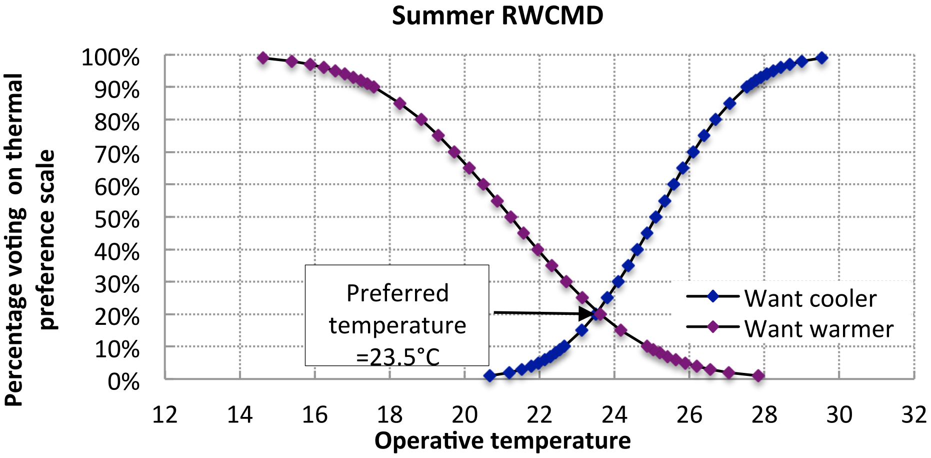

Figure 6.21 Probit regression models fitted to thermal preference percentages in summer in RWCMD.

c. Preferred sensation and temperature in WMC

Figure 6.22 shows participants' preference did not coincide with the thermal neutral condition, but it was shifted slightly toward a positive value both in winter and summer on the sensation scale. The optimal sensation occurred at levels of 0.22 and 0.02 in winter and summer respectively. As thermal sensation increased (i.e. from cold to hot), the percentage of subjects voting for '*want cooler*' generally increased. As one might expect, the percentage of those preferring to be warmer (i.e. '*want warmer*' responses) tended to increase as thermal sensation decreased from warm to cool. The analysis of preference votes demonstrated an asymmetrical correlation between thermal sensation and thermal preference in winter and a symmetrical correlation in summer.

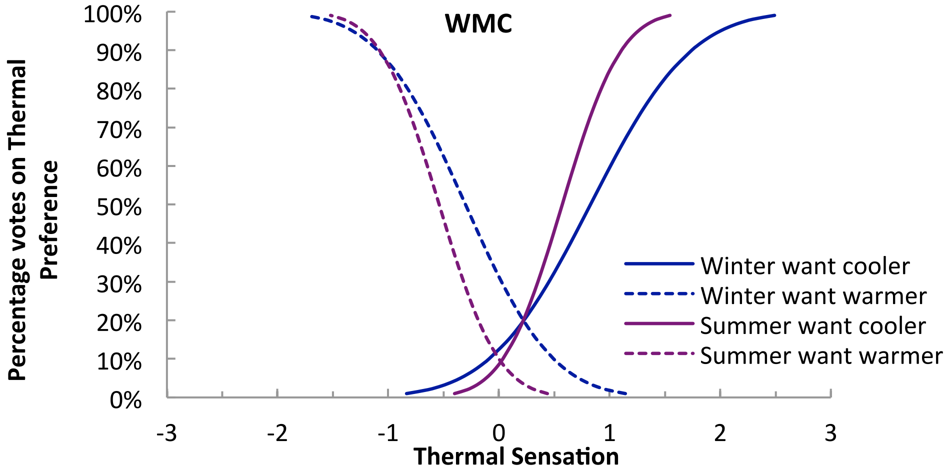

Figure 6.22 Percentage of thermal preference against thermal sensation in WMC.

To investigate preferred temperature, participants' preference votes was binned into half degree intervals of indoor operative temperature. Thermal preference votes within each half-degree of operative temperature became the basis of the probit regression model as Figure 6.23 and Figure 6.24. The point of intersection between "*want cooler*" and "*want warmer*" probit model is taken to represent the group's preferred temperature. According to the regression model, the preferred temperature in winter is 21.6 °C and in summer is 21.9 °C.

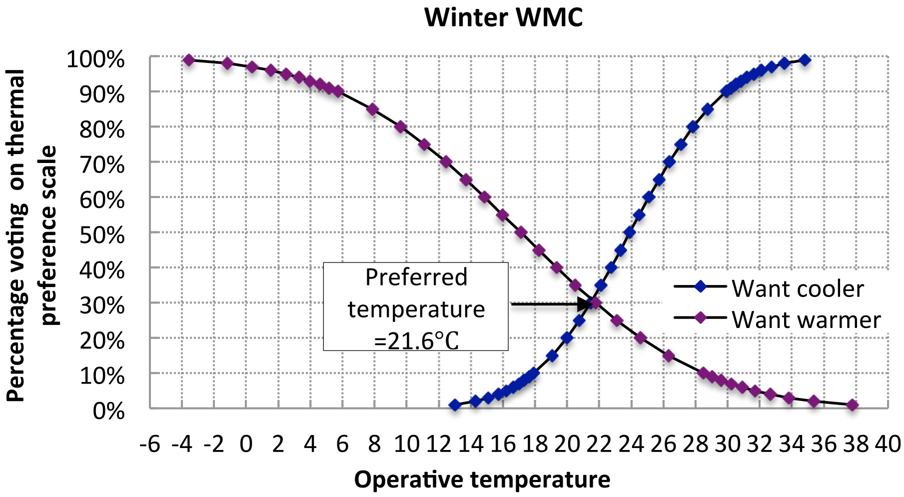

Figure 6.23 Probit regression models fitted to thermal preference percentages in winter in WMC.

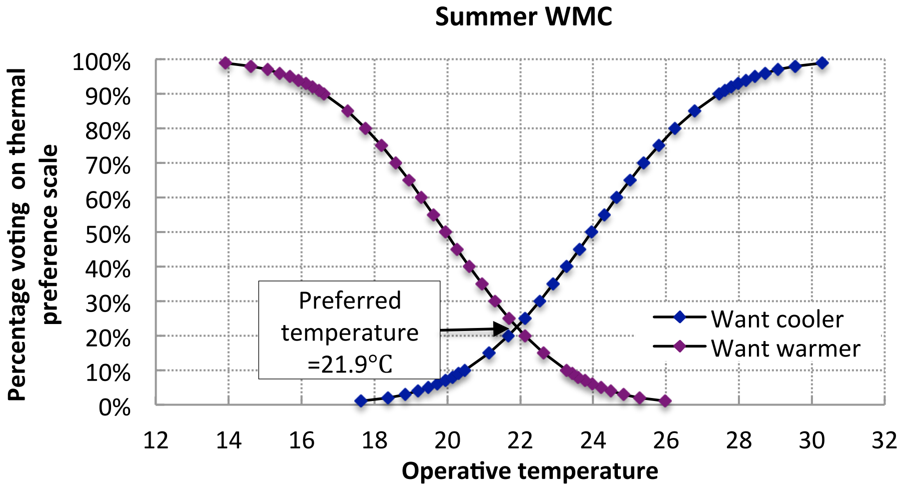

Figure 6.24 Probit regression models fitted to thermal preference percentages in summer in WMC

d. Comparison the preferred sensation and temperature in three cases

The preferred thermal sensation indicates that in winter, all groups were like the sensitivity a little warmer than neutral, as 0.21, 0.35 and 0.22 sensation level in AGU, RWCMD and WMC; when in summer people like cooler as-0.18, -0.57 and 0.02 sensation level in AGU, RWCMD and WMC. The higher sensitivity level as 0.02 in summer is proves the air temperature and mean radiant temperature in summer WMC is lower than other two cases. However, the only natural ventilated environment in these three indoor transitional spaces was in summer RWCMD indoor transitional space, it results in the lowest preferred thermal sensation level even the operative temperature in it was not the highest. Combine with the results of high acceptability rate of thermal sensation in summer RWCMD, it indicates that people stay in natural environment have a higher tolerance of their thermal environment.

The preferred temperature for AGU, RWCMD and WMC in winter was 20.2 °C, 22.5 °C and 21.6 °C; in summer was 21.5 °C, 23.5 °C and 21.9 °C. The difference in preferred temperature and neutral temperature among the three groups demonstrates the occurrence of thermal adaptation. Consequently, the comparison of neutral temperature with preferred temperature could explain which group is better adapted to its thermal environment. The differences between neutral temperature and preferred temperature in winter in AGU, RWCMD and WMC are 0.6, 0.9 and 1.5 °C separately; in summer are 0.3, 0.3 and 0.7 °C separately. The results prove that in winter AGU's participants and in summer AGU and RWCMD's participants were have the best adaptation ability (smallest different between neutral temperature and preferred temperature) to their thermal environment.

6.3.3 Thermal comfortable range

Regression equations describing the dependence of sample mean thermal sensation on mean indoor operative temperature are often used to define acceptable temperature limits for a particular sample. In the case of ASHRAE 55-2013, the so-called "*comfort zone*," as expressed on a temperature-humidity graph has its boundaries defined as -0.5 PMV on the cool side and +0.5 PMV on the warm side. The logic behind this definition is encapsulated in the Predicted Percentage Dissatisfied (PPD) index. In classic thermal comfort theory PPD reaches its minimum value when PMV equals zero (i.e. neutrality). That is, when the average person feels thermally neutral, we can expect a minimum of complaints form the entire group in that environment. Minimum PPD is set to 5%, reflecting the fact that we can never satisfy all of the occupants within a space with a single thermal environment. As PMV deviates from "*neutral*" in both the warm or cool direction, the PPD starts to increase. When the group mean thermal sensation (PMV) equals plus or minus 0.5, PPD climbs to 10% (i.e. one in ten people in the group will have a thermal sensation falling outside the satisfactory or acceptable central three categories of -1, 0, +1 on the 7-point sensation scale). To this PPD of 10% dissatisfied ASHRAE 55-2013 adds another 10% dissatisfied resulting of local discomforts like draft, vertical temperature stratification and plane radiant asymmetry, bringing the total percentage dissatisfied from global and local discomforts combined to 20%. Eighty percent acceptability (i.e. 20% dissatisfied) is the internationally agreed design target and the same definition of acceptable mean thermal sensations is adopted in the International Standards Organization's thermal comfort standard, ISO 7730 (2005); -0.5 < PMV < +0.5, corresponding to PPD=10% + another 10% dissatisfaction from local discomforts, bringing the total dissatisfied to 20%.

Different with the fundamental logic, as adopted in ASHRAE (55-2013) and also ISO (7730-2005) to define their comfort zones, some scholars research in thermal comfort of transitional spaces expand the comfort zone in these spaces as -1 < PMV < +1 (Pitts 2004), which can be applied to the results obtained in this thermal comfort survey of participant in transitional spaces in the present study. But with key difference-rather than use predicted mean thermal sensations (PMV), this survey has the advantage of actual mean thermal sensations. The mean indoor operative temperatures corresponding to mean thermal sensations of +1 and -1 is stretch from 14 °C up to 27.0 °C in winter and from 14.5 °C to 27.8 °C in summer (marked region on Figure 6.25 to Figure 6.30).

Figure 6.25 and Figure 6.26 show the mean thermal sensation votes plotted against operative temperature within each half-degree bin to find the thermal comfort zone in winter and summer AGU. The winter regression model ($r^2 = 0.60$, $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (2), when the summer regression model ($r^2 = 0.59$, $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (3). The mean indoor operative temperatures corresponding to group mean thermal sensations of +1 and -1 stretch from 15.2 °C up to 26.3 °C in winter and from 14.5 °C to 27.8 °C in summer.

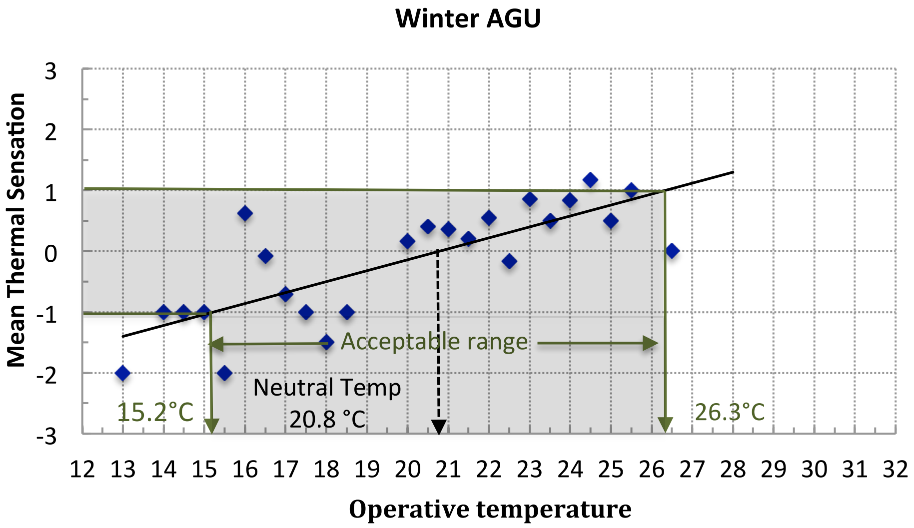

Figure 6.25 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in winter.

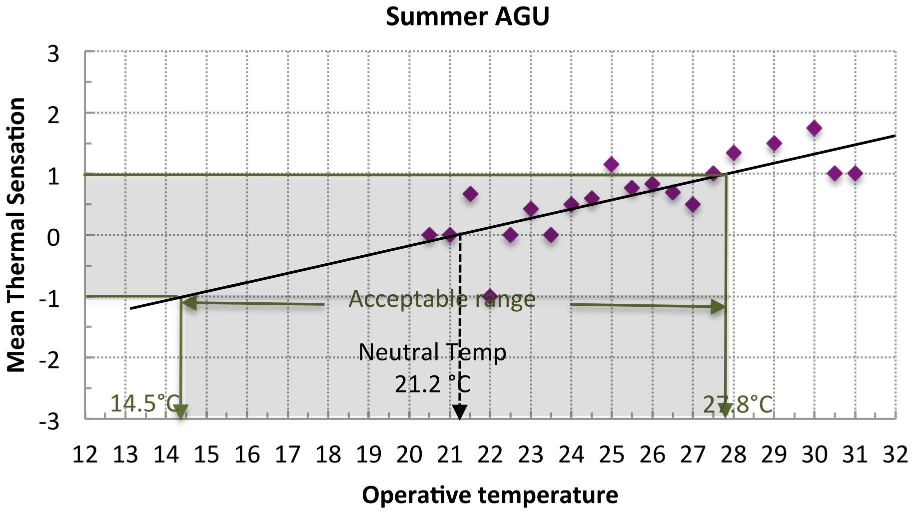

Figure 6.26 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in summer.

Figure 6.27 and Figure 6.28 show the mean thermal sensation votes plotted against operative temperature within each half-degree bin in winter and summer RWCMD. The winter regression model (r^2 = 0.70 $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (4), when the summer regression model (r^2 = 0.75 $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (5). Regression equations describing the dependence of sample mean thermal sensation on mean indoor operative temperature are often used to define acceptable temperature limits for a particular sample. The mean indoor operative temperatures corresponding to group mean thermal sensations of +1 and -1 stretch from 16.1 °C up to 27.0 °C in winter RWCMD and from 19.8 °C to 27.4 °C in summer RWCMD.

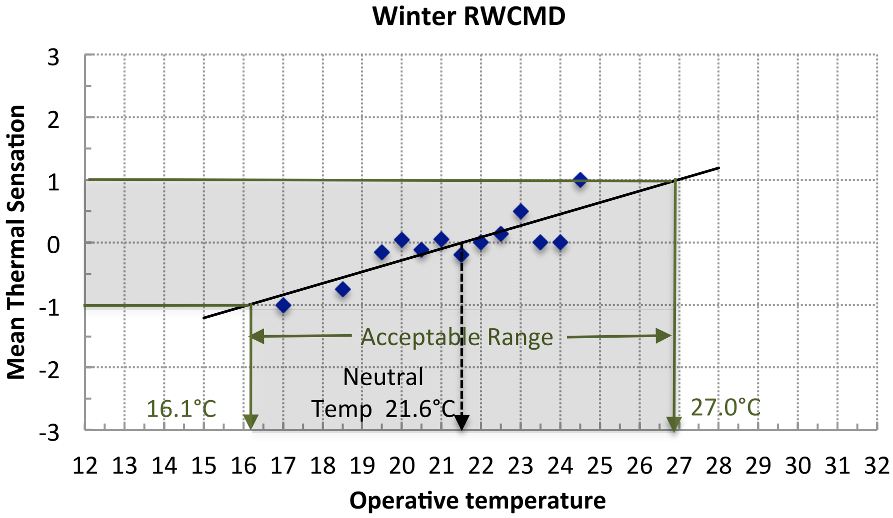

Figure 6.27 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in winter RWCMD.

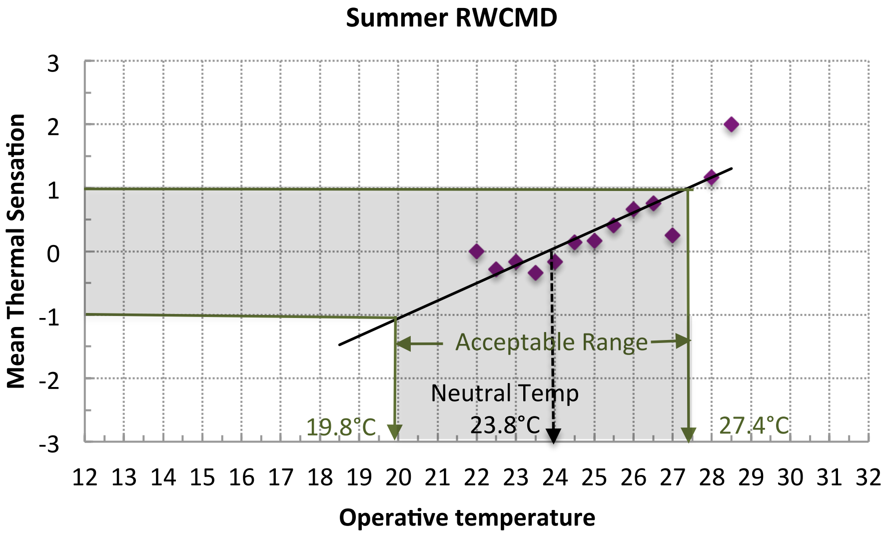

Figure 6.28 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in summer RWCMD.

Figure 6.29 and Figure 6.30 show the mean thermal sensation votes plotted against operative temperature within each half-degree bin to define the comfort zone in winter and summer WMC. The winter regression model (r^2 = 0.72 $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (6), when the summer regression model (r^2 = 0.87 $p<0.001$ for regression coefficient and constant) fitted to bin-mean vote is as equation (7). The mean indoor operative temperatures corresponding to group mean thermal sensations of +1 and -1 stretch from 14.0 °C up to 26.3 °C in winter WMC and from 18.6 °C to 26.5 °C in summer WMC.

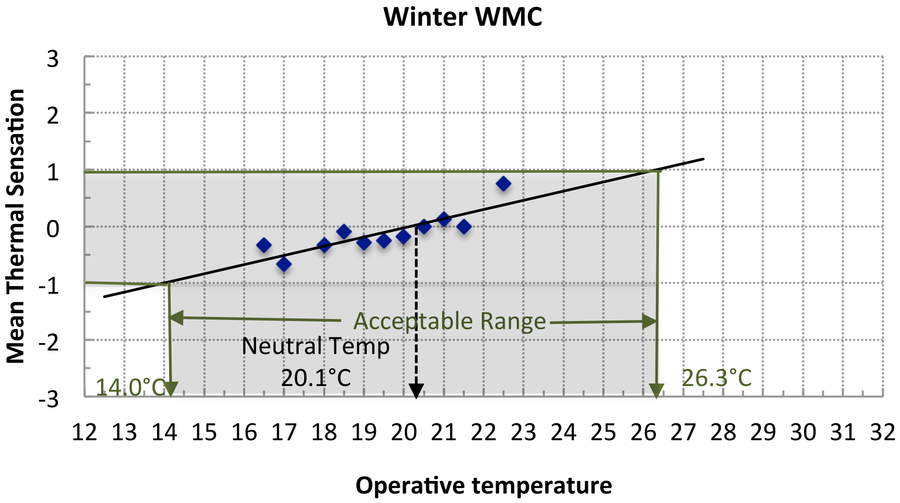

Figure 6.29 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in winter.

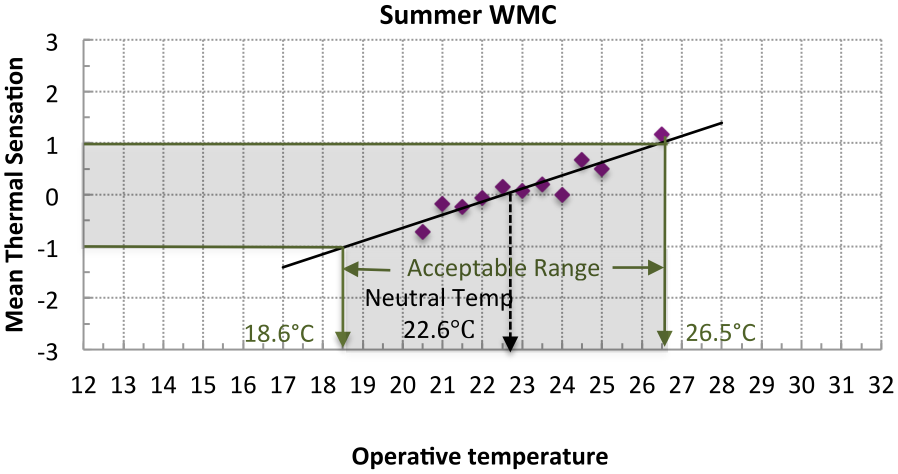

Figure 6.30 Mean thermal sensation votes (-3 = cold, through 0 = neutral to +3 = hot) related to indoor operative temperature in summer.

The range of thermal comfort zone in winter was 15.2 °C to 26.3 °C in AGU, 16.1 °C to 27.0 °C in RWCMD and 14.0 °C up to 26.3 °C in WMC; and in summer it was 14.5 °C to 27.8 °C in AGU, 19.8 °C to 27.4 °C in RWCMD and 18.6 °C to 26.5 °C in WMC. The most wider comfort temperature range in winter is in WMC as 12.3°C and in summer is AGU as 13.3 °C. The results prove again that in winter WMC participants and in summer AGU participants were have the highest toleration to their thermal environment.

6.3.4 Thermal comfort requirements of indoor transitional space

Table 6.2 presents a summary of key experimental results from all studies. It indicated that participants in these three buildings have similar cloth insulation and metabolic range in both winter and summer. Excludes in summer AGU and RWCMD, all other samples' results reveal that neutral temperature lies above or same with the mean operative temperature occupants experienced. Especially in summer AGU, mean operative temperature is as higher as 4.5 °C than neutral temperature. The comparison revealed that participants in AGU were more comforted by cooler environment than in other two transitional spaces in buildings both in winter and summer.

Table 6.2 Key information of thermal comfort in three cases.

	Winter			**Summer**		
	AGU	RWCMD	WMC	AGU	RWCMD	WMC
Clo value (clo)	1.24	0.98	1.11	0.46	0.43	0.53
Metabolic rate (met)	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5
Mean operative temperature (°C)	20.1	21.2	19.4	25.6	25.0	22.1
Mean humidity	45.0	36.1	41.0	56.0	56.0	64.1
Surveyed operative temperature range (°C)	13.1-26.9	17.3-24.9	14.5-22.0	20.5-31.4	22.4-28.8	20.0-26.4
Neutral temperature (°C)	20.8	21.6	20.1	21.1	23.8	22.6
Preferred temperature (°C)	20.2	22.5	21.6	21.5	23.5	21.9
Comfortable temperature range (°C)	15.2-26.3	16.1-27.0	14.0-26.3	14.5-27.8	19.8-27.4	18.6-26.5

The results show differences in thermal neutrality, preference and comfortable range between the two different groups in these three indoor transitional spaces. The neutral temperatures (T_n) can be calculated by using equations (2) to (7) when AMV = 0. The actual neutral temperature in winter is 20.8 °C, 21.6 °C and 20.1 °C in AGU, RWCMD and WMC; in summer is 21.1 °C, 23.8 °C and 22.6 °C respectively. As can be seen, in winter the lowest neutral temperature is in WMC and in summer it is in AGU among these three spaces. Meanwhile, thermal comfort neutral temperature of RWCMD participants is highest both in winter and summer.

The preferred temperature for AGU, RWCMD and WMC in winter was 20.2 °C, 22.5 °C and 21.6 °C; in summer was 21.5 °C, 23.5 °C and 21.9 °C. The difference in preferred temperature and neutral temperature among the three groups demonstrate the occurrence of thermal adaptation. Consequently, the comparison of neutral temperature with preferred temperature could explain which group is better adapted to its thermal environment. The differences between neutral temperature and preferred temperature in winter in AGU, RWCMD and WMC are 0.6, 0.9 and 1.5 °C; in summer are 0.3, 0.3 and 0.7 °C. The results prove that in AGU participant has the best adaptation ability both in winter and summer (smallest different between neutral temperature and preferred temperature) to their thermal environment. Besides, it indicates that people stay in the natural ventilation environment (summer RWCMD) have high thermal adaptation ability. The profile of preferred temperature follows that of the neutral temperatures and the two almost not coincide. The results in RWCMD and WMC demonstrate the preference for cooler temperature in summer and warmer temperature in winter. However even in winter AGU, participants still prefer cooler environment, which explains the overheated thermal environment in it. This phenomenon is deduced dues to the higher operative temperature in SS area in AGU, even in winter, some participants complain it is too warm in this area. The high temperature of this area is gained through the big façade of glazing, and the North-South layout also results in the longer sunshine time.

The range of thermal comfort zone in winter was 15.2 °C to 26.3 °C in AGU, 16.1 °C to 27.0 °C in RWCMD and 14.0 °C up to 26.3 °C in WMC; and in summer it was 14.5 °C to 27.8 °C in AGU, 19.8 °C to 27.4 °C in RWCMD and 18.6 °C to 26.5 °C in WMC. The most wider comfort temperature range in winter is in WMC as 12.3 °C and in summer is AGU as 6.7 °C. The results indicates that in indoor transitional space people had a wider thermal comfort temperature range in winter than in summer, and it means participants in these spaces were have the higher toleration to their thermal environment.

6.4 Thermal perception in indoor transitional space

6.4.1 Comparing the thermal reception with thermal standards

ASHRAE standard has not recommend a design temperature range for transitional spaces when CIBSE always allow for a wider temperature ranges, provides seasonal comfort criteria for some general areas in building. Although there is not a specific criteria for transitional space in CIBSE, the related spaces including in transitional spaces in buildings are provides as Table 6.3.

Table 6.3 Recommended comfort criteria for spaces related to the indoor transitional spaces (CIBSE).

	Winter			**Summer**		
	Operative temperature (°C)	Activity (met)	Clothing (clo)	Operative temperature (°C)	Activity (met)	Clothing (clo)
Bars/lounges	20-22	1.3	1.15	22-24	1.3	0.65
Exhibition halls	19-21	1.4	1.0	21-23	1.4	0.65
Corridors	19-21	1.4	1.0	21-23	1.4	0.65
Entrance halls/lobbies	19-21	1.4	1.0	21-23	1.4	0.65
Waiting areas/rooms	19-21	1.4	1.0	21-23	1.4	0.65
Small shops, department stores	19-21	1.4	1.0	21-23	1.4	0.65
Circulation spaces	13-20*	1.8	1.0	21-25*	1.8	0.65
Foyers	13-20*	1.8	1.0	21-25*	1.8	0.65

***Based on PMV of ±0.5.**
At other cases based on PMV of ±0.25.

According the CIBSE stand, the comfort temperature range in transitional space should be 13-21 in °C winter and 21-25 °C in summer and in the transitional café/bar areas it should be 20-22 °C in winter and 22-24 °C in summer, it assumed by consider related activity met and clothing insulation. Even though there is a clearly criteria comfortable temperature range of foyer space in CIBSE, but the activity rate in it is higher than the mean activity met in the indoor transitional spaces surveyed in this study.

Table 6.4 Comfort temperature range in each case in winter and summer.

	Winter			Summer		
	AGU (°C)	RWCMD (°C)	WMC (°C)	AGU (°C)	RWCMD (°C)	WMC (°C)
Comfort Temperature Range (based on AMV=±1)	15.2-26.3	16.1-27.0	14.0-26.3	14.5-27.8	19.8-27.4	18.6-26.5
Comfort Temperature Range (based on AMV=±0.5)	18.0-23.6	18.9-24.3	17.1-23.2	17.8-24.5	22.0-25.6	20.6-24.5
Comfort Temperature Range (based on AMV=±0.25)	19.4-22.2	20.2-22.9	18.6-21.7	19.5-22.8	22.9-24.7	21.6-23.5

Table 6.4 shows the comfort temperature range in transitional space of current study, It can be seen that the comfort zone is 14.0 °C to 27.0 °C in winter and 14.5 °C to 27.8 °C in summer based on AMV=±1 when the comfort temperature range is 17.1-24.3 °C in winter and 17.8-25.6 °C in summer based on AMV=±0.5, and 18.5-23.7 °C in winter and 19.5-24.7 °C in summer based on AMV=±0.25. Considering the high satisfaction rate of thermal environment (over 80%) at ±1 level of thermal sensation, it should be suggested as the base of calculating comfort temperature range in indoor transitional spaces rather than level ±0.5 and 0.25.

Table 6.4 shows the comfort zone in this study of indoor transitional is wider than the CIBSE criteria. The comfort range results from this study indicates that in both seasons, people in indoor transitional space can tolerant a wider temperature range, it might results from the freedom of participants to choose their cloth and participant's previous activities (walking coming out from lecture theatres with stairs or long walk before arriving to the building). Beside, summer RWCMD is the solely naturally ventilated (NV) building, which is different with AGU's mechanically conditioned (MC) or the WMC's air conditioning (AC). Under the same adaptive chances with MC and AC buildings (can't open windows freely and the doors are open automatically only when people going through it), the narrower thermal comfort range occurred in summer RWCMD.

The overall wider comfort temperature range in transitional space proves that people in transitional space have a higher tolerance of their thermal environment than CIBSE criteria. The main reason is occupants in transitional space have a high liberty of adjust their cloth insulation, activity level and stay area. According to the experiment, the thermal experience also contributes to the high tolerance of the thermal environment in indoor transitional spaces.

6.4.2 Comparing with other transitional space

The experimental results of this study were compared with those of a previous field study that investigated the transitional spaces. There are few previous research investigated thermal comfort in transitional space and few of them are using field survey methods to investigated the similar type of transitional space with the current study, but these research still compared to the current study to get a full picture of thermal comfort of transitional space and to improve the design of transitional space. There are several similar transitional space with current study were researched in the previous study, the summary of experimental results from these studies are presented in Table 6.5.

Three tropical country surveys conducted at summer time, it revealed that people in Taiwan were more comforted by cooler environments than those in Bangkok and Malaysia. The neutral temperature in Taiwan study was 0.8 °C lower than that in the Bangkok study. Compared to the level found by Jitkhajornwanich et al., the preferred temperature in Taiwan study was 1.0 °C lower and was beyond the lower boundary of the comfortable range in the Bangkok study. The span of the comfortable range in Taiwan study was 3.8°C, 2.2 °C narrower than the 6.0 °C span in the Bangkok study. Taiwan study identified lower temperatures in both the upper and lower boundaries of the comfortable zone. Between the Bangkok and Taiwan study, the temperature difference was 3.5 °C in the upper boundary and 1.5 °C in the lower boundary. The differences between the two studies resulted in part from the different sample populations. The study by Jitkhajornwanich et al. included a large number of people moving outside from indoors who would prefer a warm indoor environment. Another attributing factor is climatic accommodation. Bangkok and Malaysia has a hotter climate than Taiwan does through out the entire year; thus people in Bangkok and Malaysia favor warmer conditions than do people in Taiwan. It also indicates that people in cooler climate favor cooler condition than people in warmer climate. So it can assume that people in UK should favor a cooler temperature range than these in tropical climate country. It approved by the survey results in this research, the neutral temperature in Cardiff (UK) transitional space is about 4 °C lower than those tropical climate countries, while prefer temperature is 3 °C lower and the comfort temperature range is 4-5 °C lower.

Two survey related to transitional spaces surveyed in Europe are conducted in Greece and UK separately. The neutral temperature in Greece atrium is 14.98 °C in winter and 24.22 °C in summer when it is 20.8 °C in winter and 22.5 °C in summer in current study. The comfort temperature range in Greece atrium is 13.47-16.49 in winter and 22.71-25.73 °C in summer and in UK lobby is 19-20 °C in winter and 23 °C in summer when in current study it is 14.0-27.0 °C in winter and 14.5-27.8 °C in summer. It can be seen that the comfort range in this study is wider than both these two surveys in Greece and UK.

Table 6.5 Comparison of results from other field researches related to indoor transitional space.

Location	**Malaysia**	**Bangkok, Thailand**	**Taichung, Taiwan**	**Greece**	**Sheffield, UK**	**Current study**
Space type	Enclosed lift lobby	Lobby, foyer, atrium	Foyer	Atrium	Lobby	Foyer,café,corridor
Samples	113	1143	587	300	1794	759
clo value (clo)	0.62	0.53-0.65	0.54		0.72(spring) 0.57(summer) 1.01(autumn) 1.06(winter)	1.24(winter) 0.46(summer)
Metabolic rate (met)	1.2	1.0-1.9	1.0-1.2		0.7-3.8	1.0-1.5
Surveyed temperature range (°C)	23-32	23-32	20-30	10.2-16.6(winter) 19.0-29.1(summer)	21.9(spring) 23.5(summer) 21.2(autumn) 20.0(winter)	20.2(winter) 24.3(summer)
Neutral temperature (°C)	-	26.5	26.3	14.98(winter) 24.22(summer)		20.8(winter) 22.5(summer)
Preferred temperature (°C)	-	25.5	24.5			21.4(winter) 22.3(summer)
Comfortable range (°C)	26.8	25.5-31.5	24.0-27.8	13.47-16.49(winter) 22.71-25.73(summer)	21-22(spring) 23 (summer) 21.0(Autumn) 19-20(winter)	14.0-27.0(winter) 14.5-27.8(summer)

6.5 Adaptive model (Behavior and psychological adaptation)

Thermal comfort adaptive theory embraces the notion that people play an instrumental role in creating their own thermal preferences. This is achieved either through the way they interact with the environment, or modify their own behavior, or because contextual factors and past thermal history change their expectations and thermal preferences (de dear 1998). There is three levels of thermal adaptation are identified: physical, physiological and psychological (Nikolopoulou & Steemers 2003). It also claimed that the relation between physical environment and psychological adaptation is "*complementary rather than contradictory*". This complement could influence the use of transitional space. This section investigates adaptive model using in transitional space and key adaptive measures that influence thermal sensation in indoor transitional space of Cardiff, UK.

6.5.1 Adaptive model theory using

In all of the cases in this study, the adaptive opportunity of subjects does not include the way alter their environment, for example, open/close windows and doors, switch on/off a fan and so on. Even though these ways are the very most favored choices of adaptive adjustments by occupants (Mishra 2013), in these three indoor transitional spaces they are all adjusted by auto-set of the system or directly by managers. So in these three indoor transitional spaces, the main adaptive opportunity of occupants is adjust themselves' cloth, behavior and expectation of the thermal environment. As reminded in the old Norwegian proverb: "*there is no such thing as bad weather, just bad clothing*". For long time, in situations when occupants are allowed flexibility in their dressing pattern, varying clothing is seen as an easy, economic, and effective manner of adapting to the environment.

The related adaptive models according to the adaptive theory are listed in Table 6.6. Among them, the CIBSE comfort temperature band in free running (FR) and mechanical conditioning (MC) building is applicable in Europe. The running mean temperature is calculated by the equation as follows:

$$\boldsymbol{\theta_{rm(n)} = (1-a_{rm})\ \theta_{e(d-1)} + a_{rm}\theta_{rm(n-1)}} \qquad \textbf{(8)}$$

where $\theta_{e(d)}$ is the daily mean outdoor temperature for the previous day, $\theta_{e(d-1)}$ is the daily mean outdoor temperature for the day before that. $\theta_{rm(n)}$ is the running mean temperature for day n. $\theta_{rm(n-1))}$ is the running mean temperature for day n-1.

Table 6.6 Thermal adaptation equation in different standards.

Source	Equation		Remarks
ASHRAE Standard 55-2004	T_n=17.8+0.31T_{out}		FR buildings
EN15251	T_n=19.39+0.302T_{RMT};RMT>10 °C		FR buildings
CIBSE	Upper margin	θ_{com} =0.33 θ_{rm} + 20.8	FR buildings
	Lower margin	θ_{com} =0.33 θ_{rm} + 16.8	
	Upper margin	θ_{com} =0.09 θ_{rm} + 24.6	MC buildings
	Lower margin	θ_{com} =0.09 θ_{rm} + 20.6	

T_{out} is outdoor monthly mean temperature; T_n is the neutral or comfort temperature; T_{RMT} is the running mean temperature. Both the local ACEs given here that use T_{RMT} as an index of outdoor temperature, use similar formulations for T_{RMT} as EN15251; θ_{com} is the comfort temperature; θ_{rm} is the running mean of the daily mean outdoor air temperature.

A value in the region of 0.8 was found to be suitable for a_{rm} in the running mean temperature, a value previous found suitable for the data from UK (CIBSE Guide A 2006). Considering CIBSE guide is the most accurate reference stand for UK, the comfort temperature band of thermal adaptive model is calculated according the CIBSE's adaptive equation (Table 6.7). But this comfort range is providing to the office buildings in UK and there are insufficient data to provide similar advice for transitional spaces. So the adaptive temperature value is narrow and the low band of it is higher than the comfortable temperature range calculated according to the acceptable thermal sensation vote (±1).

Table 6.7 Adaptive temperature range in each case.

AGU						
Winter	θ_{rm}(°C)	θ_{com} (°C)	Summer		θ_{rm}(°C)	θ_{com} (°C)
	3.1	20.6-25.1			19.9	22.3-26.5
RWCMD						
Winter	θ_{rm}	θ_{com}	Summer	Date	θ_{rm}	θ_{com}
	4.3	21.0-25.0			19.2	21.0-28.0
WMC						
Winter	θ_{rm}	θ_{com}	Summer	Date	θ_{rm}	θ_{com}
	4.6	21.0-25.1			17.2	22.1-26.2

6.5.2 Adaptive behaviors

The basic aim of sustainable architecture is to create a thermally comfortable internal environment for building occupants whilst consuming the least possible amount of energy. It is difficult to achieve since lower and warmer ambient operative temperature in winter and summer create a barrier to comfort. Architecture type of indoor transitional spaces has evolved to try and help people to adapt to a state of thermal comfort under these adverse conditions.

The thermal adaptation activity of occupants is shows in Table 6.8. It indicates that in winter transitional space the conflict activities like "Put on more clothes" "*Remove clothing*" "*Hot drink*" "*Cold drink*" are account a quiet close percentage in all case. Even the percentage of "*Remove clothing*" is quite higher than "*Put on more clothes*" in winter AGU, this also evident that the overheated thermal environment in winter AGU. In summer, the most popular thermal adaptive activities are removing clothing and cold drink, when quite big percentage of occupants (about 40%) did no adjust activity. It assumed that the quiet close percentage of four main adjust activities is results from the thermal environment change of the occupants, because not all the interviewed occupants stay in the transitional space 20 minutes long until they interviewed, so their choice might including the activity when they come into the interior environment from exterior. However, the obvious tendentiousness of their choice in summer and the non-advocacy choice in winter illustrates a close indoor and outdoor thermal environment in summer and a big difference indoor and outdoor thermal environment in winter.

Table 6.8 Thermal adaptation activity of occupants in three cases.

	Winter			**Summer**		
	AGU	RWCMD	WMC	AGU	RWCMD	WMC
Put on more clothes (%)	18	16	27	7	1	9
Remove clothing (%)	33	19	26	19	12	19
Hot drink (%)	22	19	15	6	5	7
Cold drink (%)	20	24	20	19	29	7
Walking (%)	7	5	3	6	7	8
Move close to conditioner (%)	0	0	0	6	3	3

Sit in shadow (%)	0	1	1	0	1	1
Others (%)	0	0	0	1	5	1
None (%)	0	15	9	38	39	45

6.5.3 Clothing as a factors affect thermal evaluation

Comparing with other criteria and field study results, mean clothing insulation in current study is higher in winter and lower in summer. In current study, the mean clo value in winter is 1.11 clo and in summer it is 0.47 clo; in the CIBSE standard criteria of similar spaces the recommend comfort clo value is 1.07 clo and 0.65 clo separately. Occupants in indoor transitional space have the high degree of freedom to adjust their cloth insulation to get their thermal comfort condition.

Clothing thermal resistance was estimated based on a clothing list provided by the participants, the dress of participants was converted to a numerical clo value according to CIBSE. In summer the transitional space occupants had very similar clothing insulation values, while in winter, the effect of outdoor weather resulted in distinct variations in clothing levels between the different individuals. In AGU the estimated mean clo value was 1.24 with a standard deviation of 0.33 in winter and 0.46 with a standard deviation 0.13 in summer. In RWCMD the estimated mean clo value was 0.98 with a standard deviation of 0.32 in winter and 0.43 with a standard deviation 0.14 in summer. The max clo value is 2.16 and the min value is 0.4 in winter when they are 0.98 and 0.22 in summer. In WMC, the estimated mean clo value was 1.11 with a standard deviation of 0.34 in winter and 0.53 with a standard deviation 0.16 in summer. The max clo value is 2.03 and the min value is 0.37 in winter when they are 0.98 and 0.26 in summer.

Clothing adjustments is an important and natural behavior to improve thermal comfort. It was shows in Figure 6.31 to Figure 6.33 that people's mean cloth insulation in RWCMD is lower than other two cases in both winter and summer, and this possibly due to the moderate air temperature and mean randiant temperature in RWCMD. In winter, the difference in clothing values was greater than in summer. The difference of the average clothing insulation value in winter was 0.13-0.26 clo while in summer it was just 0.03-0.1 clo.

Figure 6.31 shows the clothing insulation value as a function of operative temperature in AGU. It can be observe clearly that there are two separate groups of values: one of it is under 18 °C and another one is above 20 °C subjects. As the figure shows, in the first group, most participants maintained a high clothing insulation value between 1.2 - 1.6 clo when the operative temperature was from 13-18 °C. In the second group, the most clothing insulation value was from 0.4-1.2 clo when the operative temperature range was from 20-31 °C. In AGU, participants maintain a seasonal clothing insulation value, which was almost always high in winter and moderate in summer. The minimum average clo value in AGU was 0.36 clo at 31 °C.

Figure 6.32 shows the clothing insulation values as a function of operative temperature in RWCMD. It can be seen that higher values corresponded to lower. For instance, the clothing insulation values remained from 0.4-2.16 clo in winter when the operative temperatures were below 25 °C. The value remained around 0.4 clo when the air temperature exceeded 26 °C. In RWCMD, people maintain a seasonal value always lower in winter and summer. The minimum average clo value in RWCMD was 0.34 clo at 27 °C.

Figure 6.33 shows the clothing insulation values as a function of operative temperature in WMC. It can be seen clearly that there are winter and summer groups of values: winter group is under 21 °C and summer group over 21 °C. In winter, participants maintained a high clothing insulation value between 0.9-1.5 clo when the operative temperature is 14-21 °C. In summer, the clothing insulation values were around 0.5 clo and the temperature range is from 21-24 °C. The minimum average clo value in WMC was 0.34 clo at 25 °C.

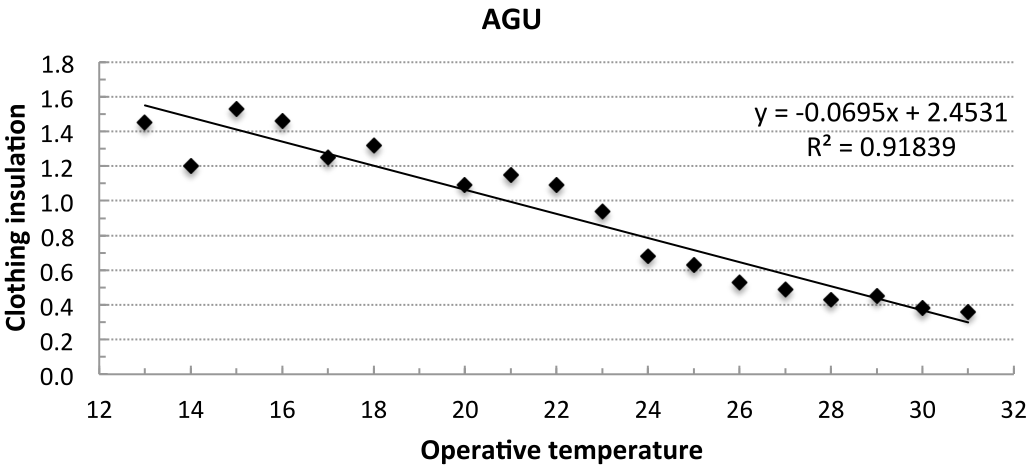

Figure 6.31 Clothing insulation as a function of operative temperature in AGU.

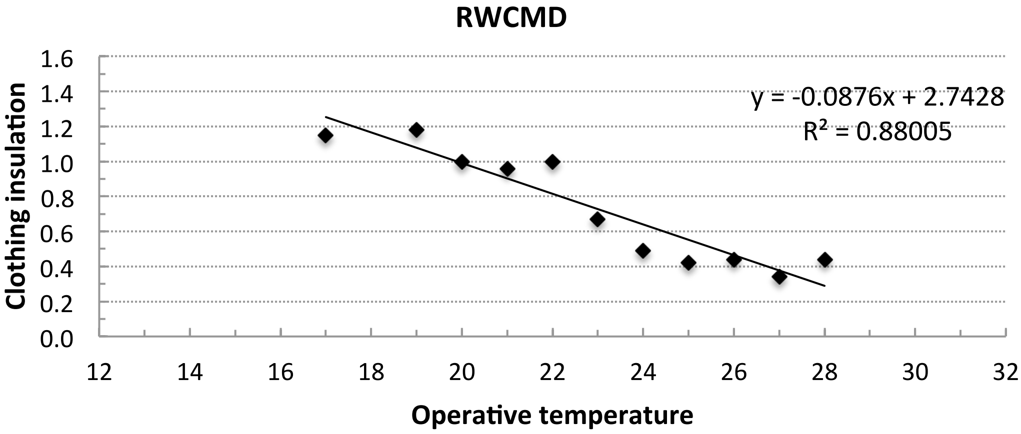

Figure 6.32 Clothing insulation as a function of operative temperature in RWCMD.

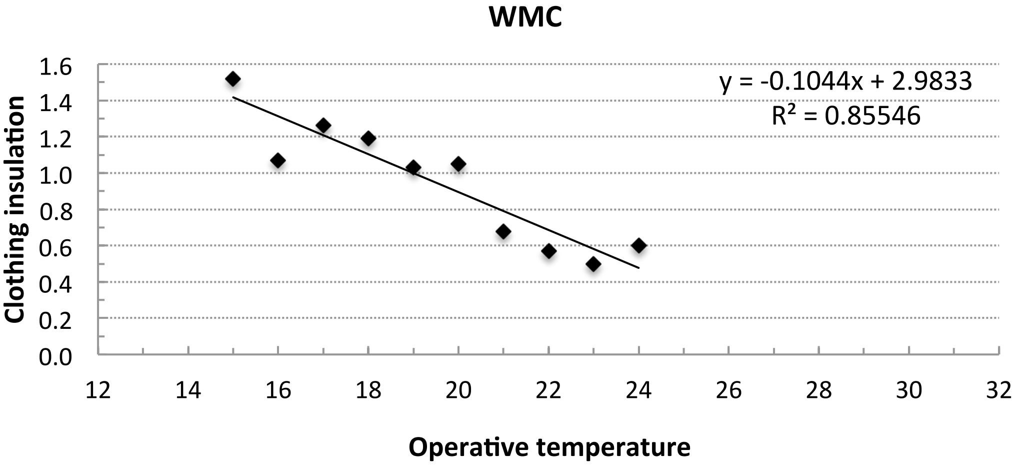

Figure 6.33 Clothing insulation as a function of operative temperature in WMC.

The difference of clothing insulation levels for all groups in AGU, RWCMD and WMC in winter was greater than in summer (Figure 6.34). It was interesting to notice that the highest clothing insulation values of participants in winter was not in WMC and in summer the lowest was not in AGU, even participants in winter WMC and summer AGU have the highest thermal tolerance with the environment.

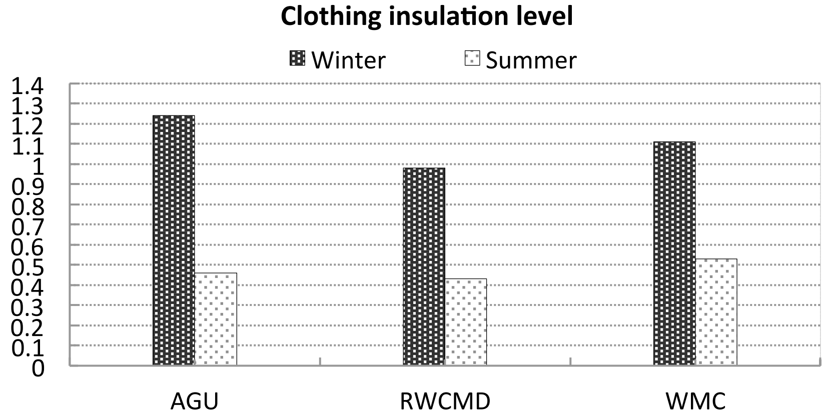

Figure 6.34 The difference of clothing insulation levels for all groups in AGU, RWCMD and WMC.

6.5.4 Changing place as a factor affects thermal evaluation

This study has identified several thermal comfort adaptive actions that a person might take to achieve comfort. One of these actions is moving to a different thermal environment from one causing the discomfort. The different thermal environments in the same transitional space provide the possibility of this adaption choice.

Since very little can be done to mitigate high or low temperatures in indoor transitional space by participants, people tend to maintain their thermal comfort by moving to the warmer or cooler area. Seeking warmer or cooler area is an action of adaptation that people may use to reduce the effect of thermal uncomfortable of their bodies in indoor transitional space. To investigate the influence of changing area on people’s thermal evaluation and the usage of different area, the number of people stay in different areas according to 1 °C interval operative temperature is analyzed.

Figure 6.35 and Figure 6.36 show the number of participants in different area in AGU transitional space, and the number of people were calculated for 1 °C of operative temperature in winter and summer. Figure 6.35 shows that in winter AGU, the total amount of participants stay in SS shows an apparently increase from 13 to 17 °C and a decrease from 21 to 27 °C. Figure 6.36 shows in summer AGU the dominant trend of the percentage of participants stay in SS is decreased when the temperature increased, from 100% of the total number to 50% of the total number with the temperature increase from 22 °C to 30 °C. It indicates that in AGU indoor transitional space, change stay area is a dominant way people choose to maintain their thermal comfort.

Figure 6.37 and Figure 6.38 shows a different seasonal situation in RWCMD: in winter changing stay area as an obvious way of moderate people thermal comfort condition (the number of people in FS decreased from 100% to 40% of the total number with the temperature increased to 23 °C), when in summer it seems an obvious variation with the temperature increasing from 24 to 29 °C.

Figure 6.39 and Figure 6.40 shows in WMC people choosing the way of changing stay area to get their thermal comfort station. In winter the number of people stay in SF area was increased from 17 °C to 20 °C (43% to 69% of the total number) while in summer it was increased from 20 °C to 23 °C (14% to 44% of the total number). In summer, number of people stay in CO and CI increased from 20 °C to 24 °C. The number of people stays in NF and CS seems not effected by the temperature change.

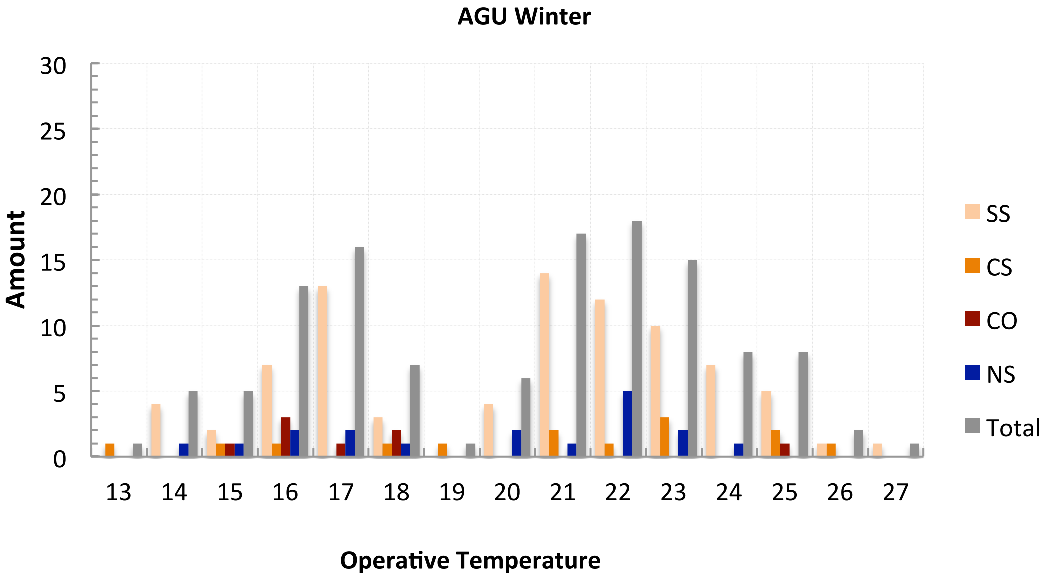

Figure 6.35 Total number of participants in different areas of AGU transitional space as a function of operative temperature in winter.

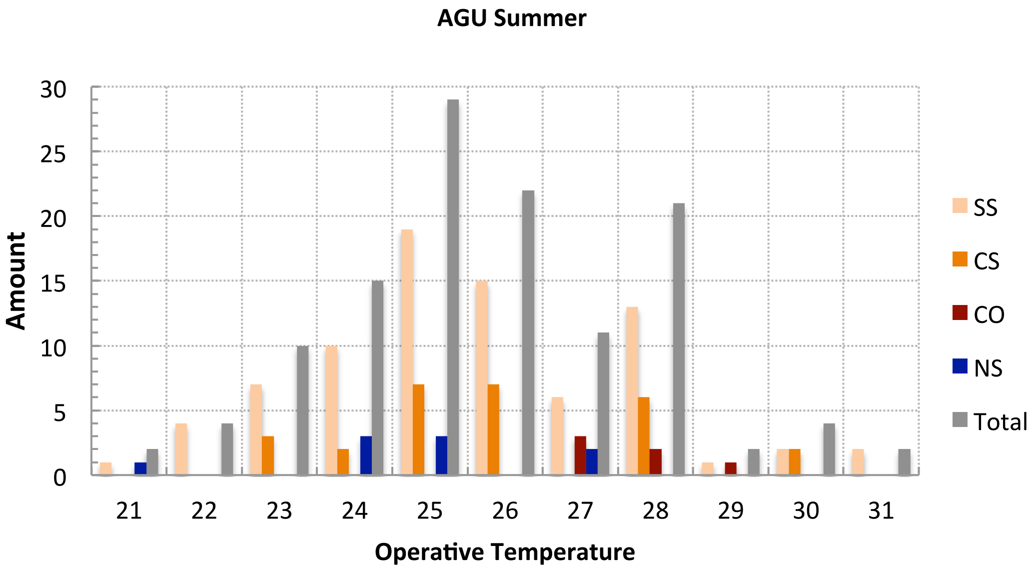

Figure 6.36 Total number of participants in different areas of AGU transitional space as a function of operative temperature in summer.

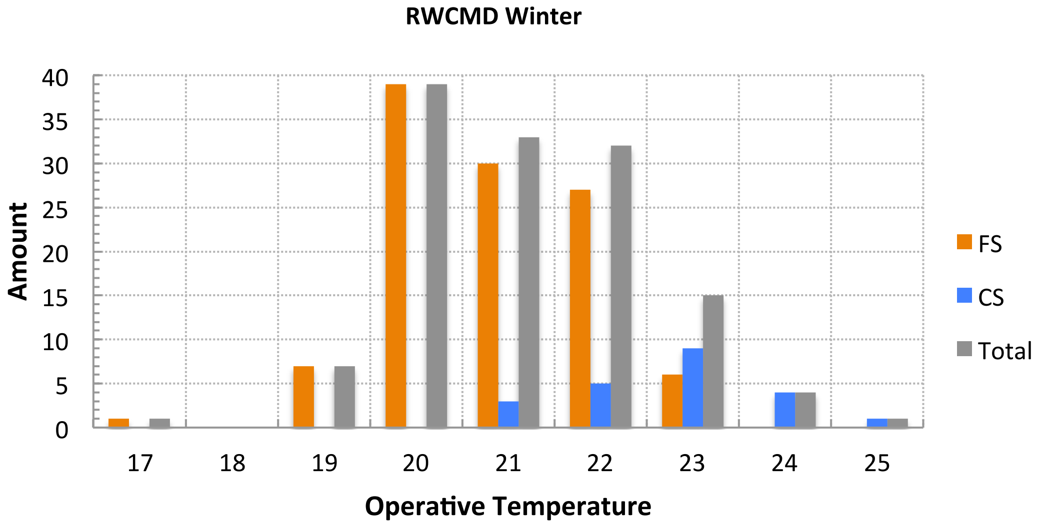

Figure 6.37 Total number of participants in different areas of RWCMD transitional space as a function of operative temperature in winter.

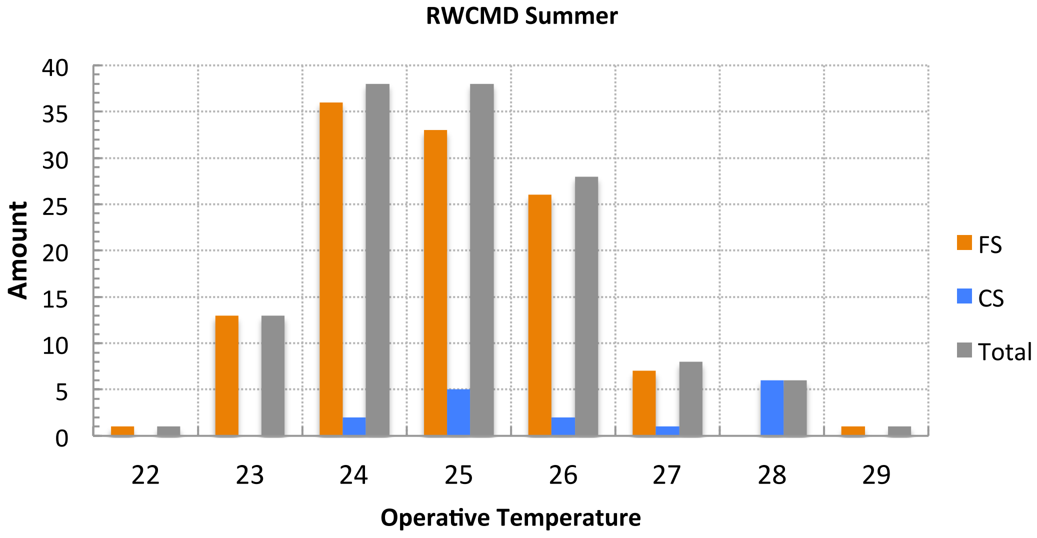

Figure 6.38 Total number of participants in different areas of RWCMD transitional space as a function of operative temperature in summer.

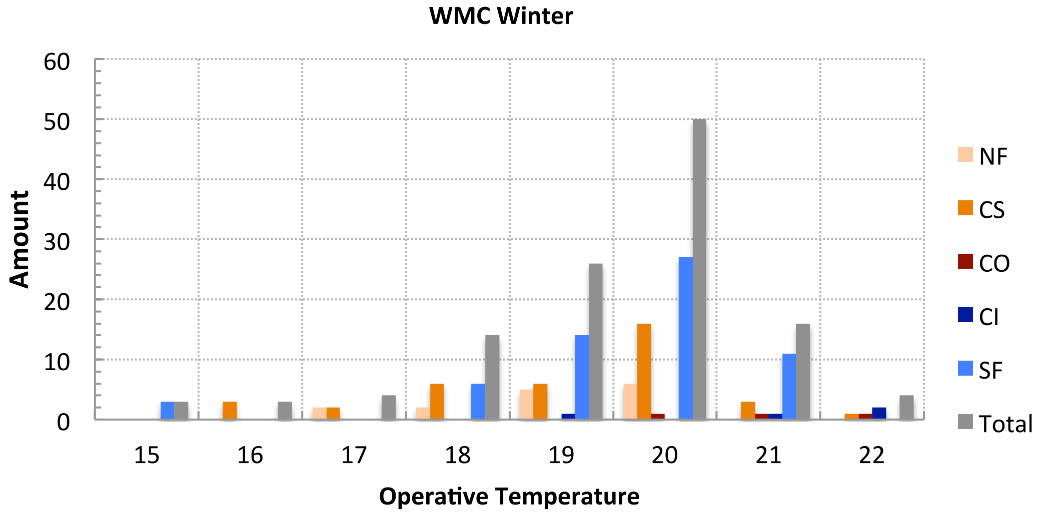

Figure 6.39 Total number of participants in different areas of WMC transitional space as a function of operative temperature in winter.

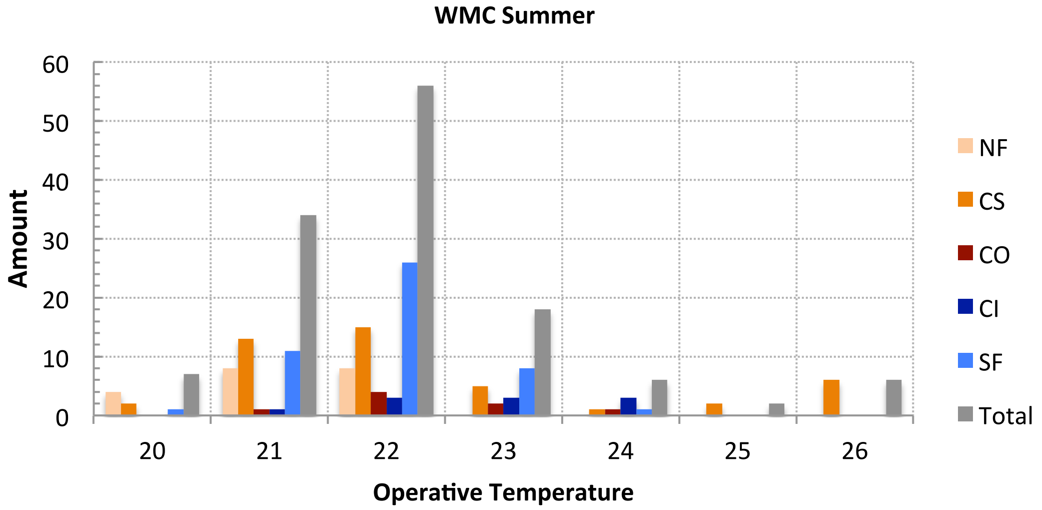

Figure 6.40 Total number of participants in different areas of WMC transitional space as a function of operative temperature in summer.

6.5.5 Drinking as a factor affecting thermal evaluation

In the people's personal activities, consuming cold or hot drinks is one way to alter the metabolic rate as a behavioral action to make people feel comfortable. As Figure 6.41 shows that almost 50% participants in all three transitional spaces in winter consumed hot drink as a method to maintain their heat balance and eventually their thermal sensitivity. In summer, about 70% participants in AGU and RWCMD consumed cold drink as a way to modify their sensation of thermal comfort, but in WMC there is only 37% of participants consumed cold drink but 50% of participants consumed hot drink.

The reason for this phenomenal might can be explained by two reasons: firstly, the operative temperature in WMC summer is lower than other two transitional spaces; secondly, there is more older age participants in WMC transitional space, drink coffee or tea is just a habit of them. In winter AGU, the consumed cold and hot drink is almost equal in winter, it might caused by the high operative temperature in winter and a high clothing insulation. However, a high percentage of consumption of cold drink in other two cases in winter is hard to explain by these two reasons. According to the observation work, it should be results from the expectation and experience of participants; for example, a participant ride a bike before coming to the transitional space would like to drink something cold whether the thermal environment is warm or cool.

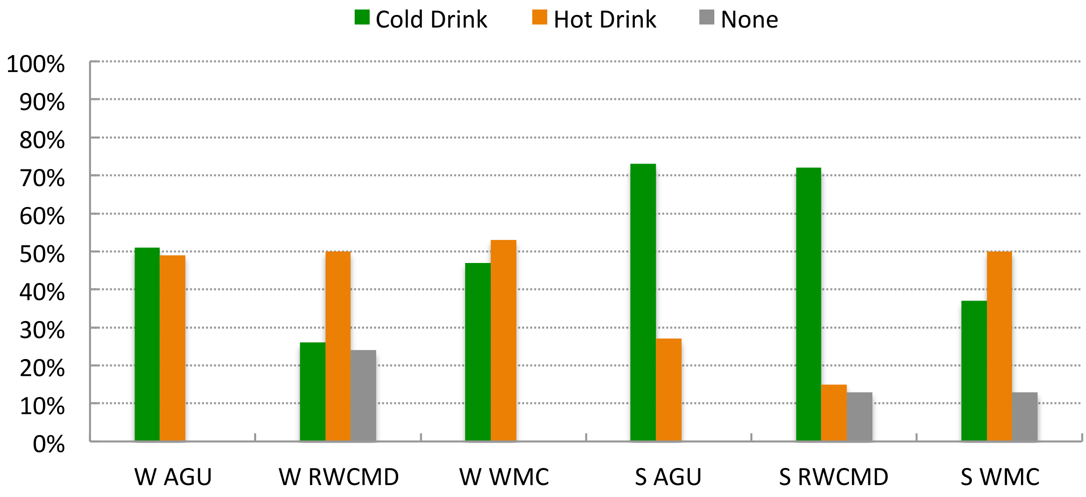

Figure 6.41 Percentage of participants who were drinking cold or hot water to modify their thermal comfort in winter and summer.

Consumption of cool or hot drinks to alter metabolic rate is considered as an action of coping with variable thermal comfort. According to Nikolopoulou and Steemers 's opinion (2003) that it is related to the long-term experience that people have gained through years to use similar spaces. This experience affects participants' expectations so that they get prepared for actions to alter the thermal stress when in the transitional space (such as having cool or hot drinks). Consuming cold or hot drinks in the indoor transitional spaces investigated in this study is further evidence that adaptation was occurred to alleviate thermal discomfort.

6.5.6 Expectations and experience

Past experience makes people expect the thermal environment in a space to be in a certain condition. These expectations sometimes do not match the actual conditions in a transitional space and therefore affect the thermal perception of occupants. This effect can be examined by comparing the neutral and the preferred temperatures, in addition to the time spent by participants in the transitional space.

The comparison of neutral and preferred temperature is calculated and shows in Table 6.9. The difference found is 0.6 to 1.5 °C in winter of three transitional spaces and 0.3 to 0.7 °C in summer. The small difference between the neutral and preferred temperatures illustrates the possibility that occupants in winter WMC and summer AGU and RWCMD have the best expectations of thermal conditions.

Table 6.9 The difference between neutral and preferred temperature.

	Winter			**Summer**		
	AGU	RWCMD	WMC	AGU	RWCMD	WMC
Neutral temperature (°C)	20.8	21.6	20.1	21.2	23.8	22.6
Preferred temperature (°C)	20.2	22.5	21.6	21.5	23.5	21.9
The difference between Neutral and Preferred temperatures (°C)	0.6	0.9	1.5	0.3	0.3	0.7

Expectations strongly link and according to experience, people prepare themselves for the expected thermal environment by choosing appropriated clothes, time of spend in indoor transitional spaces, activity type etc. Neutral temperature was observed differently among three groups. People’s thermal perception is change through different seasons. According to the temperature difference in winter and summer indoor transitional space environment, the thermal neutrality of participants in winter is expected lower than in summer and Table 6.9 confirm this. In this study, the difference in neutral temperature among three groups was greater in summer than in winter. This indicates that respondents from all indoor transitional spaces had similar expectations of thermal environment conditions in winter but not in summer.

The following parameters might be able to explain what findings above. Experience reminds people that air temperature in summer is higher than in winter in indoor transitional space. Since the mechanically conditioned environment in winter is dominated in all of these three indoor transitional spaces, people tolerant a smaller difference temperature in winter. The greater difference in summer was results from the difference between mechanically or air conditioned and natural ventilated environment. On the other hand, the higher clothing insulation level in AGU in winter and in RWCMD in summer could have an influence on the relatively lower neutral temperature in different seasons.

6.6 Thermal comfort and use of indoor transitional space

The use of the indoor transitional space was studied by observing the attendance of occupants and the activity took place in the space; the frequency of visiting the space and the length of stay in the transitional space. Visit frequency and time spend in the transitional spaces can be regards as an indicator of the satisfaction with the predominant conditions in a place. The more frequently of visit the space and the longer the time spent in the transitional space evident the more successful the space is. Due to the high percentage of thermal acceptability and thermal sensation satisfactory rate, the analysis mainly focuses on the relations with thermal preference.

6.6.1 Attendance and Activity

Because indoor transitional space is always an auxiliary space of a building, the attendance and activity of occupants in these spaces is close related to the purpose of people visit these building. Figure 6.42 shows the main reason of people visit these building, it can be seen that in AGU the main visit reason was study and working while in RWCMD it was study, working and entertainment, but in WMC the main visiting reason is working and entertainment. It indicates that there is certain number occupants visit these spaces frequently and regularly due to they are working or study in the building, and the largest amounts of this part occupants was in AGU as 80 % when in RWCMD it was 35 % and in WMC it was only 18 %. According to the real observation results, WMC always have a high visit number especially at the performance day, weekend or some special festivals, it also evident the quite high percentage of people visiting the building for entertainment.

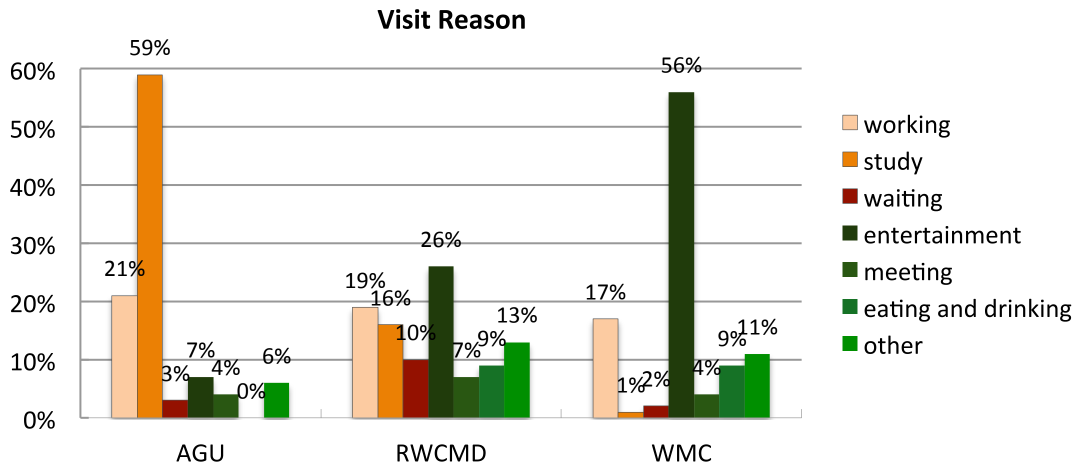

Figure 6.42 Percentage of people's visiting reason in each case (AGU N=245, RWCMD N=265 and WMC N=249).

In this study, working, study and entertainment in the building are the most important reasons for a high attendance in the building according to the main function characteristic of the building. To investigate if the reason of visiting the building influence on the thermal perception of indoor transitional space, and further investigate influence of thermal environment on use of the transitional space, the stay reason is analyzed as show in Figure 6.43 to Figure 6.45. As the figures indicated, only a very small part participants stay in the space where they asked did the questionnaire because of thermal consideration, as 4% in AGU, 13% in RWCMD and 8% in WMC. Most participants chose they staying space according to the function consideration, as use the space for waiting, studying and have lunch etc. In all of these three spaces, in two educated institutes most popular stay reasons for the participants are waiting and study/working when in the culture and commercial institute the most popular stay reasons are waiting and having a break, this situation is corresponds to the main characteristic of transitional spaces.

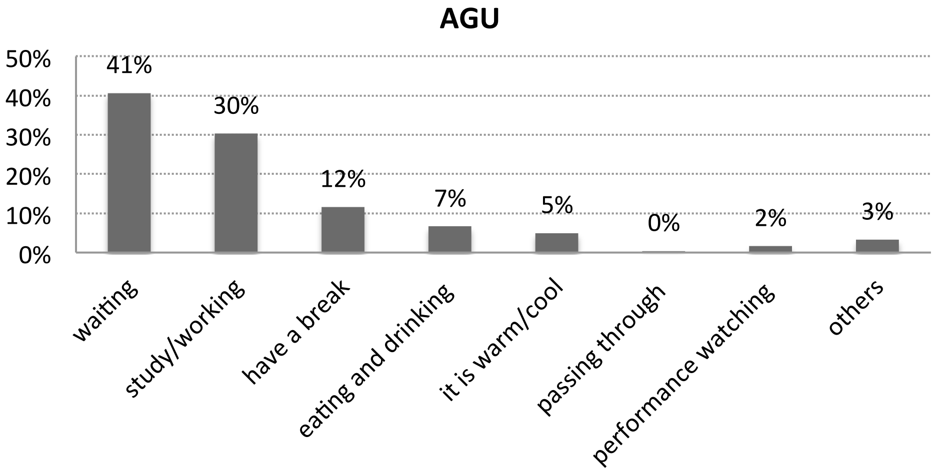

Figure 6.43 Percentage of the reason participants in AGU chose stay in the area (N=245).

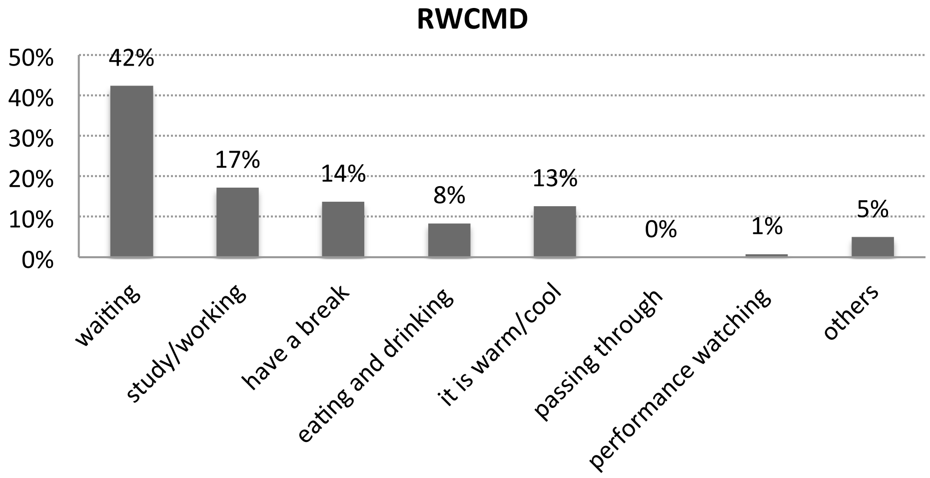

Figure 6.44 Percentage of the reason participants in RWCMD chose stay in the area (N=265).

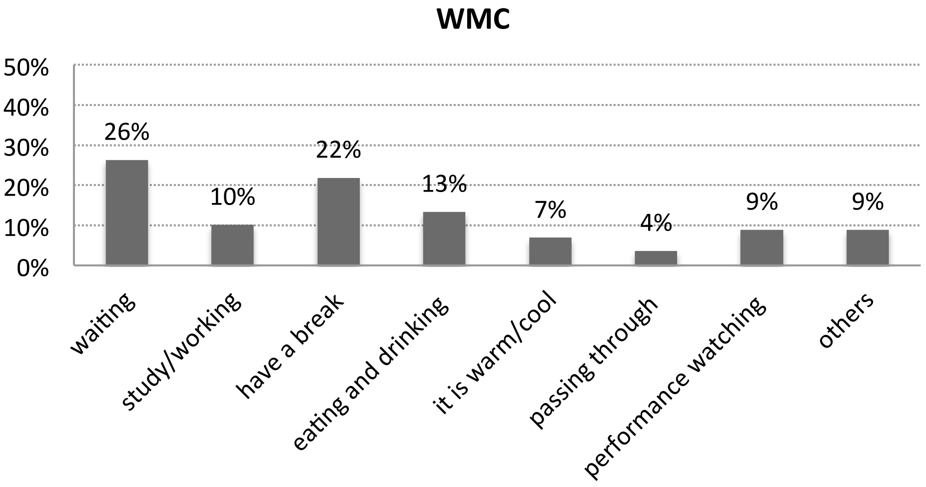

Figure 6.45 Percentage of the reason participants in RWCMD chose stay in the area (N=249).

Figure 6.46 to Figure 6.48 indicate that people in AGU have a higher thermal preference rate in all of the stay reasons but in RWCMD and WMC this rate is lower. It can be seen that the stay reason of passing through have the highest thermal no preference rate, it means people passing through the indoor transitional space care less or less sensitivity about the thermal environment. The stay reason of working/study shows a highest thermal preference rate, it means people stay in the indoor transitional for working/study cares more and more sensitivity to the thermal environment in indoor transitional space. People stay in the indoor transitional spaces for the thermal reasons (warm/cool) shows a high preference rate as expected. The results of the analysis of thermal preference depends on the stay reason indicates that the participants' thermal perception have a close relationship with participants' the stay reasons in the indoor transitional spaces.

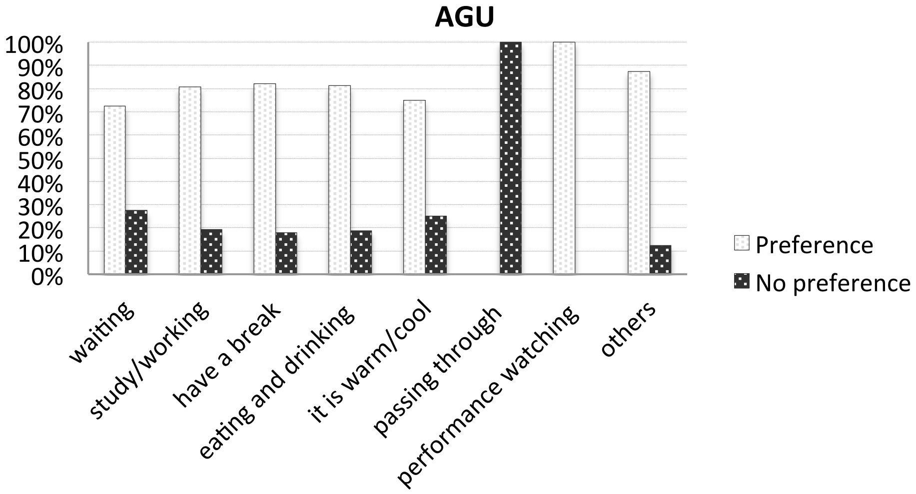

Figure 6.46 Thermal preference of participants depends on the stay reason in AGU.

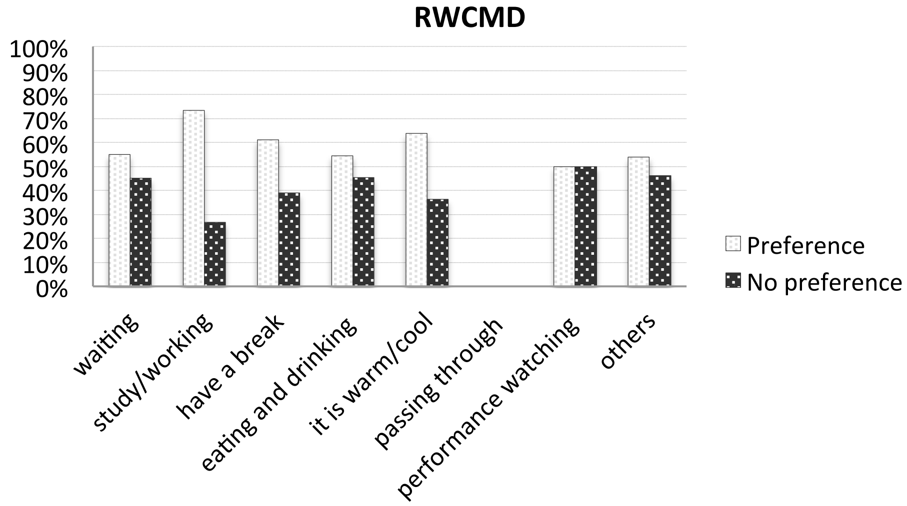

Figure 6.47 Thermal preference of participants depends on the stay reason in RWCMD.

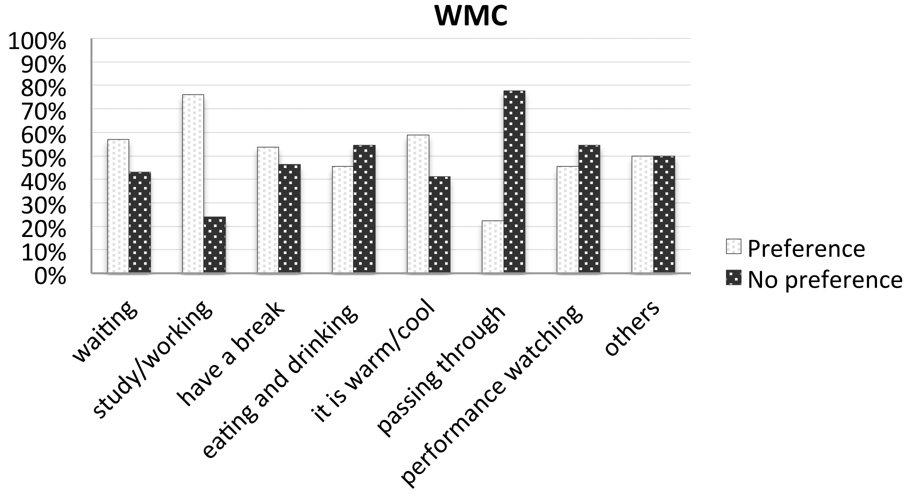

Figure 6.48 Thermal preference of participants depends on the stay reason in WMC.

Figure 6.10 shows the most popular areas the participants choose to stay and the popular reason of it in these three cases. It indicates that in all of these three indoor transitional spaces, thermal consideration truly is a reason with quiet proportion when people choose a favorite space to stay. But this reason is always not the most important one, people frequently put their use requirements consideration as the most significant reason to choose a space to stay.

Table 6.10 Most popular area and popular reasons.

Transitional space		AGU	RWCMD	WMC
Most popular area		South foyer seat area	Foyer seat area	South foyer seat area
Popular reason	For warm/cool	25 %	13 %	13 %
	For quite	4 %		6 %
	For light	4 %	17 %	19 %
	For facilities	35 %	15 %	13 %
	Good view	13%	46 %	
	For performance			44 %
	For social	5 %		6 %
	Fresh air	9 %		
	For refreshment	9 %		
	No draft		2 %	

6.6.2 Visiting frequency

The correlation analysis shows visit frequency correlated with thermal preference at the 0.05 level among three thermal satisfaction criteria: thermal acceptation, thermal sensation and thermal preference. Comparing to other two spaces, participants in AGU visiting the space more frequently than most participants in RWCMD and WMC (as Figure 6.49). It can be seen that the percentage of high visit frequency in AGU is apparently happened more than in other two indoor transitional spaces. Conversely, the high visit frequency of RWCMD indoor transitional space is lower than expected (it is belong to a educational institute and should be quite a lots of student visit this building frequently), only 11% participants visit the indoor transitional space daily and 29% visit it frequently. Besides, the percentage of each visit frequency interval of RWCMD is quite close to that of WMC. To investigate the influence of thermal comfort on the visiting frequency of indoor transitional space, the analysis of thermal preference by visit frequency is carried out.

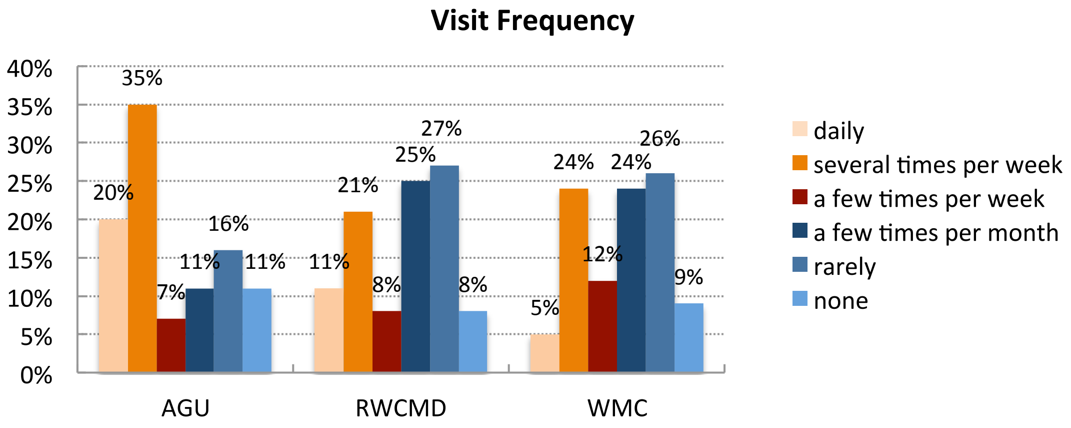

Figure 6.49 Percentage of visit frequency in three cases (AGU N=245, RWCMD N=265 and WMC N=249).

Figure 6.50 to Figure 6.52 show the thermal preference/no preference percentage depend on the visit frequency. Visit frequency is classified to three intervals: daily (daily), frequently (several times per week, few times per week) and not frequently (a few times per month, rarely, none). It is indicates that the highest thermal preference rate in AGU at each visit frequency rate than other two buildings. Combining this result with the observations and participants' complain during the survey progress, and the thermal satisfaction rate, it can be seen that people in AGU indoor transitional space are most dissatisfied with their thermal environment. People complained that the SS and CF area is too warm some times even in winter. It is mainly results from the south-north layout of the building with a big façade glass, which make no shelter from the direct sunlight that cause the overheating environment some times. Additionally, it can be seen that people visit this pace frequently and not frequently have a higher preference than those visit daily. It is advents the people's thermal adaptation of uncomfortable thermal environment, the thermal dissatisfaction rate (preference rate) was decreased when they get used to the environment they stay in.

In other two indoor transitional spaces, the no preference rate was increased with the decrease of visit frequency. People visit the building more frequently has a higher preference rate. That indicates people visit these two spaces daily are more familiar with the thermal environment and less tolerance to the thermal discomfort. It also explain the possibility that people visit these space rarely are less care about the thermal environment in indoor transitional space.

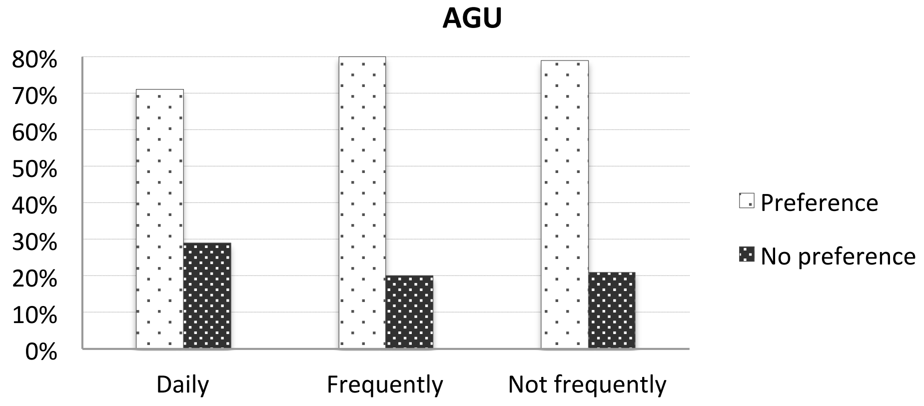

Figure 6.50 Thermal preference of participants depends on the visiting frequency in AGU.

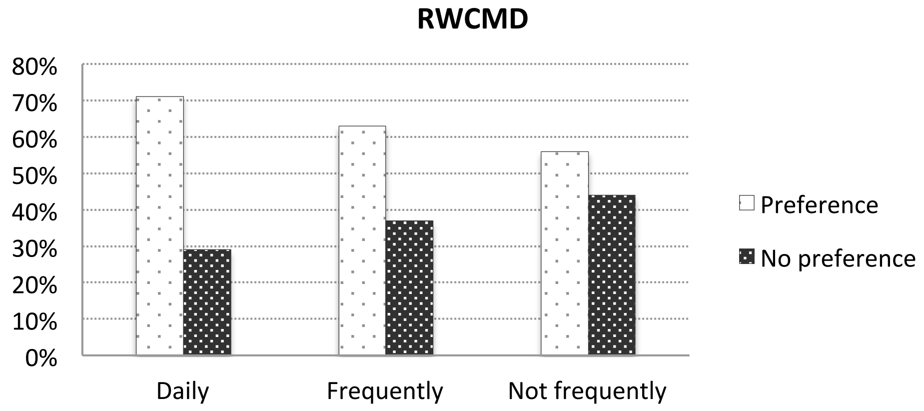

Figure 6.51 Thermal preference of participants depends on the visiting frequency in RWCMD.

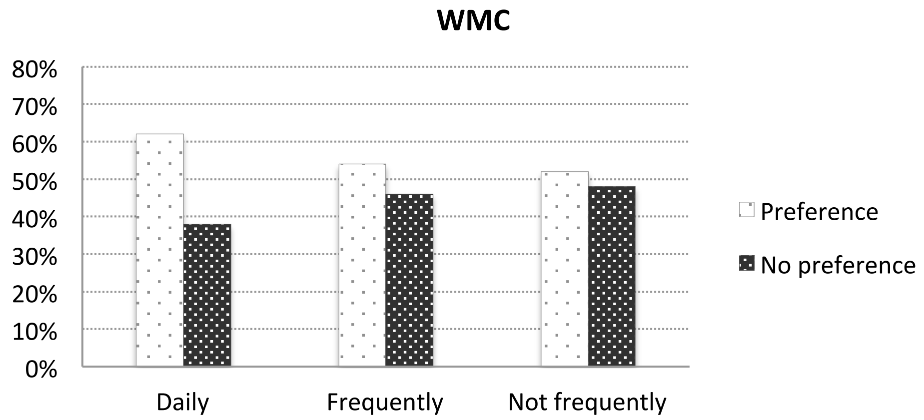

Figure 6.52 Thermal preference of participants depends on the visiting frequency in WMC.

6.6.3 Time of stay

Examining time of people stay in the space may reveal some variation among three groups of participants' thermal preference. The percentage of thermal preference and no thermal preference labeled by the length of people often stay in the space. Figure 6.53 to Figure 6.55 show that most participants in indoor transitional spaces are often stays in the space more than 20 minutes. In AGU and RWCMD, the thermal preference rate is always higher than the no preference rate either of people stay in the space less than 20 minutes or more than 20 minutes. This difference is particular apparently in AGU indoor transitional space. It is noticeable that 100% of subjects who stay in the AGU transitional space less than 20 minutes with thermal preference are like their environment cooler than current time. The most possibility explanation of this situation is the high temperature in winter AGU indoor transitional space, as the subjects complained to the researcher when they filled the questionnaire. But in WMC the no preference rate of people stay in this space less than 20 minutes is higher than the rate of preference. Therefore, this provides the evidence that people stay in a space less than 20 minutes have a lower thermal preference than these people stay in the space more than 20 minutes, in another words, people stay in a short time care less about their thermal environment than those stay in the indoor transitional space for a longer time. It is evident Nikolopoulou's explanation that people tend to tolerate uncomfortable short periods of time in uncomfortable conditions when they know it's going to be for a short period, in specific when it was people's chose to be there.

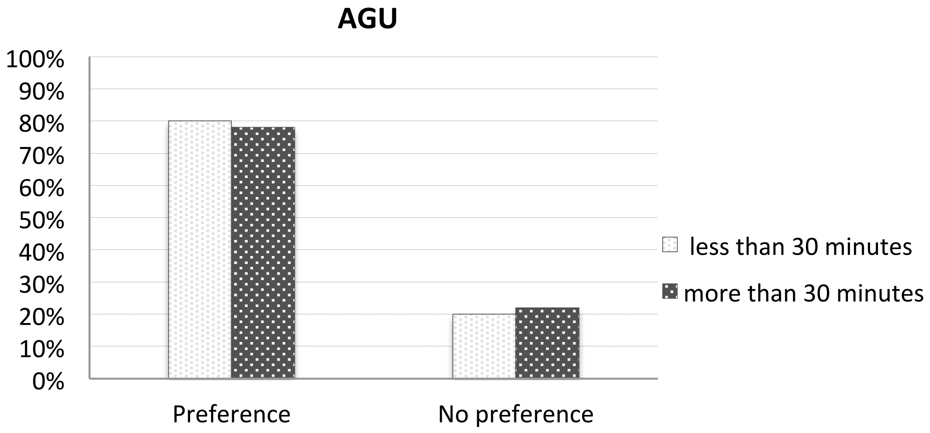

Figure 6.53 Thermal preference of participants depends on the often stay time of the space in AGU.

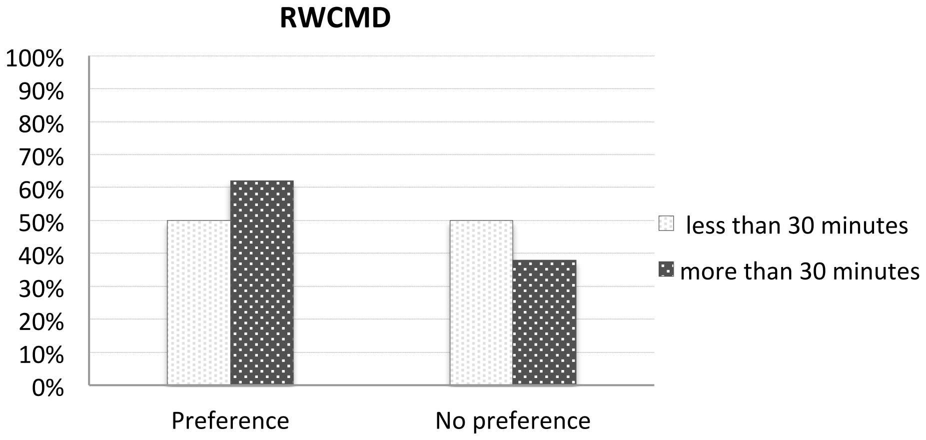

Figure 6.54 Thermal preference of participants depends on the often stay time of the space in RWCMD.

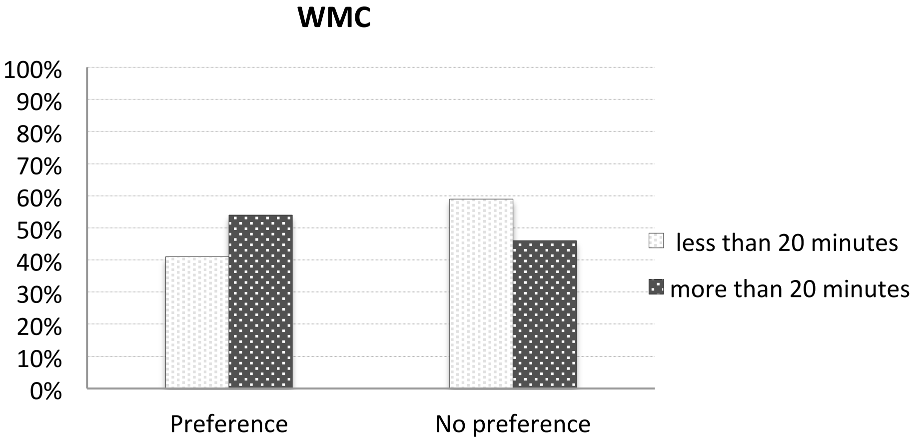

Figure 6.55 Thermal preference of participants depends on the often stay time of the space in WMC.

As discussed above, a good design that meets the thermal environment is essential to a successful indoor transitional space. However, it could be the type of activity taking place that encourages people to get involved and start socializing with others, spending longer time in the indoor transitional space and therefore attract more people in the indoor transitional space. This study revealed that indoor transitional spaces in the Cardiff that offer good thermal environment design and allow social activities are likely to influence their user to stay longer. In addition, the visit frequency, stay time and stay reason interactive with the thermal perception in transitional spaces in building.

6.6.4 The influence of environmental parameters on the use of space

Figure 6.56 to Figure 6.61 mark the position people stay in the three indoor transitional spaces when they were filled the questionnaire and the thermal environment parameters in different spaces in indoor transitional spaces. This is presents the participants' regular way of using the three indoor transitional spaces as well.

The correlation between mean environment value of each space of indoor transitional spaces and the distribution of participants' position in indoor transitional spaces illustrate: 1) the way of people use indoor transitional spaces are mainly decided by the provided facility rather than environmental parameters; 2) except the "necessary requirements" (eg. eating and drinking, going to toilet), people were inclined to stay in the warmer space in winter and cooler space in summer. As Figure 6.57, Figure 6.62 and Figure 6.61 shows, even the operative temperature of café sitting area is higher than other sitting area in summer, people still choose stay in café sitting area because they have breakfast or lunch and dinner at there; 3) even if the above non-thermal parameters influence on the way of people use the indoor transitional spaces, thermal environmental parameters still have a significant influence on the way people use the indoor transitional spaces. As can be seen from the figures, in summer people always avoid the area with direct sunlight exposure (especially obvious in the North-South layout space); the number of people stay in cooler area in summer is more than in winter; in winter more people stay close to the heater (in winter AGU, people stay close to the trench heater) and in summer people stay close to the cool wind outlets (in summer WMC, more people stay in the Corridor sitting area that is close to the cool wind outlets).

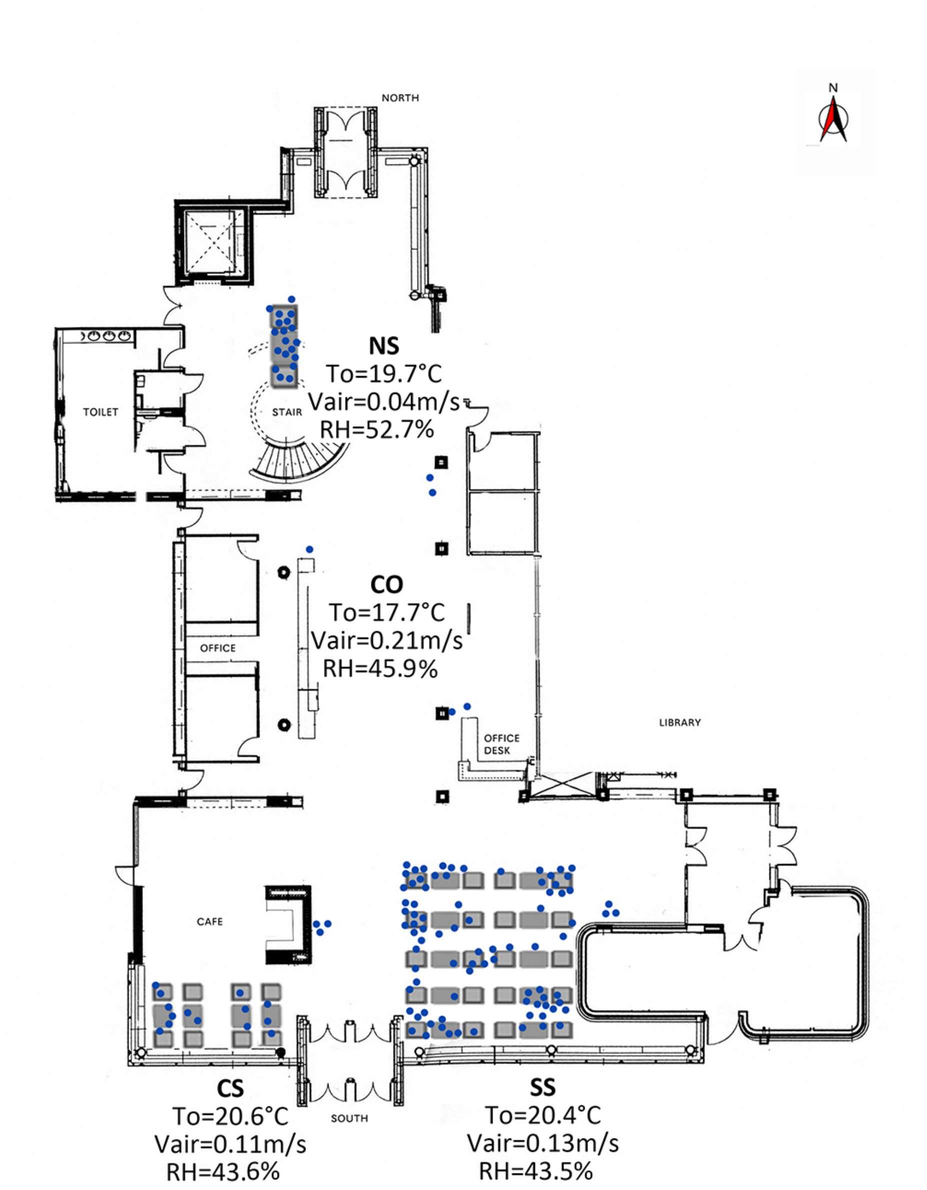

Figure 6.56 Mean environment parameters' value in different spaces and participants' position when they attend the interview in winter AGU

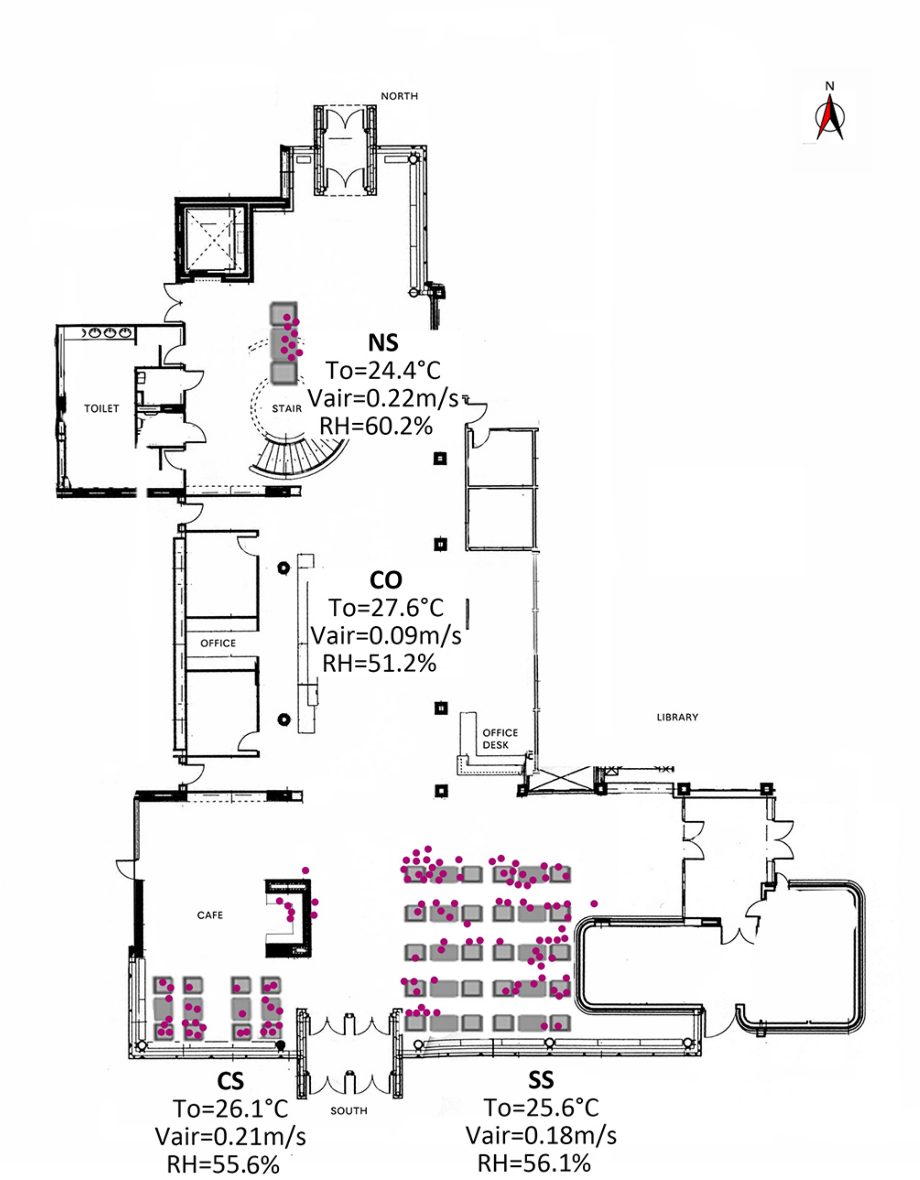

Figure 6.57 Mean environment parameters' value in different spaces and participants' position when they attend the interview in summer AGU

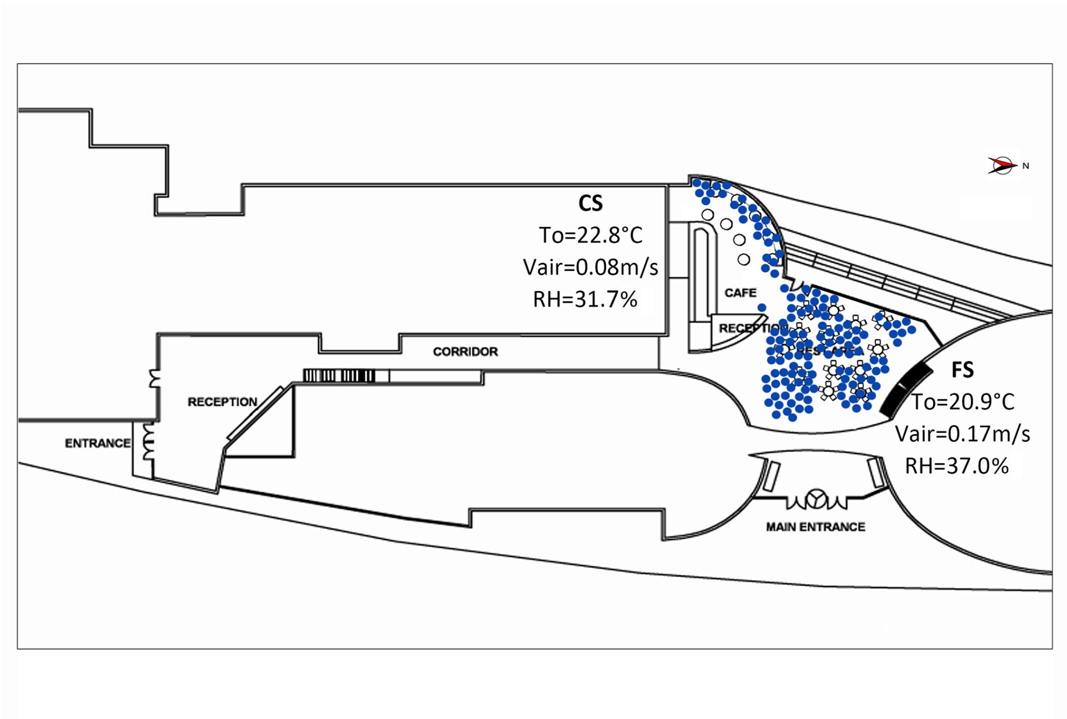

Figure 6.58 Mean environment parameters' value in different spaces and participants' position when they attend the interview in winter RWCMD

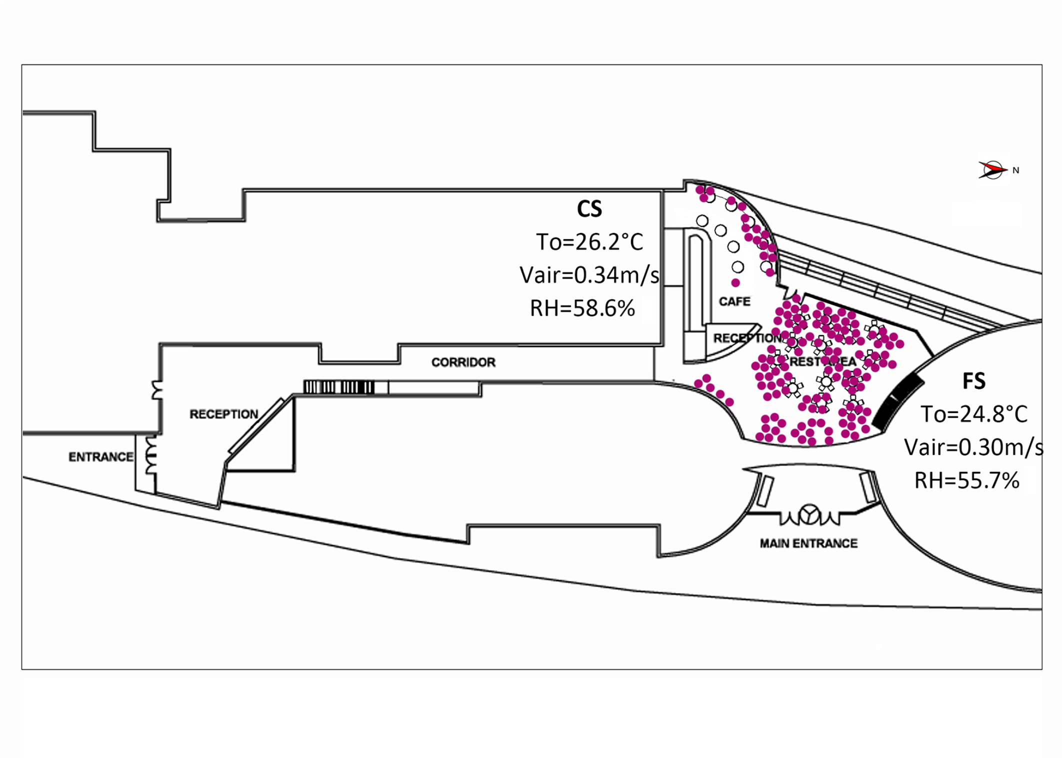

Figure 6.59 Mean environment parameters' value in different spaces and participants' position when they attend the interview in summer RWCMD

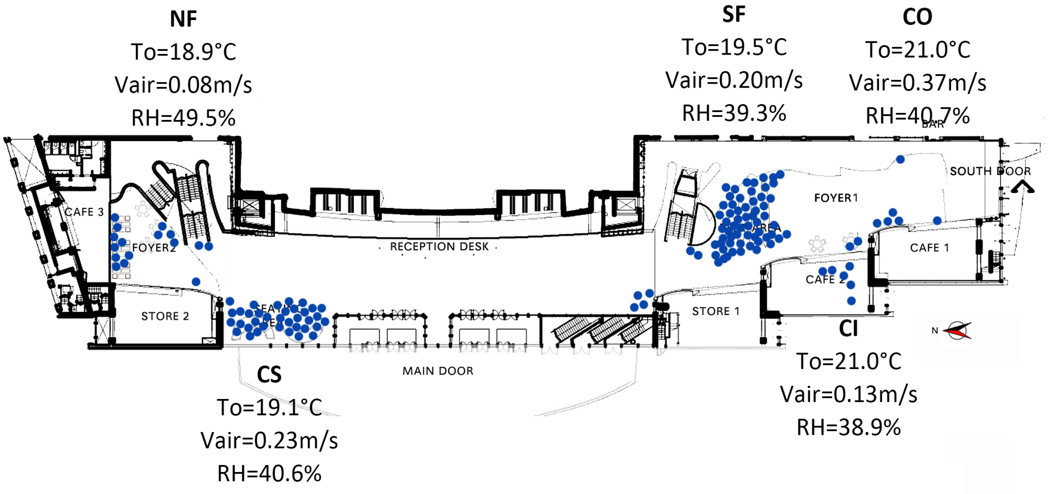

Figure 6.60 Mean environment parameters' value in different spaces and participants' position when they attend the interview in summer WMC

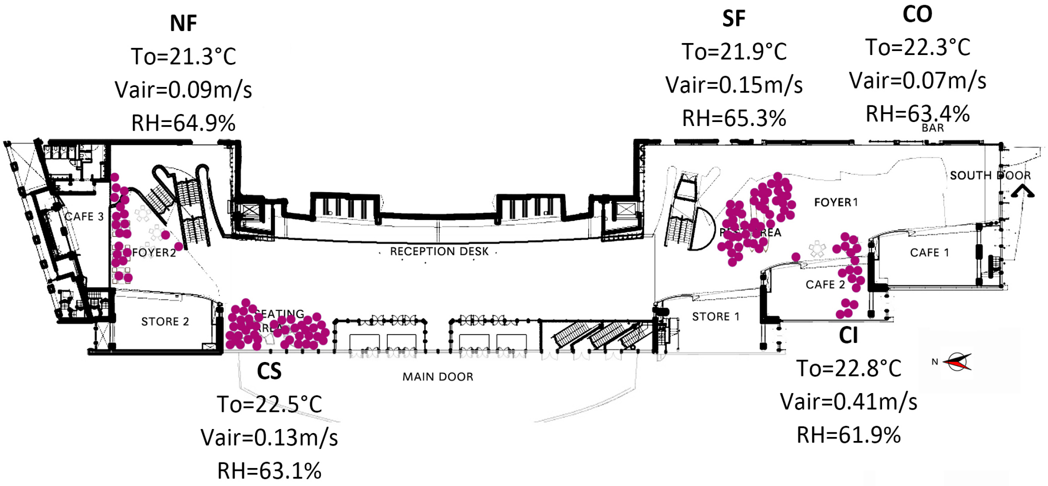

Figure 6.61 Mean environment parameters' value in different spaces and participants' position when they attend the interview in summer WMC

Further analyses were performed in more detail by showing three variables: number of people, visit time and environmental parameters in each of the spaces in indoor transitional spaces in winter and summer. The number of people in each site was labeled by the time of the day (morning, noon and afternoon). It appeared that the attendance during afternoon intervals in indoor transitional spaces is higher than during the time intervals of morning and noon as can be seen from Figure 6.62 to Figure 6.64. This difference is especially apparently in WMC indoor transitional spaces, it is because this is a cultural and entertainment center and people always visit it after work. In the morning, the number of people visit AGU and RWCMD indoor transitional spaces is more than visit WMC, it means people use indoor transitional spaces in two educated institutes AGU and RWCMD were more evenly during the three time intervals of a day than in WMC.

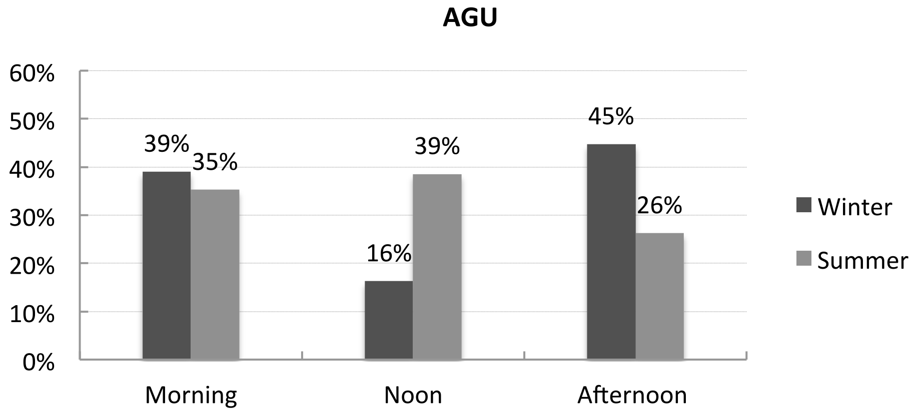

Figure 6.62 The percentage of people in morning, noon and afternoon in AGU (Winter N=123, Summer N=122).

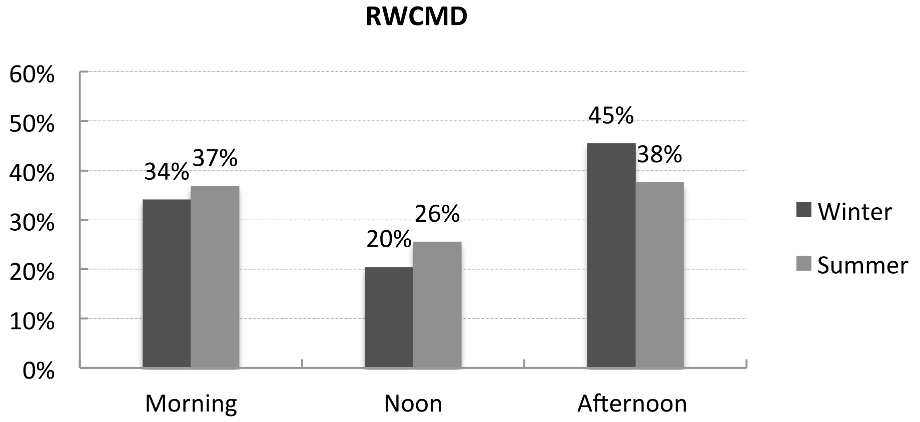

Figure 6.63 The percentage of people in morning, noon and afternoon in RWCMD (Winter N=132, Summer N=133).

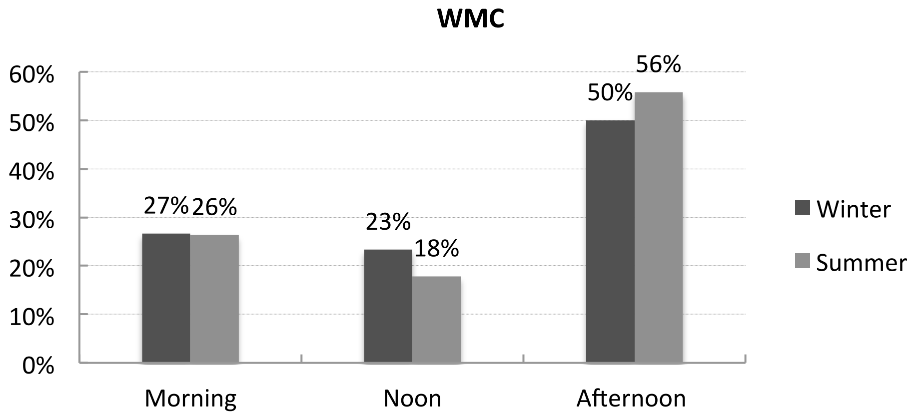

Figure 6.64 The percentage of people in morning, noon and afternoon in WMC (Winter N=120, Summer N=129).

To further investigate the influence of environmental parameters on the use of indoor transitional space, mean value of thermal environment and light environment parameters in morning, noon and afternoon in different spaces in indoor transitional spaces are listed as Table 6.11 to Table 6.16, and the number of people visit the different spaces of indoor transitional spaces in morning, noon and afternoon is shown in Figure 6.65 to Figure 6.70.

Figure 6.65 shows that in AGU transitional space, the number of people stay in South sitting area (SS) is about three times more than in other areas. The main reason is this space provided more sitting facilities than in other spaces but the thermal and light environment still pays a significant contribution. As can be seen, in morning, noon and afternoon, the mean operative temperature in SS is most close to the neutral temperature 20.8 °C and preferred temperature 20.2 °C in AGU winter. The mean operative temperature in SS is 1 °C to 4 °C higher than in other spaces in morning and noon. Meanwhile, the more popular area of SS and Café sitting area (CS) are brighter than other two spaces as Table 6.11 shows. The number of people stay in North sitting area (NS) is almost same in morning, noon and afternoon. It means the reason people choose to stay in NS is less correlated to the operative temperature change.

Figure 6.66 shows the percentage of participants stay in the different spaces in summer AGU in morning, noon and afternoon. As can be seen, the percentage of participants' number in SS is still quite higher than in other three spaces. The mean operative temperature value in these four spaces in noon and afternoon is quite close in SS and CS. However the operative temperature in morning SS is about 2 °C lower than in noon and afternoon, the air speed in morning SS is higher than in other times too. This result shows that in AGU, about the participants’ percentage stay in morning is 20% higher than in noon and afternoon. Even if the similar operative temperature difference is happen at space CS, the people stay in CS in noon and afternoon is still more than in morning, which is because CS provide food and drinks so people stay in CS for lunch and afternoon tea.

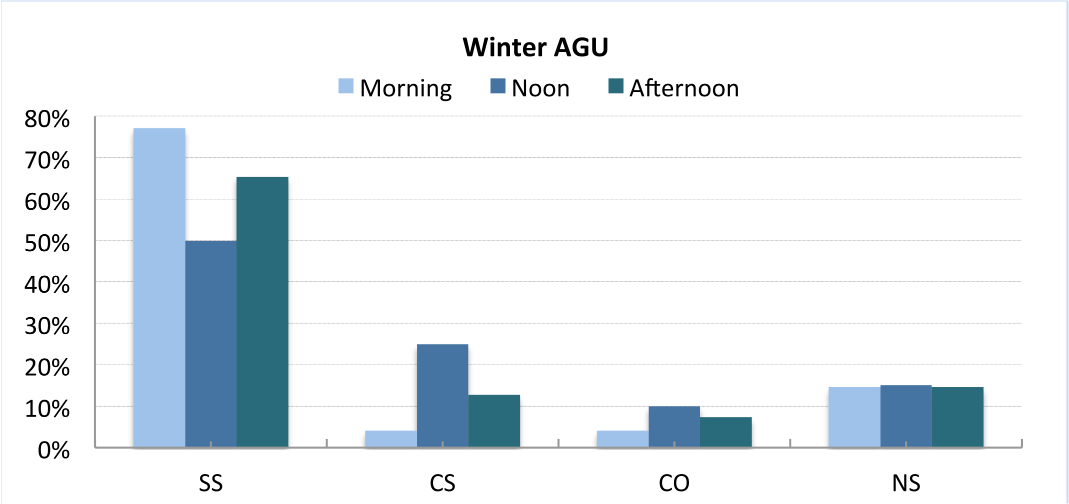

Figure 6.65 The percentage of participants stay in different spaces in winter AGU in morning, noon and afternoon (Morning N=48, Noon N=20, Afternoon N=55).

Table 6.11 Mean environment parameters' value in different spaces in morning, noon and afternoon in winter AGU.

	Winter AGU															
	SS				CS				CO				NS			
	T_o (°C)	AS (m/s)	RH%	Illum. (lux)	T_o (°C)	AS (m/s)	RH%	Illum. (lux)	T_o (°C)	AS (m/s)	RH%	Illum. (lux)	T_o (°C)	AS (m/s)	RH%	Illum. (lux)
Morning	20.0	0.13	43.8	3350	17.6	0.18	51.0	1205	17.2	0.15	46.8	185	18.9	0.06	53.2	671
Noon	21.5	0.18	40.8	5343	18.6	0.08	43.5	5568	20.5	0.30	44.0	1725	17.6	0.00	51.0	1657
Afternoon	20.4	0.11	43.9	491	22.9	0.11	41.5	1220	16.5	0.20	46.3	48	21.2	0.04	52.9	490

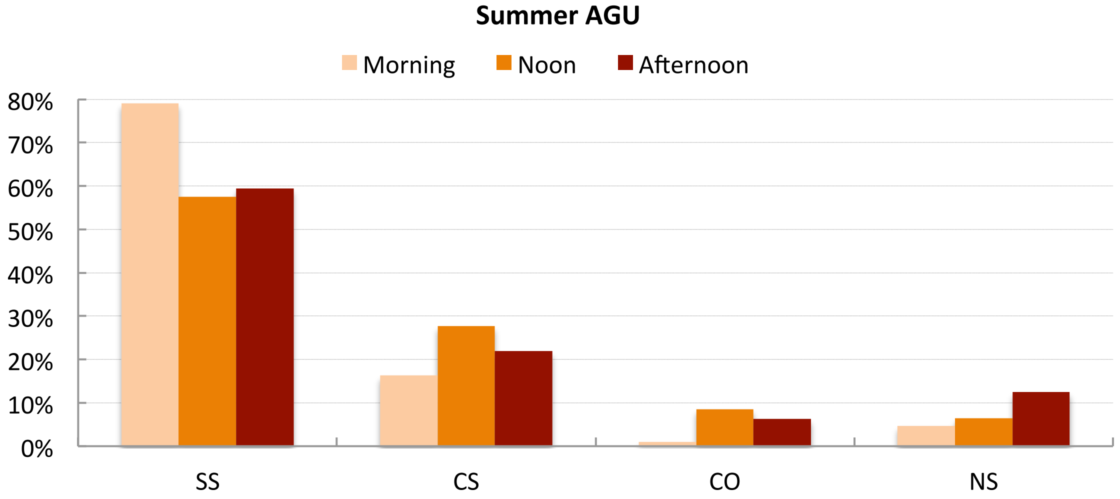

Figure 6.66 The percentage of participants stay in different spaces in summer AGU in morning, noon and afternoon (Morning N=43, Noon N=47, Afternoon N=32).

Table 6.12 Mean environment parameters' value in different spaces in morning, noon and afternoon in summer AGU.

	Summer AGU															
	SS				CS				CO				NS			
	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)
Morning	24.4	0.19	59.8	6711	24.5	0.16	58.8	13182	26.5	0.15	58.9	9983	22.8	0.38	60.6	1441
Noon	26.7	0.17	54.6	18212	26.6	0.29	56.4	20489	28.2	0.07	53.8	10863	24.3	0.28	60.2	1338
Afternoon	26.3	0.18	51.3	2424	26.7	0.10	50.9	3319	26.5	0.13	46.0	1055	25.4	0.10	60.5	1809

Figure 6.67 and Figure 6.68 show both in winter and summer RWCMD the percentage of participants stay in Foyer sitting area (FS) is four times more than in Café sitting area (CS). As can be seen that the percentage of people stay in CS in winter is more than in summer when both in winter and summer the mean operative temperature in CS is higher than in SS. In winter it is about 2 °C higher and in summer it is 0.9 °C to 1.8 °C (Table 6.13 and Table 6.14). This indicates that in winter more people inclined to stay in the warmer area CS but in summer they choose stay in the cooler area FS, the increasing percentage of participants in summer FS is evident this again. The mean value of environmental parameters also illustrate that in summer RWCMD, people alike stay in the area with higher air move speed in all of morning, noon and afternoon too. In another words, in summer indoor transitional spaces, people like stay in the area with lower operative temperature but higher air move speed. Relative humidity and illuminate seems did not effect the way of people use the space because there is no apparently difference of these two parameters among three time intervals.

Figure 6.69 and Figure 6.70 indicates in WMC that the percentage of visit people stay in CO and CI is quite lower than in other spaces, it can be seen that the operative temperature value and illuminate level of these two areas are higher than other spaces either in winter and summer (
Table 6.15 and Table 6.16). However, this is not the reason of lower percentage of participants stay in these two areas. The lower occupied rate is results from the limited sitting facility and the cultural influence (most people would not like to sitting in this areas without order any drinks or foods, they would rather sitting in other areas). It can be seen that there is no big difference among NS, CS and SS in both winter and summer WMC. The differences are apparently shows in the air speed value, which effects the sitting area people choose to stay. Both in winter and summer people stay in CS and SS is more than in NS and the air speed value in CS and SS is higher than in NS, it means in indoor transitional spaces people prefer to stay in the area that air move faster. This is proved that in the other two cases AGU and RWCMD, the spaces with higher percentage of participants always have a higher air movement speed.

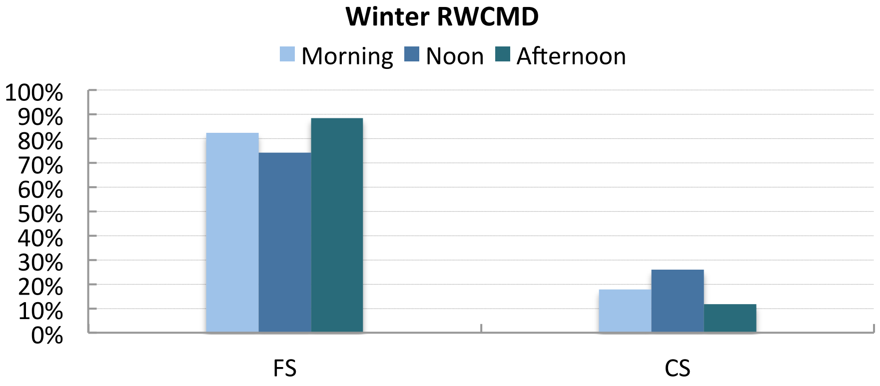

Figure 6.67 The percentage of participants stay in different spaces in winter RWCMD in morning, noon and afternoon (Morning N=45, Noon N=27, Afternoon N=60).

Table 6.13 Mean environment parameters' value in different spaces in morning, noon and afternoon in winter RWC

	Winter RWCMD							
	FS				CS			
	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)
Morning	20.3	0.11	37.5	295	22.3	0.11	30.0	334
Noon	21.0	0.17	36.1	391	22.9	0.04	32.2	367
Afternoon	21.2	0.22	37.0	251	23.3	0.07	33.1	324

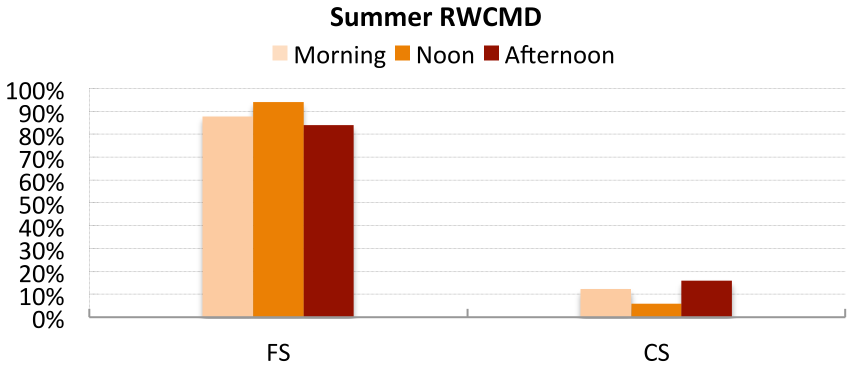

Figure 6.68 The percentage of participants stay in different spaces in summer RWCMD in morning, noon and afternoon (Morning N=49, Noon N=34, Afternoon N=50).

Table 6.14 Mean environment parameters' value in different spaces in morning, noon and afternoon in summer RWCMD.

	Summer RWCMD							
	FS				CS			
	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)
Morning	23.8	0.28	57.2	584	24.7	0.22	57.8	466
Noon	24.9	0.23	56.1	629	24.7	0.15	63.0	675
Afternoon	25.9	0.36	53.8	1127	27.7	0.48	58.0	1960

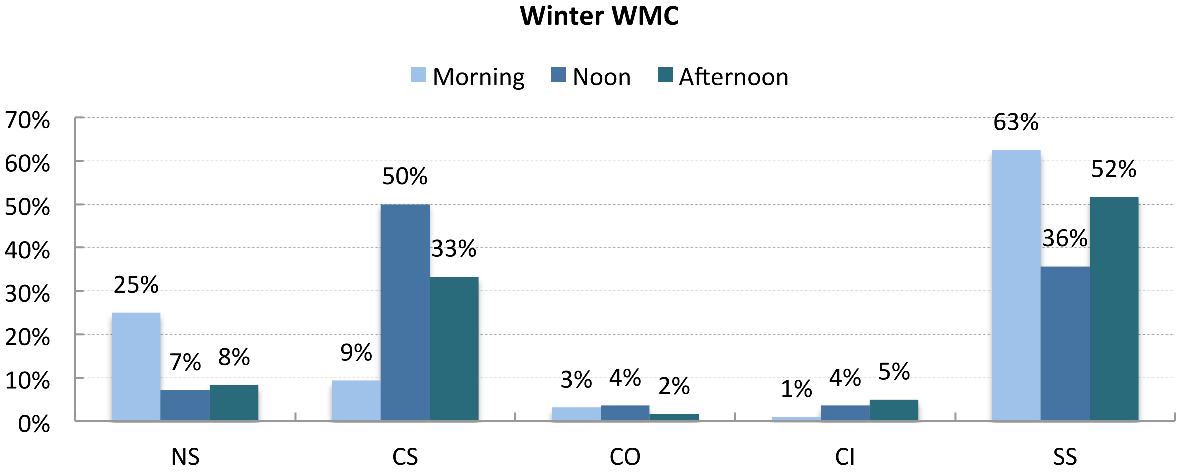

Figure 6.69 The percentage of participants stay in different spaces in winter WMC in morning, noon and afternoon (Morning N=32, Noon N=28, Afternoon N=60).

Table 6.15 Mean environment parameters' value in different spaces in morning, noon and afternoon in winter WMC.

	Winter WMC																			
	NS				CS				CO				CI				SS			
	T_o (°C)	AS (m/s)	RH %	Illum (lux)	T_o (°C)	AS (m/s)	RH %	Illum (lux)	T_o (°C)	AS (m/s)	RH %	Illum (lux)	T_o (°C)	AS (m/s)	RH %	Illum (lux)	T_o (°C)	AS (m/s)	RH %	Illum (lux)
Morning	18.6	0.08	51.3	133	18.6	0.13	41.6	120	22.0	0.50	45.5	260	21.1	0.10	42.9	498	19.2	0.21	40.1	117
Noon	18.4	0.10	42.3	140	18.8	0.25	41.7	376	20.4	0.20	35.6	230	19.1	0.00	37.0	660	19.8	0.19	38.1	128
Afternoon	19.7	0.08	49.4	44	19.4	0.24	39.6	528	20.7	0.40	41.0	70	21.6	0.17	39.5	553	19.6	0.19	39.2	49

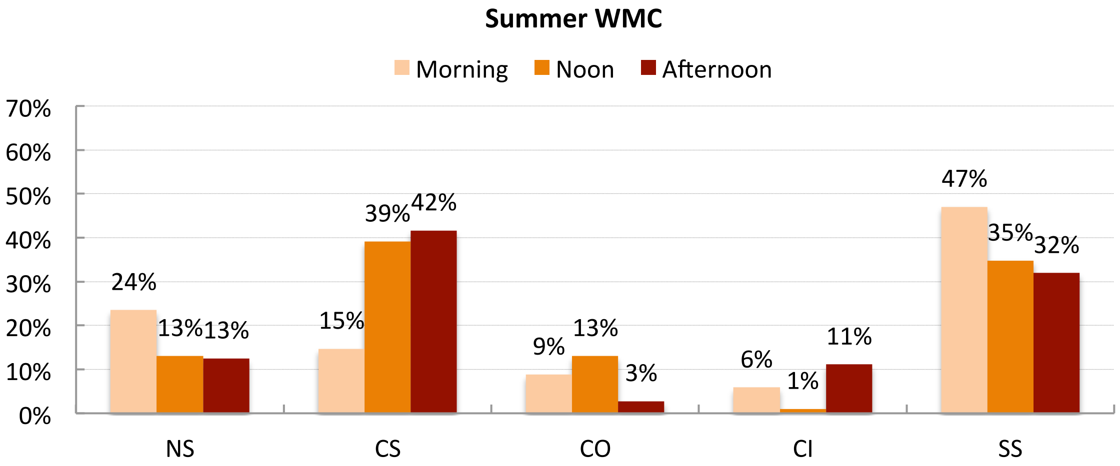

Figure 6.70 The percentage of participants stay in different spaces in summer WMC in morning, noon and afternoon (Morning N=34, Noon N=23, Afternoon N=72).

Table 6.16 Mean environment parameters' value in different spaces in morning, noon and afternoon in summer WMC.

	Summer WMC																			
	NS				CS				CO				CI				SS			
	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)	T_o (°C)	AS (m/s)	RH %	Illum. (lux)
Morning	20.6	0.07	64.2	142	20.8	0.13	69.3	331	21.8	0.05	60.2	412	21.4	0.00	65.9	437	21.3	0.10	66.3	92
Noon	21.8	0.07	63.5	96	21.4	0.11	60.9	782	22.2	0.08	65.1	152	22.0	0.02	62.3	886	22.2	0.08	68.8	88
Afternoon	21.8	0.11	66.1	104	23.1	0.13	62.7	3008	23.1	0.08	65.8	228	23.2	0.51	60.9	5882	22.2	0.21	63.3	99

To get the subjective evaluation of thermal parameters influence on the way of people use indoor transitional spaces, two questions reflect this design in questionnaire as "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*". The analysis of the correlation of these two questions shows that temperature have a relatively important influence on the way people use the indoor transitional space and proves that the light environment have an influence on the way people use these spaces too. However, this results is influenced by the number of participants answer these questions. Only about one third participants choose the definite answer to the question "*do you have a favorite area to stay in this space?".* Others did not answer the question because they do not have a favorite area or they visit not frequently and they do not familiar with this space so they do not known which area is their favorite area.

In winter AGU, a few part (24%) of the participants stated that temperature or other thermal conditions influenced where they decided to sit, but the correlation analysis between "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*" shows a relatively important correlated relationship between them as the $r^2=0.338$ and $p<0.01$. Thirty percentages of participants have a favorite place to stay in this transitional space, among these participants, 50% of them like seating at South Seating area (SS) and 44% like the Café Seating area (CS). This indicates that SS is the most popular area in AGU transitional space in winter. In terms the reason they favorite this area, the main obvious reason (29%) participants like sitting in this area is this area is warm. The mean temperature in this areas is close to the thermal comfort neutral temperature in winter of 20.4 °C. When in summer AGU the percentage of participants stating that temperature or other thermal conditions influenced where they decided to sit is same as the percentage of participants who have a favorite place to stay as 28%. The correlation analysis between "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*" shows that $r^2=0.342$ and $p<0.01$. Fifty-five percentages of participants choose SS area as they favorite space for seat when 32% of them choose CS. There are only 10% of participants sitting at the favorite area because it is a cool place. In summer the thermal comfort neutral temperature is 21.2 °C, 4 °C lower than the mean temperature in this popular area.

In winter RWCMD, only 18% of the participants stated that temperature or other thermal conditions influenced where they decided to sit, but the correlation analysis between "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*" shows a relatively important correlated relationship between them as r^2=0.352 and p<0.01. Thirty two percent of participants have a favorite place to stay in this transitional space, among these participants, 46% of them like sitting in the Foyer Seating area and 43% like Café Seating area when other participants choose other areas in transitional space as they favorite space. This indicates that Foyer Seating area (FS) is the most popular area in RWCMD transitional space in winter. The main obvious reason participants like sitting in these two areas stated they choose these area because they are warm, 39% of participants choose FS because it is warm but 16% of participants choose it because they like cool environment. The mean operative temperature in FS (20.9 °C) is evidenced that more close to the neutral and preferred temperature in RWCMD transitional space. When in summer RWCMD, the percentage of participants stated that temperature or other thermal conditions influenced where they decided to sit is similar with the percentage of participants have a favorite place to stay as 28% and 29%. The correlation analysis between "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*" shows that r^2 =-0.50 and p>0.05. It means there is no obvious correlation between these two parameters. Fifty-two percentages of participants choose CS area as they favorite space for seat when 45% of them choose FS. Most participants like sitting at the CS area because it is light and have a good view. In summer the thermal comfort neutral temperature is 1 degree higher than the mean thermal temperature at CS as 23.8 °C.

In winter WMC, only 12% of the participants stated that temperature or other thermal conditions influenced where they decided to sit, and the correlation analysis between "*if temperature have an influence when people choose a sitting* *area*" and "*if occupants have a favorite area*" shows a relatively important correlated relationship between them as r^2=0.123 and p>0.05, which means a weak correlation between these two parameters. Twenty-eight percentages of participants have a favorite place to sit in this transitional space, among these participants, 67% of them chose the North Foyer Seating area (NF) outside the café as their favorite space. In terms the reason of they favorite this area, the main reason participants like sitting in the area is because it is warmer. The mean temperature in the outside café area of NF is 1.2 °C lower than the thermal comfort neutral temperature in winter as 18.9 °C. When in summer WMC, the percentage of participants stated that temperature or other thermal conditions influenced where they decided to sit is as lower as 11%, and the percentage of participants have a favorite place to stay is 27% .The correlation analysis between "*if temperature have an influence when people choose a sitting area*" and "*if occupants have a favorite area*" shows that r^2=0.161 and p>0.05. It means there is no obvious correlation between these two parameters. Thirty three percent of participants choose SF area as they favorite space for sitting; it occupied the highest percentage of favorite area of participants. In summer the thermal comfort neutral temperature is 0.5 °C higher than the mean thermal temperature at CS as 21.9 °C.

It clearly indicates from above discussion that subjective evaluation of thermal parameters influence on the way of people use indoor transitional spaces, and it also prove that operative temperature and illuminate level significantly influence on the way of people use the indoor transitional space.

6.7 Summary

This study has found great inconsistence between PMV and AMV values, it is because the thermal comfort sensation of subjects in indoor transitional space in UK cannot be explained by heat-balance indices alone. Other behavioral and psychological factors may explain the difference between PMV and AMV.

Thermal sensitivity and neutrality of visitors in three indoor transitional spaces were examined. The study has shown difference in thermal sensitivity and neutrality among the three indoor transitional spaces. In winter people in AGU and RWCMD were more sensitive to the thermal environment than people in WMC, while in summer people in RWCMD and WMC were more thermal sensitive than people in AGU. The difference is occurred should due to the differences of clothing insulation and the service system in three buildings (natural ventilated in summer RWCMD).

Probit analyses, conducted separately on request for warmer and cooler conditions, it was found that in all of these three indoor transitional spaces, the preferred thermal sensation does not coincide with thermal neutrality in both winter and summer. The preferred temperature for AGU, RWCMD and WMC are different both in winter and summer. The difference in preferred temperature among the three groups demonstrates the occurrence of thermal adaptation. Consequently, the comparison of neutral temperature with preferred temperature could explain which group is better adapted to its thermal environment. The differences between neutral temperature and preferred temperature in winter in AGU, RWCMD and WMC are 0.6, 1.3 and 0.5 °C; in summer are 0.3, 0.3 and 0.7 °C. The results prove that participants in winter WMC and in summer AGU were have the best adaptation ability (smallest different between neutral temperature and preferred temperature) to their thermal environment.

The results of current study showing a wider thermal comfort accept temperature range when conducted the comparison between it and CIBSE standard and results from other transitional space researchers. This wide comfort temperature indicates the strong thermal adaptability of participants in indoor transitional spaces. The adaptive behaviors of subjects include put on/off clothing, changing place and hot/cold drinks. Thermal experience and expectations also evident is the significant parameters to influence participants' thermal sensation.

The influence of thermal comfort on the use of the indoor transitional space was studied by analyzing the reason of visit the space, the frequency of visiting the space and the length of stay in the transitional space depend on the thermal preference. The analyzing of relationship between thermal comfort and people's attendance and activity indicates that thermal consideration truly is a reason with quiet proportion when people choose a favorite space to stay. But this reason is always not the most important one, people frequently put their use requirements consideration as the most significant reason to choose a space to stay. The result of visiting frequency and thermal comfort indicates that people visit indoor transitional spaces daily are more familiar with the thermal environment and less tolerance to the thermal discomfort. It also explain the possibility that people visit the space rarely are less care about the thermal environment in indoor transitional space. The relationship of thermal comfort and spending time in a space indicates that good thermal environment design in indoor transitional space allows more social activities and influence their users stay longer in the space. The correlation between environmental parameter and using of the space indicates that operative temperature and illuminate level significantly influence on the way of people use the indoor transitional space, which evident by the directly subjects' evaluation.

Chapter 7 Conclusions

7.1 Introduction

This chapter mainly includes two sections: firstly, gives a summary of the research and outlines the answers to the research questions; secondly, states the research scope and limitations of this research and suggests issues for future work and further investigation

7.2 Summary of the study

This study investigated the thermal comfort conditions and how they influence on the way of people use indoor transitional spaces. Despite the increasing interest in outdoor and indoor thermal comfort researches, little attention has been paid to the spaces between indoor and outdoor. Although there is a diversity in transitional spaces, there are only a few kinds of research on transitional spaces like atria and lobbies, which leaves a shortage of research on indoor transitional spaces that have a closer relationship with fully occupied spaces. Besides, most field study research on transitional spaces is found in Asia, such as in Japan, Thailand and Malaysia, with few studies in the UK. It results in a gap to verify the comfort temperature range in indoor transitional space in UK as regulated by CIBSE. Finally, the view that transitional space can help building save energy as proposed by other scholars has yet to be shown.

For these reasons case studies were carefully selected in three different buildings in the UK to study a variety building users in similar climatic contexts. This enabled the study to consider the effects of socio-economic and anthropological differences on thermal sensation, behavior and use of space. To meet the objectives of this study, the choice of sites considered the following factors: the selected sites had to be located in the UK; different functional characteristics of buildings enabled examination of the effects of using on participants' thermal sensations; different spatial typologies enabled exploration of how design affects the use of space. Furthermore, field studies enabled the study of complex relations between both physical and subjective differences. Therefore, a comparative design based on field studies was chosen for this study. A combination of physical and human measurements was used to collect environmental data and to measure human attitudes.

The physical measurements of this study consist of measuring the microclimatic variables in each indoor transitional space and estimating activity level and clothing insulation of the investigated subjects. Monitoring the human behavior consisted of a questionnaire to which participants responded through structured interviews.

This thesis aimed to extend the understanding of thermal comfort in indoor transitional spaces to the UK climate. It studied the complex relationship between the indoor transitional space thermal environments and the thermal sensation of visitors, their adaptive actions, and how they use space. Pre-field work preparation and pilot study were carried out to select suitable sites and research materials were also arranged and tested. After initial analysis of each one of selected sites the actual field study was started. Data collection included both physical measurements and human behavior monitoring.

7.3 Addressing research questions and objectives

There are three questions this study attempts to answer as already mentioned in the introduction of this thesis:

- How relevant is the adaptive thermal comfort model to indoor transitional spaces?

- How do thermal conditions influence people’s use of indoor transitional space?
- Whether people will accept lower temperature (requiring less energy) in indoor transitional space than in other types of spaces?

Therefore, the following set of objectives was developed:

1. to investigate the occupants’ comfort perceptions in indoor transitional spaces;
2. to measure and compare neutral temperature, preferred temperatures and comfort temperature range of the occupants in different indoor transitional spaces, using the mean thermal sensation vote responses;
3. to investigate the relationship between the environment parameters and the actual sensation vote in different indoor transitional spaces;
4. to examine the influence of thermal condition on the use of indoor transitional space;
5. to examine physical and psychological factors that affect thermal adaptation between different transitional spaces by studying behavior of people; and
6. to decide whether occupants have lower comfort expectations for transitional spaces that could lead to savings in energy consumption.

7.4 Summary of the study’s findings

7.4.1. The physiological approach and the thermal comfort assessment

This study approve that the solely physiological approach is deficient to assess the indoor transitional space thermal comfort conditions in UK climates. The subjective thermal sensations, represented by actual thermal sensation vote were compared with the PMV as a heat balance model. The outcome shows a significant inconsistency between AMV and PMV values, which indicate that heat balance indices cannot explain the thermal preferences of subjects in UK climates. This finding is in agreement with Chun (2004) in the study showed that PMV is not suitable for use in transitional space. Therefore, this finding expands the existing knowledge and provides evidence that indoor transitional spaces’ thermal comfort merely depends on physiological approach to evaluating in the UK climate. Other factors as behavioral and psychological adaptation explain the different between the actual thermal sensation and the calculated thermal sensation bases on steady-state models such as PMV.

7.4.2. The relative contribution of environmental parameters

To find the relative contribution of the environmental parameters on thermal perceptions of the visitors to indoor transitional spaces in UK climate, two steps analysis were conducted: 1) correlation analysis between AMV and the environmental parameters; 2) ordinal regression analysis of the best correlated environmental parameters with AMV. The correlation analysis shows that only T_o is significantly correlated with AMV in all three cases both in winter and summer. Therefore, it can be analyzed by using ordinal regression analysis. The ordinal regression was used because the actual sensation vote AMV is an ordinal variable.

The ordinal regression analysis was carried out to examine how the environmental variable related to the actual thermal sensation votes of participates. Operative temperature T_o appeared to be the most important predictor of thermal sensation in three cases. Since operative temperature combines the effect of both solar radiation and air temperature, its influence suggests the importance of air temperature together with mean radiant temperature. Comparing to air temperature, solar radiation can be multiplied easier by design and decorate. For instance, opening bigger windows that can be used as increasing sunlight in winter and using blind in summer to mitigate sunlight. Environmental variables such as air temperature and mean radiant temperature could have a great impact on the use of indoor transitional spaces in the UK climate, and may determine the number of people and activities in them.

7.4.3. Factors influencing thermal sensation

a. Clothing

Clothing adjustments is an important and natural behavior to improve thermal comfort. It plays an important influence on people’s thermal adaptation in indoor transitional spaces. The influence of clothing insulation level on participants’ thermal perception is quite apparently in this study, for example, the lowest preference temperature and the correlated highest clothing insulation level in winter AGU among these three indoor transitional spaces. Besides, the non-normal subjective complains of the overheat environment in winter AGU during the survey progress even if the mean temperature of this space is just mediate but the mean clo value is the highest among this three indoor transitional space. The difference of clothing insulation level for participants in three indoor transitional spaces of this study in winter was greater than in summer. This difference may influence by the limitation of lowest clothing insulation value in summer.

b. Changing place

Since very little can be done to modulate temperature environment, in addition to clothing adjustments, moving from uncomforted area to comfort area is another way by which participants adapt to mitigate their thermal conditions. Moving from direct sunlight to shade or from draft area to no draft area is the common form of adaptation seen during the observations. In AGU people choose both of these action of adapt their thermal comfort when in RWCMD and WMC people mainly choose the way of moving draft area to no draft area to mitigate their thermal comfort. It is shows in this study that changing place is not dominant way people maintain their thermal comfort, the apparent trend of changing place depend on the temperature change only happened at for certain times during the survey.

c. Cold or hot drinks

Consuming cold or hot drinks is another way to make people feel comfortable. In this study, almost 50% participants in all three transitional spaces in winter consumed hot drink as a method to maintain their heat balance and eventually their thermal sensitivity. In summer, about 70% participants in AGU and RWCMD consumed cold while in WMC there is only 37% of participants consumed cold drink to modify their sensation of thermal comfort. But unexpectedly, 50% of participants in WMC consumed hot drink even in summer, the plausible explanation for this phenomenon is that more older age participants in WMC transitional space than other two spaces and drink coffee or tea is a habit for them.

d. Experience and expectations

Comparing the neutral and the preferred temperatures and the time spent by participants in the transitional space is employed as the way to evaluated the effects of expectations and experience on thermal sensation. The small difference between the neutral and preferred temperatures in winter illustrates all indoor transitional spaces created similar expectations of thermal environment conditions in winter but not in summer.

7.4.4. Thermal evaluation of indoor transitional space

The thermal sensation vote indicates that participants in three indoor transitional spaces were had quite a high level of satisfaction with their thermal environment from 82% to 99%. However, the comparison between observed thermal acceptability and predicted percentages of dissatisfied from Fanger's model, and between thermal and predicted percentages of dissatisfied from Fanger's model shows that the PPD model overestimates the percentage of thermal sensation unacceptability but underestimated the percentage of preference dissatisfied on all indoor transitional spaces in both winter and summer. It means people in indoor transitional space can accept the environment below their preference. This provides evidence that people in indoor transitional space have a higher tolerance of their thermal environment.

7.4.5. Thermal comfort requirements of indoor transitional space

In this study, the calculation of thermal comfort requirement parameters includes neutral temperature, preference temperature and comfort temperature range. The results indicates that in indoor transitional space people had a wider thermal comfort temperature range than CIBSE guide and fully occupied spaces such as office in mediate climate. It indicates participants in indoor transitional space were have the higher toleration to their thermal environment, which evident the possibility of useful energy saving by a modest (and realistic) relaxation of comfort standards regulation in transitional spaces.

7.4.6. Thermal comfort and using of the indoor transitional space

a. Attendance and Activity

The attendance and activity of occupants in these three transitional spaces is close related to the purpose of people visit these building. The results of the analysis of main reason people visit these building shows that in educational institute transitional spaces, the main visit reason was study and working, but in the commercial and cultural building the main visiting reason is working and entertainment. It indicates that there is certain number of occupants visit these spaces frequently and regularly for working or studying, but a considerable amount of visitors visit the indoor transitional space not frequently, normally just for entertainment at the performance day, weekend or some special festivals.

In this study, working, study and entertainment in the building are the most important reasons for a high attendance in transitional spaces. The visit reason also related to the activity of occupants in transitional spaces. The number of activities in three transitional spaces is similarly due to the similar facility provided by these three spaces, includes reading, chatting, watching performance, drinking or eating, talking on phone etc.

The analysis of thermal preference depends on the stay reason in three cases show that the participants' thermal perception has a close relationship with participants' the stay reasons in the indoor transitional spaces. People stay in the space for work and study care more and more sensitivity to the thermal environment than people just passing through the space.

b. Visiting frequency

The results of the analysis about the relationship between subject's visiting frequency and thermal preference rate in these three indoor transitional spaces show an opposite trend. It shows an increase rate of thermal preference in one case and a decrease rate of thermal preference rate in other two cases by the decrease visit frequency. This opposite happened due to the significantly overheating thermal condition in an indoor transitional space, people use this space not frequently feeling more uncomfortable than these people who visit it frequently and get used to the environment they stay in. This evident the exist of thermal adaptation while the results of other two spaces indicate people who visit the space daily are more familiar with its thermal environment and less tolerant of thermal discomfort, it also explains the possibility that people visit these space rarely care less about the thermal environment there.

c. Visit duration

The results of evaluate relationship of thermal comfort and time of stay in indoor transitional space indicates that people stay in a space for a short time have a lower thermal preference rate than people stay in a space for a longer time. In another words, they care less about their thermal environment than those stay in the space for a longer time. In this study the demarcation point of short-time and long-time of stay in the space is 30 minutes.

d. The influence of environmental parameters on the use of space

To investigate the influence of environmental parameters on the use of space, firstly the position people stay in indoor transitional space is marked and the relevant environmental parameters in this position are provided. This directly shows the number of participants stay in each space in indoor transitional space and the influence of relevant environment parameters (for example, people in summer AGU stay in South sitting area incline to stay in the area away from the directly sunlight). Secondly, further analyses were performed in more detail by showing three variables: number of people, visit time and environmental parameters in the each of spaces in indoor transitional spaces in winter and summer. It illustrates the apparent difference of the people use indoor transitional space at different times intervals of a day. Finally, a more detailed analysis of environment parameters in each area in indoor transitional space at three time of the day is carried out, which revealed that environmental parameters, such as operative temperature, air speed and illumination levels have a significant influence on the area people choose to stay and the time intervals people choose to visit. The most important environmental parameter is operative temperature, which is approved by the direct subjective attitude reflect from the questionnaire analysis.

The results of this section indicates that the way of people use indoor transitional spaces are mainly decided by the provided facility, but environmental parameters especially operative temperature still put a quite important influence on people how to use the indoor transitional space. In addition, attendance and activity, the visit frequency, visit duration and reasons for staying interactive with the thermal comfort of indoor transitional space.

7.5 Contribution to knowledge

The current study found that thermal comfort requirement (lower temperature) of participants in indoor transitional space in UK is lower (than CIBSE Guide and full occupied spaces as office). In other words, people in indoor transitional spaces have a higher thermal tolerance than people in the fully occupied space. It means indoor transitional space have the potential for save energy. Besides, this study has found that thermal comfort is an important influence on the way of people use indoor transitional spaces.

Environmental variables such as operative temperature could have a great impact on the use of the indoor transitional spaces in the UK’s mediate climate. The thermal environment in the indoor transitional space can be decided by the design and setting of the cooling/heating system inside it.

Design-related environmental improvements are necessary but it may not be sufficient for a successful design to indoor transitional spaces. On the other hand, physical features provides appear to play an important role in attracting people to indoor transitional space but thermal comfort play a significant influence on how to people use the indoor transitional spaces. Access to good indoor transitional spaces is a luxury or a need for people, which decided by the function of the building and each area of indoor transitional spaces. Indoor transitional spaces that offer good design and allow social activities are likely to influence their user to stay longer.

7.6 Building design and thermal comfort in indoor transitional space

In all these three cases, there is a uniform character of them that the highest mean temperature was always found in café areas in both seasons. This is due to four main factors: 1) the independent heating facilities at this area in winter; 2) the relatively closed space, comparing to other areas in transitional spaces, café area always not connect to external temperature directly; 3) compact nature and the higher occupancy level; 4) the heat released by the machine (coffee machine, fridge and so on) used in café area.

The surveys were aimed at an investigation of indoor transitional spaces, in which changeable environment variables affect comfort sensation and comfort preference, which enable the big influences on the way of people use indoor transitional spaces. The design of indoor transitional space put a significant influence on the thermal environment and the way people use indoor transitional spaces.

7.7 Research scope and limitations

This study focuses on the human thermal comfort and the use of indoor transitional spaces in UK. The studied sites are only located in Cardiff, UK and the research focuses only on transitional spaces in public buildings. It does not consider transitional spaces in other types of buildings, such as hotels or retail centers. Moreover, only guests who were sitting or standing were considered in interview; staff were excluded from analysis to ensure that the sample presents participants who have self-adaptive freedom (staff were limited to moving their location and adjusting their clothing to modify thermal comfort conditions). In addition, this research does not focus on a specific age group or gender. The research was further limited by the resources available to a PhD student and what was feasible to address in a time-bound, resource-constrained study. The main constraint was in the number of visits that could be made to each building which perhaps limits the scope of the collected data.

7.8 Recommendations for future research

It is recommended that further research on thermal comfort in indoor transitional spaces in UK to be undertaken in the following areas:

- This study is investigates the participants' thermal perception in steady-state, the thermal perception of participants in dynamic state should be investigated in the future work.

- The design and allocation of seating facilities require further investigation. What implication has the rigidity or flexibility of seats on the thermal comfort of users of the indoor transitional space?
- Operative temperature was used in this study as the thermal comfort index. Other thermal comfort indices, for example, air temperature and globe temperature might be used and compared for best evaluation.
- Further work needs to be done to cover more geographical areas within UK climate since this study covers only Cardiff. Such an expansion may generalize the findings of this study or explain any particularity associated with the sites of current study.
- More research is needed to study the influence of thermal comfort on the use of indoor transitional spaces in UK climates by people's age (young and older) and the education level. A greater focus should be on the relationship between thermal comfort and the time being spent by young and older people and people with a different education level, which might be affect their way of using indoor transitional space.
- More detail research about the physical design of indoor transitional space and the effect on thermal environment in it should be conducted in the future work, it will put an important influence on improve thermal environment in indoor transitional space and improve the possibility of energy saving in indoor transitional space.
- Considering the limited researches of thermal comfort in transitional space, more research needs to be done in more types of transitional spaces.

7.9 Summary

This research investigated the breadth of thermal comfort conditions in three transitional spaces in non-residence buildings with different design characteristics and capacities. The indoor environment was extensively monitored in the different indoor transitional spaces' areas where in total 759 people were interviewed for the evaluation of comfort conditions. Through observation of practical situation and analysis of related data, the questions and objectives were answered and achieved. Additionally, the results challenged exiting perspectives and offered more comprehensive ideas for thermal comfort in indoor transitional space in UK. Overall, the experiment not only indicated a way to understand the thermal comfort condition and energy save potential of transitional space, but also gave practical suggestions of design indoor transitional space in UK.

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Appendix 1 Consent Form

Consent Form

Title of research project: Thermal perception

Name of researcher: Guoying Hou

I confirm that I have read and understand the information.

I understand that the information provided by me will be used anonymously.

I understand that my participation in this project will involve completing one questionnaire about my attitudes toward thermal comfort condition in this building, which will require approximately 10 minutes of my time.

I understand that participation in this study is entirely voluntary and that I can withdraw from the study at any time without giving a reason and without loss of payment (or course credit).

I understand that I am free to ask any questions at any time. I am free to withdraw or discuss my concerns with Guoying Hou.

I understand that the information I provide will be shared with the research team or research supervisor and may be used in subsequent publications.

I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study if I'd like to.

I understand that the information provided by me will be held confidentially, such that only the Experimenter can trace this information back to me individually. The information will be retained for up to 2016 when it will be deleted/destroyed. I understand that I can ask for the information I provide to be deleted/destroyed at any time and, in accordance with the Data Protection Act, I can have access to the information at any time.

Signed (Researcher):

Signed (Participant):

Date:

Appendix 2 Questionnaire

Questionnaire

Date and Time: ______________________ **Location:** ________________________

Section One

1-Where do you live?

☐ **Cardiff**

☐ **Outside Cardiff**

2- How long have you live there?

☐ **less than 1year**

☐ **1-2years**

☐ **3-5years**

☐ **More than 5 years**

3-Would you describe the weather today?

-3	-2	-1	0	1	2	3
Very warm	Warm	Slightly warm	Neutral	Slightly cold	Cold	Very cold

4-Why are you visiting this space?

____

5-How often have you visited this space before today?

☐ **Daily**

☐ **Several times per week**

☐ **A few times per week**

☐ **A few times per month**

☐ **Rarely**

☐ **None**

6- On average, how long do you stay in this space?

☐ **Less than 20 minutes**

☐ **20 minutes--2hours**

☐ **2-4hours**

☐ **4-6hours**

☐ **6-8 hours**

☐ **More than 8 hours**

7- Which area are you most likely to visit on this floor? Please indicate on the floor plan or describe it. (Map of this floor is attached)

____

8-If you have used this space before; do you have a favorite place to sit?

☐ **Yes**

☐ **No**

If yes, please where it is and why

____

____

9- If this place was not available, where else would you sit and why? (See follow map)

____

10- What is the main reason for you being this area at the moment?

☐ **Waiting for some body/meeting**

☐ **Study**

☐ **Work**

☐ **Have a break**

☐ **Eating and drinking**

☐ **Sociality**

☐ **It is warm**

☐ **It is cool**

☐ **Passing through**

☐ **Performance watching**

☐ **It is convenient**

☐ **Other, , please describe**____

☐ **Don't known**

11- How would you rate the quality of the thermal environment in this place?

1	**2**	**3**	**4**	**5**
Very poor	**Poor**	**Neutral**	**Good**	**Very good**

12- How are you feeling about the temperature in this space at the moment?

-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Cold	**Cool**	**Slightly cool**	**Neutral**	**Slightly warm**	**Warm**	**Hot**

13- What would you like to be at this moment?

-3	-2	-1	0	1	2	3
Much cooler	**Cooler**	**Slightly cooler**	**Neutral**	**Slightly warmer**	**Warmer**	**Much warmer**

14- Have you done any of the following to make you environment warmer or cooler in the past hour? (Tick all that apply)

☐ **Put on more clothes**

☐ **Remove clothing**

☐ **Hot drink**

☐ **Cold drink**

☐ **Walking**

☐ **Move closer to conditioner**

☐ **Other, please describe** ____

☐ **None**

15- If you have to choose, what would you prefer to drink to make you warmer/colder at the moment?

☐ **Cold water**

☐ **Soft drinks**

☐ **Hot water**

☐ **Tea**

☐ **Coffee**

☐ **Hot chocolate**

☐ **Other, please describe**____

☐ **None**

16- Has the temperature or other thermal conditions influenced where you decided to sit?

☐ **Yes**

☐ **No**

If yes, please specify in what way

____

____

17- On a scale on 1 to 5, where 1 is very poor and 5 is very good, how would you rate the quality of the light environment in this place?

1	2	3	4	5
Very poor	**Poor**	**Neutral**	**Good**	**Very good**

18- How would you rate the lighting level in this space at the moment?

3	-2	-1	0	1	2	3
Very dim	Dim	Slightly dim	Neither dim or bright	Slightly bright	Bright	Very bright

19- Has the sunlight entering the space or other lighting conditions (like glare) influenced where you decided to sit?

☐ **Yes**

☐ **No**

If yes, please specify in what way

____

____

20- Can you describe your main activity/ies in the last hour? (Maximum Of 3)

1) ____
2) ____
3) ____

21- If you have to choose, what would be your priority in the winter?

☐ **Fresh air**

☐ **Warmth**

☐ **Both**

22- Do you have any specific complaints about this space?

☐ **Too cold**

☐ **Too warm**

☐ **Very dim**

☐ **Very bright**

☐ **The air is not fresh**

☐ **Too humid**

☐ **Too dry**

☐ **Too draughty**

☐ **Other, please describe**____

☐ **None**

23- Are you suffering from the cold or flu at the moment?

☐ **Yes**

☐ **No**

Section Two

Gender: Male ☐ Female ☐			Occupation:			
Age: 16-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ 65-74 ☐ Over74 ☐						
What clothes are you wearing at the moment (tick all that apply)						
TOPS	Long sleeve shirt/T shirt	Short sleeve shirt/T shirt	Sleeveless shirt/T shirt	Sweater	Woolen vest	Coat
	Thick ☐ Thin ☐	☐	☐	Thick ☐ Thin ☐	Thick ☐ Thin ☐	Thick ☐ Thin ☐
	Cotton padded coat	Down coat	One piece dress	Scarf	Hat	
	Thick ☐ Thin ☐	Thick ☐ Thin ☐	☐	☐	☐	
TROUSERS AND SHOES	Jeans	Outerwear trousers	Cotton padded trousers	Woolen trousers	Short skirt	Stockings
	Thick ☐ Thin ☐	Thick ☐ Thin ☐	☐	☐	Thick ☐ Thin ☐	Thick ☐ Thin ☐
	Sandals	Sport shoes	Leather shoes			
	☐	☐	☐			

Appendix 3 Pilot Study

1.1. Introduction

Transitional space in a building is the space not directly occupied in relation to the primary activity of the building, which poses an interesting and fruitful area for energy and comfort research (Pitts and Saleh 2007). Transitional space in buildings can be the most important part in architectural design terms because of the form-giving characteristics of large volumes. TS, because of its impact on a wide range of sense and perceptions of human occupants, have an important role in improving the physical environment in buildings. The complexity of thermal conditions in TS is increased with the diversification of building spaces.

Realistically, such spaces may not require the same high level and close environmental control of more fully occupied spaces, thus a wider variation in conditions and interpretation of thermal comfort maybe permitted. Some studies show that useful energy savings (particularly for heating) are possible by allowing for a modest (and realistic) relaxation of prescribed comfort standards in transitional spaces (Pitts, 2007; Chun et al: 2004).

The fieldwork presented here is a pilot study for a larger study. It focuses on four research questions: 1) Do environmental conditions influence the way people inhabit and use transitional space? 2) What kinds of thermal conditions do people prefer in transitional space? 3) Do people have a higher tolerance towards environmental conditions in transitional space? 3) Can transitional space be designed to use less energy?

One significant advantage of carrying out a pilot study is that it may serve to highlight potential weaknesses or inadequacies in the proposed research methodology. A carefully designed and well-executed pilot study can have substantial benefits in optimizing the research procedure and providing advanced insights on the possible outcomes of the research. The pilot survey of this research was carried out in July-August 2012. It was carried out before a full research project in order to test whether the methodology is valid and to establish whether the strategy is fully capable of capturing the types of data that are required. Furthermore, the pilot study can help to ensure that the research strategy is fully optimized and that the information acquired is reliable (Eng. 1997).

1.2. Methodology

This study used a questionnaire survey to obtain occupants' perceptions of thermal comfort. Although subjective assessment is difficult to analyze, due to psychological influences, finding the occupants' need to achieve better thermal comfort is an essential first step. Also, this research used physical measurement and monitoring of the surveyed transitional space in building to confirm the findings from the questionnaire. Details of the questionnaire are described below.

1.2.1. Thermal comfort questionnaire

Thermal comfort investigations in transitional space in building are more dynamic than those found in the indoor full-occupied space, such as office room, theater etc. When the monitor of thermal environment in transitional space in building was carried out, there is a greater variety of adaptive opportunities should available and more types of environment condition should be allowed, especially while providing sufficient response without interrupting factors.

To record occupants' perceptions of comfort, there are two methods: observation and recording by camera; and face-to-face surveys (questionnaire and interview). Video recording was rejected because it was considered to be too intrusive and would be likely to interfere with the reporting of comfort perceptions or even skew those perceptions. A face-to-face questionnaire was identified as a way of minimizing disruption and avoiding reliance upon on 'participant self-reporting', which provides the context to the investigation using some background information about the subject. When accompanied by the recording of local environmental conditions, the approach should provide useful data.

Aims and objectives

- The questionnaire had two main aims:
- To get the personal information about participants in surveyed transitional spaces; and
- To get the information about thermal history, thermal satisfaction, thermal

sensation and thermal expectation condition of participants.

Design of the questionnaire

The working day in Cardiff usually runs from 9.30am to 5.30pm. The questionnaire survey was conducted during this period. According to ASHRAE Standard 55 (2004), the survey should be conducted after at least 20 minutes step change of occupants and this is the needed to enable actual perceived conditions to be reported. The approximate time required to complete the questionnaire was 5-8 minutes.

The questionnaire survey can be divided into subjective and objective variables. The objective variables include gender, age group, and occupation. The subjective variables include occupant satisfaction with their thermal environment and occupant health related categories. The second section asks subjects to rate their thermal satisfaction, sensation and expectation. Thermal satisfaction is ranged as 5 degrees, from very poor to very good. Thermal sensation is rated on ASHRAE 7-point thermal sensation vote (TSV) scale (i.e., -3, much too cool; -2, too cool; -1, slightly cool; 0, neutral; 1, slightly warm; 2, too warm; and 3,much too warm). The thermal expectation was assess by the occupants' desired thermal comfort preference scales. In the pilot study, the calculation of thermal satisfaction is based on the result of thermal sensation. It was improved as an independent question in formal studies to get a more reliable satisfaction measure of participants. The responses were time stamped.

The questionnaire responses were analyzed using SPSS and Microsoft Excel. The results were analyzed by descriptive analysis including frequency, percentage, and chi-square and cross-tabulation method. Regarding to further investigation of the correlation between various responses, the data were analyzed through cross-tabulation. All the relationships are statistically significant to $P<0.05$. The missing answers were not analyzed in the assessment and the missing values are not significant to be interpreted in this survey.

The basic method of this research used a questionnaire to collect information about thermal perception of participants in transitional space in building. This is then connected to the measurement of physical environmental conditions to determine the environment's effect on people's thermal perception in TS in building. A schedule for the questionnaire and interviews was developed on the following basis: the sample size should be large enough to capture the diurnal temperature swing and a variety of subject activity; a five-minute questionnaire applied every twenty minutes was used; a short interview was used with staff working in each space rather a questionnaire to avoid unnecessary interference with their work.

1.2.2. Physical measurement

The field experiments aimed to assess the indoor and outdoor thermal condition of targets buildings with transitional space in Cardiff, UK. Air Temperature, Globe Temperature, Ventilation and Relative Humidity were measured inside the case studies while Air Temperature and Relative Humidity of outside were measured simultaneously during field experiments.

Aims and objectives

- The aim and objectives of the field experiments are:
- To quantify the thermal environment in transitional space in building and combine the results with questionnaire to investigate participant's thermal perception in TS in building.
- To establish the range of internal and external thermal conditions found in transitional space field experiment procedure.

After gaining permission in two selected buildings in Cardiff, the field experiments were conducted. These buildings were chosen from a mixture of types including highly glazed, modem design in heavy weight and lightweight structure up to 10 years old. Although the sample type is not a representative of the transitional spaces' type as a whole in Cardiff, these two buildings have been selected to compare their environmental conditions and to establish some initial information on TS in building. The field experiments were carried out during the summer in Cardiff (August). The measurements were recorded in occupied transitional spaces in both buildings. The equipment was placed close to the occupants and in the spaces with multiple occupants. The equipment was placed in locations deemed representative of the space as a whole with almost the same distance from the occupants. The equipment was positioned away from windows, sunlight, cooling/heating units and computers. In all the studied transitional spaces the air temperature, humidity, ventilation and globe temperature have been measured as environmental factors and the measurement has been continued for 7-8 days. The interval recording was set to 2 minutes for air temperature and humidity and 5 minutes for globe temperature. These parameters were measured in different parts of transitional spaces in each building.

Equipment and arrangement

Depending on the size of the space, 5-7 sensors were used to measure the thermal environment. Air temperature and relative humidity were measured using the same sensor, a solid-state device that changes its electrical characteristics in response to extremely small changes in air temperature and humidity. Globe temperature determines heat flow between the bodies and surrounding surfaces, it is measured as the internal temperature of a hollow sphere exposed to environment. The recorded temperature were transferred onto a computer connect to the data receiver. Air velocity was measured using a hotwire thermo-anemometer.

The dividing of physical measurement areas in transitional space in building was based on the different functions and area of space. Different numbers of sensors for air temperature and relative humidity were stationed in each area, and mounted 1.5-2m from floor. The air speed meter was handheld and used when the researcher carried out the questionnaire survey.

The fundamental characteristic of all measuring systems is that they will be influenced slightly by many factors other than the parameters of interest and this will contribute to the quality of measurements. It is no exception in this research. The interference factors will be excluded as much as possible by the methods of questionnaire and observation.

1.3. Key information of Cases

Generally, transitional space in building space is public space of the whole building; people carried out more flexible and diverse activities than in rooms with specific functions in the same building. There are some similar characteristics of these two cases transitional space in building:

- Generally, the types of transitional space includes: corridors, reception， collecting and distributing area and resting area.
- There is greater variety in the activities in these spaces than other spaces in this building.
- Most visitor stay in TS in building for a relatively short time, this is different to fully occupied indoor space.

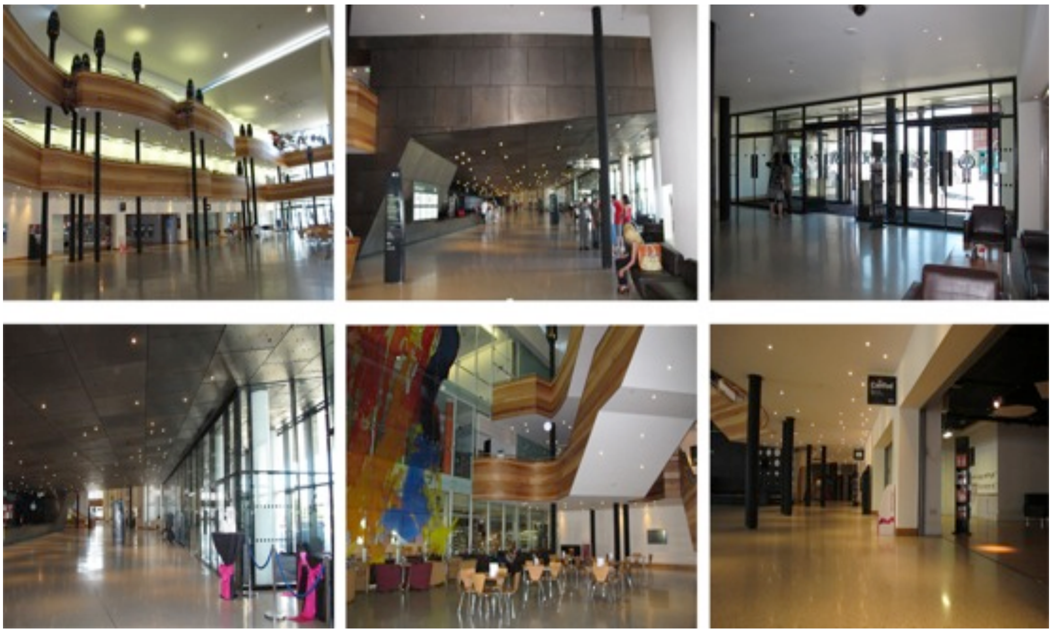


Figure 5.1 The foyer of the AGU.

Figure 5.2 The foyer of the WMC.

According to the regulation above, two suitable cases were chosen in this research: the foyer of the ATRiuM Building of Glamorgan University (AGU) (Figure

1.1) and the foyer of the Welsh Millennium Centre (WMC) (Figure 1.2). The main physical characters of these three cases are shown in Table 1.1.

Table 1.1 Basic information about physical characteristics of three cases.

Building		AGU	WMC
Date of building		2007	2004
Building area		3450 m²	19020 m²
Transitional space area		810.25m²	2198.41m²
Building Service system	Winter	Electrical Under floor heater	Mechanical ventilation with heating
	Summer	Mechanical ventilation	Mechanical ventilation
Building orientation		South	East
Business type		Academic	Cultural-business
Dates of studies		16,17,20,21,22,23 24 August 2012	29,30,31 August, 02,03,04,05 September 2012

1.4. Analysis and discussion of research results

The pilot study was carried out at AGU and WMC at the end of August and beginning of September 2012. The questionnaire responses were analyzed using the SPSS statistical analysis program. The studied transitional spaces in buildings with the response rate are 97% (161 out of 165). The survey responses were 73 and 88 respondents separately in AGU and WMC respectively. The results and discussion of this survey are divided into the five sections below.

1.4.1. Basic data

The respondent's background and response has been summarized from 17 survey questions. The basic data about personal information for the occupants responding to the survey are summarized in Table 1.2. Among the participants, 33.8% of them are professional, 15.5% are clerical and 50.7% are student in AGU; and in WMC, 57.1% are professional and 32.5 % are clerical, only 10.4% of participants are student. The participants' age group shows that the majority of the participants are at the age group of 16-44 years with 61.3% male and 37.3% female participants in AGU, and majority of the participants are at the age group of 16-74 years and ranged averagely with 55.1% male and 44.9% female participants in WMC.

Further questions revealed that 82.7% of participants in AGU live in Cardiff, but in WMC, 74.2% of participants live outside Cardiff, and most of them stay there more than three years. It means that the participants in AGU are more familiar and used to Cardiff's weather than the participants in WMC, so participants in AGU have a more exact judgment about the discomfort of the local weather.

In terms of the reason of visiting the building, 77.7% participants come to the building for working and studying in AGU. However, most participants in WMC come to the building just for visiting and entertainment, 43.2% and 19.3% respectively. It is obvious that the participants in these two buildings visit them with different objectives. According to their experience, participants in AGU tend to be more exact or fastidious about the temperature of their environment, because people's requirements from an environment for studying and working is higher than for visiting and for entertainment.

It shows than 75.6% of the respondents in AGU and 51.7% in WMC are visit the building more than rarely. Among it, 29.7% of the participants visit AGU daily while 18.9% are visit it several times a week and 27.0% are several month a week. In terms of WMC, there is only 9% of the participants visit it daily while 37% of them visit it several times a week, and there are 11.2% of them visit it several times a month. In AGU, most of the participants stay in the building more than 2 hours, and in WMC most of them stay in the building more than 20 minutes. It is indicated that most participants were familiar the TS in building they occupied and able to judge any thermal environment discomfort in the transitional space in building.

Table 1.2 Personal basic information got from questionnaire.

		AGU	WMC
Elements	Category	Percentage	Percentage
Gender	Female	37.3%	44.9%
	Male	61.3%	55.1%
Age	16-24	32.0%	18.0%
	25-34	37.3%	13.5%
	35-44	13.3%	16.9%
	45-54	10.7%	18.0%
	55-64	4.0%	13.5%
	65-74	2.7%	19.1%
	74over	0%	1.1%
Occupation	Professional	33.8%	57.1%
	Clerical/secretarial	15.5%	32.5%
	Student	50.7%	10.4%
Live Location	Cardiff	82.7%	25.8%
	Outside Cardiff	17.3%	74.2%
Period of occupant	Less than 1year	9.8%	4.9%
	1-2years	21.3%	6.1%
	3-5years	29.5%	12.2%
	More than 5years	39.3%	76.8%
Frequency of visit	Daily	29.7%	9.0%
	Several times per week	18.9%	31.5%
	Several times per month	27.0%	11.2%
	Rarely	17.6%	25.8%
	None	6.8%	22.5%
Duration of Visit	Less than 20minutes	10.0%	7.9%
	20 minutes-2 hours	14.3%	57.3%
	2-4 hours	24.3%	9.0%
	4-6 hours	12.9%	10.1%
	6-8 hours	32.9%	10.1%
	More than 8 hours	5.7%	5.6%

1.4.2. Thermal environment

Figure 1.3 to 1.5 indicate that the recorded environment condition at outside building and inside building during the survey time in two cases. The measured outside environment parameters include air temperature, humidity and air velocity. The inside measured environment parameters include humidity and air temperature measured by sensors set close to participants (Tair), air temperature around participants measured by hand held equipment (Tha), globe temperature (Tg) and air velocity. These figures indicate that the average temperature in

WMC transitional space is 2.5°C lower than in AGU during the survey time they are 23.9°C and 21.4°C separately, and the air velocity in it during a day is more dynamic than in AGU. Also the recorded air temperature and globe temperature compared in Figure 1.3 and Figure 1.6 indicates that almost the same value with little time discrepancy not greater than 4.5 °C in each transitional space. It also indicates that the temperature in AGU is more stable than in WMC. The analysis from these figures overall, compared together and shows that the temperature in transitional spaces in buildings was affected by both indoor and outdoor temperature.

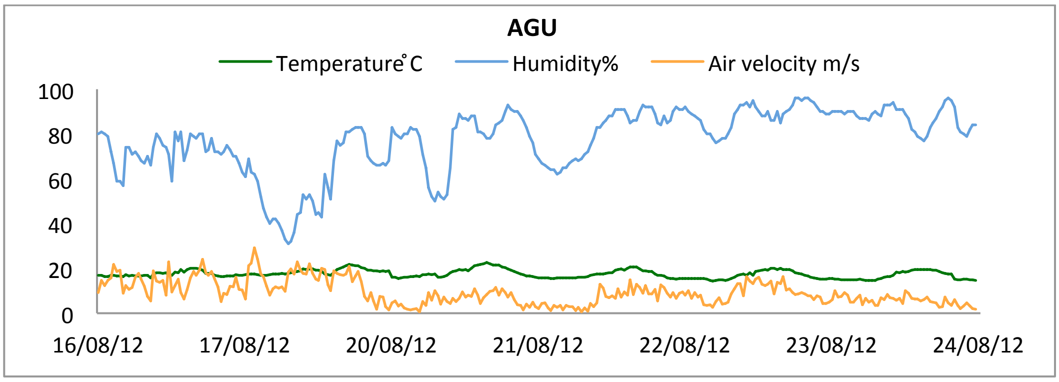


Figure 1.3 Exterior temperature, Humidity And Air Velocity of AGU.

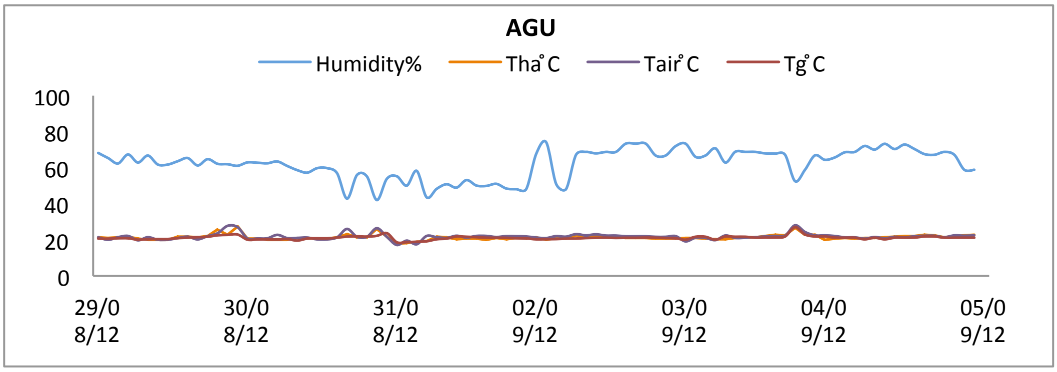


Figure 1.4 Interior temperature, Humidity of AGU.

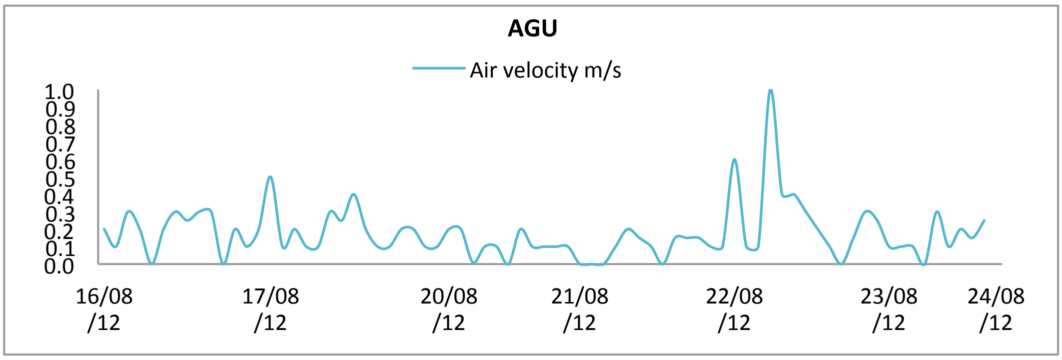


Figure 1.5 Interior Air Velocity of AGU.

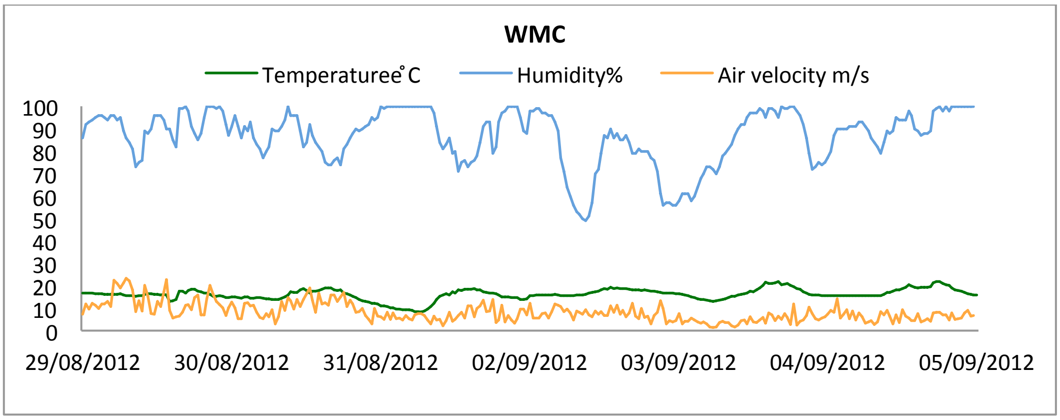


Figure 1.6 Exterior Temperature, Humidity And Air Velocity of WMC.

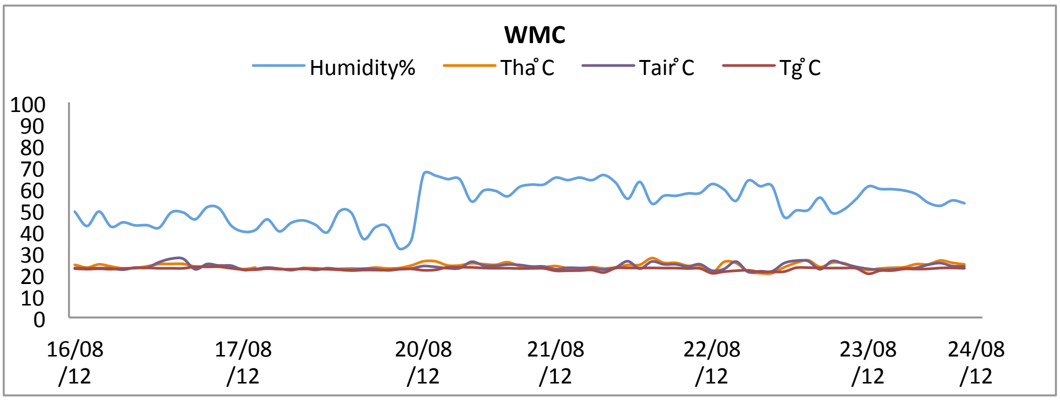


Figure 1.7 Interior Temperature, Humidity of WMC.

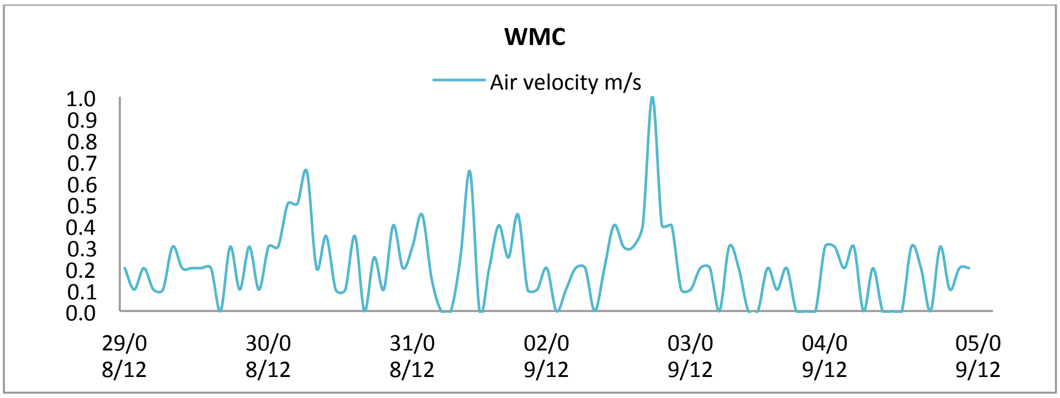


Figure 1.8 Interior Air Velocity of WMC.

1.4.3. Thermal sensation and satisfaction

Figure 1.9 shows the distribution of thermal comfort satisfaction scores for all occupants (the satisfied rate range is from slightly warm to slight cool, other ranges are dissatisfied rate). Overall, in AGU, more occupants are satisfied (86.3%) than dissatisfied (13.7%). Note that the relatively high percentage of response is in the neutral category (41.1%) and in slightly warm (31.5%). However in WMC, there is a totally different view, the satisfied rate is quite high as 98.9%, and the neutral category is as high as 73.9%. Also Figure 1.9 compares the results of the questionnaire over all the transitional spaces studied with the ASHRAE Standard 55 (2010) thermal comfort conditions. With regard to this result it can be said that overall the thermal environment in respondent's occupied transitional space was generally reported neutral and slightly warm condition in the studied spaces in later summer.

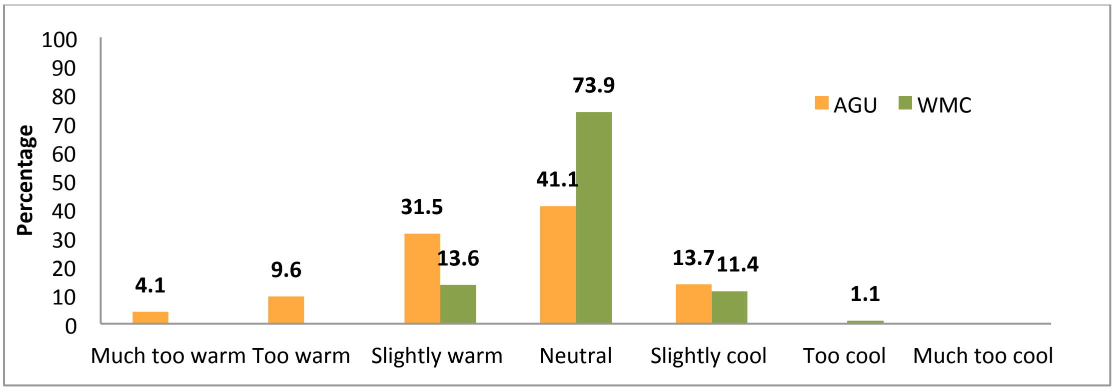
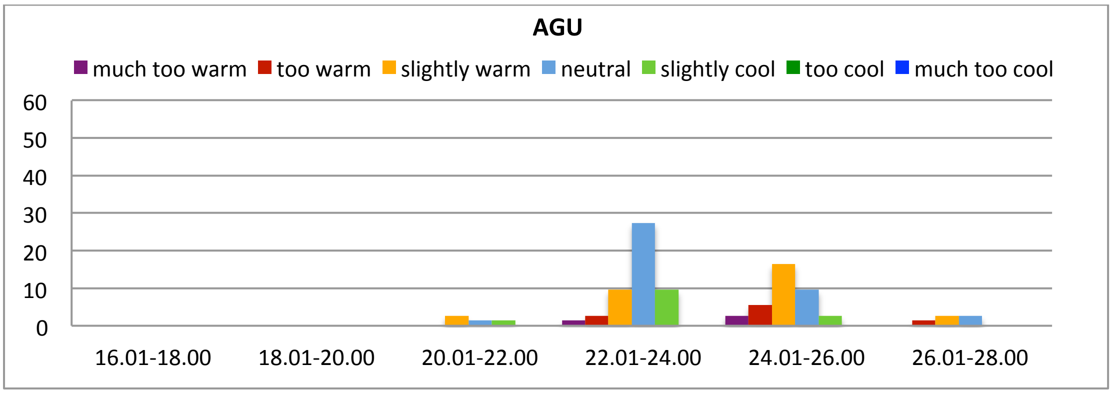


Figure 1.9 Respondent's satisfaction with thermal comfort in the transitional space of AGU and WMC.



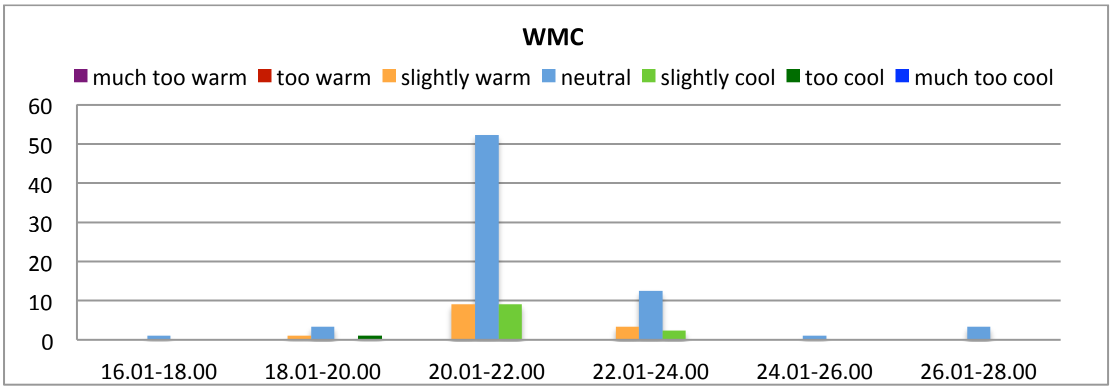


Figure 1.10 A cross-tabulated between the respondent's satisfaction with the temperature and the buildings.

ASHRAE Standard 55 (2010) defines acceptable conditions in which at least 80% of people are satisfied with their thermal environment. In this study, the calculation of thermal satisfaction is base on the rate of thermal sensation. The survey result shown in Figures 1.9 clearly indicates higher rates of thermal satisfaction in each transitional space in building. It reveals in AGU more than 13.7% of the occupants were positively dissatisfied with the temperature in transitional spaces which is more close the acceptable dissatisfied range (10%) specified by ASHRAE Standard 55 (2010). However, in WMC the dissatisfied rate is just 1.1%, far below the acceptable dissatisfied range. Figure 1.9 indicates that both two buildings are in compliance with the ASHRAE Standard 55 (2010). At the same time, it appears that the occupant's perceived satisfaction with the temperature in these two transitional spaces in building are in compliance with the acceptable thermal satisfaction rate within ASHRAE Standard 55 (2010) either.

The thermal sensation of different temperature range in each transitional space is compared as Figure 1.10: 1) in WMC, the temperature range is wider than in AGU; 2) at the temperature range 20.01-22.00°C, only few participants in AGU are feel neutral but most participants in WMC are have the same feeling and a highest satisfactory rate (70.5%) than other temperature range; 3) at the temperature range 22.01-24.00°C, participants in AGU have a higher response at neutral category than participants in WMC and a highest satisfactory rate as 46.6% than other temperature range; 4) at the temperature range 24.01-26.00°C, there is a highest rate of slightly warm in AGU and a higher satisfactory rate(28.7%), which is totally different with WMC because almost no response at this temperature range.

This was generally supported by the physical measurement that the temperature in AGU transitional space is high than WMC. It can be responsibly refer to that occupant's thermal history have an important influence on their thermal sensation and satisfaction. In transitional spaces, when participants experience a warmer thermal environment, they have a higher tolerance about higher temperature and vice versa.

1.4.4. Thermal expectation

The analysis in Figure 1.11 shows the distribution of thermal expectation votes across all respondents. It indicates that most of the respondents (80.7%) in WMC were like to thermal condition around them keep at neutral while about half occupants (50.7%) in AGU have the same feeling. In the transitional space of AGU, 24.7% participants like their environment slightly cooler when just only 4.5% participants in WMC have the same feeling. In terms of the thermal expectation category of slightly warmer, these two building have a similar equal scores, 11% in AGU and 12.5% in WMC. And there are 8.2% participants like cooler and 4.1% like much cooler in the transitional space of AGU, but in WMC, nobody choose these expectation categories.

Table 1.3 A cross-tabulated between thermal sensation and thermal expectation in transitional space in AGU

		Thermal expectation						
		Much warmer	Warmer	Slightly warmer	Neutral	Slightly cooler	Cooler	Much cooler
Thermal sensation	Much too warm	0	0	0	0	0	0	0
	Too warm	0	0	0	0	6.8%	2.7%	0
	Slightly warm	0	0	2.7%	11%	13.7%	4.1%	0
	Neutral	0	0	4.1%	34.2%	2.7%	0	0
	Slightly cool	0	1.3%	4.1%	5.5%	1.3%	1.3%	0
	Too cool	0	0	0	0	0	0	0
	Much too cool	0	0	0	0	0	0	0

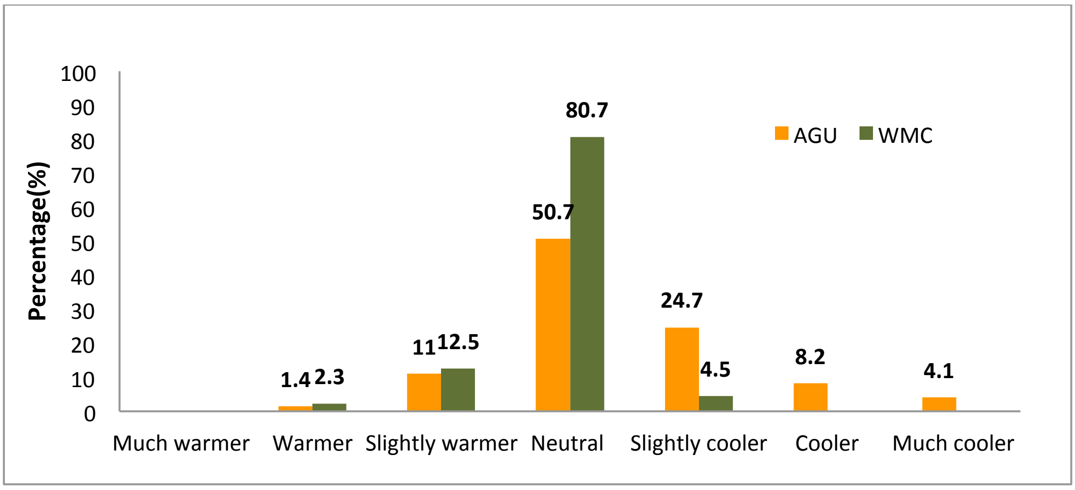


Figure 1.11 Respondents' expectation with thermal comfort in the transitional space of AGU and WMC.

Table 1.4 A cross-tabulated between thermal sensation and thermal expectation in transitional space in WMC.

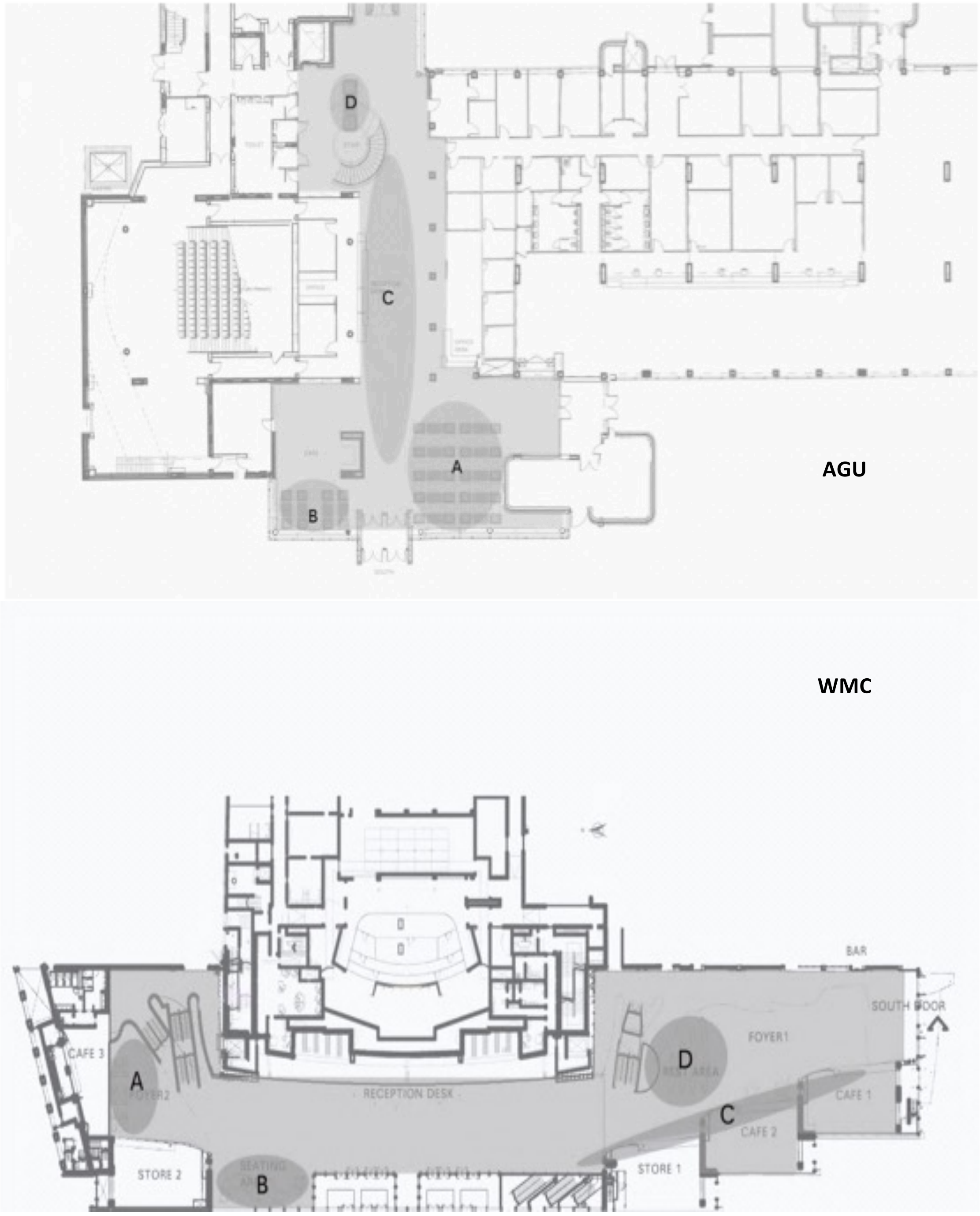
		Thermal expectation						
		Much warmer	Warmer	Slightly warmer	Neutral	Slightly cooler	Cooler	Much cooler
Thermal sensation	Much too warm	0	0	0	0	0	0	0
	Too warm	0	0	0	0	0	0	0
	Slightly warm	0	0	1.1%	9%	3.4%	0	0
	Neutral	0	1.1%	4.5%	68.2%	0	0	0
	Slightly cool	0	0	6.8%	3.4%	1.1%	0	0
	Too cool	0	1.1%	0	0	0	0	0
	Much too cool	0	0	0	0	0	0	0

In the transitional space of AGU, during the number of participants feel their environment is neutral (41.1%), there were 34.2% of participants choose not change their thermal environment, but there is only 4%of them like to slightly warm and 3%of them like to slightly cool. And among the participants feel their environment is slightly warm, there are 2.7% of them like to slightly warmer, 4.1% of them like to cooler, 11% of them like their thermal environment became neutral and 13.7% of them like to slightly cool. This is a totally different situation in the transitional space of WMC. During the participants choose their thermal environment as neutral score, 9% of them like too slightly warmer, 68.2% participants like to keep neutral and only 3.4% of them like their environment slightly cooler. (Table 1.3 and 1.4)

These two table indicate that: 1) in TS in buildings, occupants' thermal expectation is obviously effected by their thermal history in the same environment; 2) comparing to WMC, there are about 10% occupants' in AGU choose cooler as their favor thermal comfort station, the most possible explain is AGU have a higher thermal environment temperature than WMC; 3) in TS in buildings, most occupants think neutral is the most satisfied thermal condition, especially in WMC, this percentage is as high as 81.6%; 4) it is proved that the thermal sensation range from slightly warm to slightly cool is the occupants satisfied range in TS in building.

1.4.5. PMV and PPD model

The PMV-model by Fanger is used to predict whole-body thermal comfort. It is also recommended to use the PMV index only for values of PMV between -2 and +2 (ISO 7730 2010). The PPD (The predicted percentage of dissatisfied) index predicts the mean value of thermally dissatisfied people, and the PPD index values of PPD<15% is the normal satisfaction range. The PMV-PPD model was used in this study to predict participants' satisfaction of their thermal environment around them.



▨ Transitional space in building ▨ Surveyed areas in transitional space in building

Figure 1.12 Surveyed areas in transitional space of AGU and WMC.

To investigate if occupants in transitional space in buildings have special favor area, transitional space in each building is split as four areas as area A, B, C and D as Figure 1.12. The results of satisfaction rate in different area of transitional space is as Figure 1.13, it shows that there is an obvious favorite area A in AGU with the satisfaction rate as 54.9%. In WMC the satisfaction rate in each area is average, but area C and D is still have an obvious higher satisfaction rate than area A and B. The results of satisfaction rate in each area get form questionnaire used to comparing with the results get from PMV-PPD model to test the feasibility of this model work in transitional space in buildings.

Figure 1.13 indicates that this model is work in AGU very well because the result is consistent with the result of questionnaire survey. However, in WMC, the result of this model is totally converse with the questionnaire results. To investigate the reason of this phenomenon, a comparison of physical and participants' character between these two cased is conducted as Table 1.5.

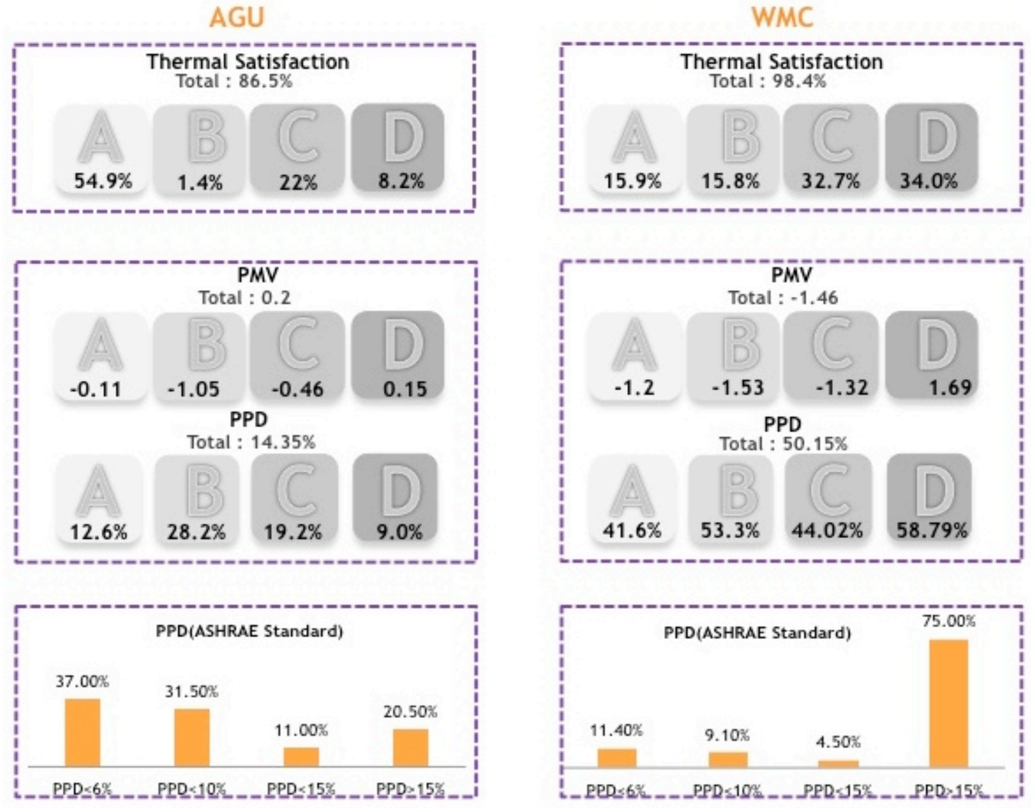


Figure 1.13 The result of PMV-PPD model using in cases.

After combining these results with SPSS correlation and regression analysis, it is inferred that the main reason of PMV-PPD model does not work in WMC is its dynamic thermal environment. The WMC is a very popular space in Cardiff Bay, people visit it for refreshment, exhibition, opera, performance, using toilet, using cash machine and to access the tourist center etc.. So, the main door of transitional space is opened and closed very frequently, and because this is not a revolving door but a slow response automatic door, the inside thermal environment of transitional space in WMC is not as stable as in the AGU. It is almost as dynamic as the outside thermal environment, as a result the PMV-PPD model cannot work in this space. To investigate if participants are happy with the dynamic thermal environment in transitional spaces, a new question about that added to the subsequent formal study questionnaire.

Table 1.5: The main different characters of two cases.

		AGU	WMC
Physical Characteristic	Area	810.25m²	2198.41m²
	Air temperature (average)	23.90 °C	21.41°C
	Thermal environment	Relatively stable (more closing to inside environment)	Relatively dynamic (more closing to outside environment)
Participants' Characteristics	Age	16-34 years old: 69.3%	Average
	Live in Cardiff	82.7%	25.8%
	Visit frequently	75.6%	51.7%
	Stay time (2-8hours)	70.1%	29.2%

1.5. Conclusions

This study is giving a more detailed definition of transitional spaces in buildings. It shows that transitional spaces in buildings are complex and diverse in design, and always serve multiple functions for participants. Transitional space can offer a wide range of adaptive opportunities (choice of sitting area, wider range of possible physical activities, greater tolerance of dress code etc.). When people stay in the transitional spaces in buildings, they tend to experience a dynamic interaction with changes in temperatures.

Due to the dynamic thermal condition in transitional spaces in buildings, occupants experience at multisensory levels and tolerate greater temperature range than in fully occupied spaces, it can help to reduce energy consumption in building. But the PMV-PPD model is not suitable for all of the transitional spaces in buildings, because in some spaces the thermal environment is as dynamic as outside environment condition.

This fieldwork is the pilot study for a larger research investigation. It has highlighted some improvements to benefit to the formal study as follows: 1) improving the design of questionnaire (content, format and layout); 2) changes to the method of recruiting participant to get more reliable and trustable responses; 3) change a more flexible timetable to apply questionnaires to cover a widely temperature range; 4) changes to the location of monitoring equipment to get the results with least interference; 5) increasing the number of monitoring devices, and making the equipment more manageable to improve accuracy; 6) improving the method of combining questionnaires with physical measurements to get a more reliable results.

Appendix 4 Outdoor environment parameters during the survey time

Table 1 Outside environmental parameters during field study in AGU in winter.

		Winter						
		24/01/13	25/01/13	27/01/13	28/01/13	29/01/13	30/01/13	31/01/13
Air temperature (°C)	Mean	1.9	3.1	7.3	8.0	12.2	9.8	9.4
	Max	2.8	3.6	8.7	11.1	13.2	10.5	10.3
	Min	0.5	2.8	5.1	5.7	8.8	8.9	8.0
	SD	0.6	0.2	0.9	1.6	0.7	0.5	0.6
Humidity (%)	Mean	71.3	71.9	64.2	76.0	82.8	63.9	64.7
	Max	77.1	85.4	75.0	84.2	87.7	72.1	74.7
	Min	66.0	62.8	55.4	62.7	77.6	60.0	53.2
	SD	2.6	6.5	4.5	4.9	2.5	3.3	5.8
Air speed (m/s)	Mean	1.78	3.9	4.73	4.33	4.77	5.90	5.33
	Max	2.97	5.7	8.82	7.72	7.13	7.96	7.94
	Min	0.13	2.62	2.83	2.08	0.18	3.71	3.45
	SD	0.60	0.78	0.99	1.42	1.22	0.85	0.97

Table 2 Outside environmental parameters during field study in AGU in summer.

		Summer							
		29/07/13	30/07/13	31/07/13	01/08/13	02/08/13	05/08/13	06/08/13	07/08/13
Air temperature (°C)	Mean	20.2	20.9	20.8	26.9	22.6	18.8	21.1	20.6
	Max	21.4	22.4	22.4	31.0	24.7	22.3	24.9	23.3
	Min	17.9	19.3	19.7	21.4	19.8	16.2	17.6	17.1
	SD	0.7	0.7	0.6	2.7	1.0	1.7	1.6	1.4
Humidity (%)	Mean	56.7	54.7	73.0	51.8	51.1	74.0	42.3	47.8
	Max	75.8	63.3	82.0	68.7	63.6	83.7	58.7	62.3
	Min	48.5	44.3	64.2	38.0	43.0	60.7	33.0	37.1
	SD	6.6	5.2	4.9	8.6	3.8	6.7	6.8	7.7
Air speed (m/s)	Mean	3.98	2.75	2.31	2.28	2.42	2.11	1.52	1.65
	Max	6.31	4.47	4.12	4.22	4.06	4.20	2.71	3.43
	Min	1.83	0.74	0.74	0.93	1.35	0.79	0.30	0.15
	SD	0.87	0.84	0.75	0.72	0.55	0.79	0.52	0.81

Table 3 Outside environmental parameters during field study in RWCMD in winter.

		Winter						
		05/02/13	06/02/13	07/02/13	08/02/13	09/02/13	10/02/13	11/02/13
Air temperature (°C)	Mean	5.0	5.9	4.7	6.3	6.7	6.1	2.5
	Max	6.7	7.0	5.7	7.8	7.5	7.0	3.0
	Min	2.9	4.6	2.9	3.0	4.8	5.2	1.9
	SD	1.1	0.7	0.8	1.2	0.8	0.6	0.3
Humidity (%)	Mean	57.4	48.3	68.3	63.1	80.7	84.7	74.6
	Max	70.6	70.0	80.8	81.7	85.9	86.8	81.7
	Min	47.2	36.3	61.9	55.4	73.5	76.3	69.5
	SD	6.2	10.2	4.9	5.5	4.0	2.5	3.5
Air speed (m/s)	Mean	5.01	5.02	1.72	1.80	1.46	2.66	3.26
	Max	7.45	7.88	3.71	4.20	2.98	4.08	5.76
	Min	1.53	2.00	0.19	0.39	0.08	1.10	1.46
	SD	1.20	1.15	0.81	0.94	0.72	0.63	0.72

Table 4 Outside environmental parameters during field study in RWCMD in summer.

		Summer						
		08/07/13	12/07/13	15/07/13	16/07/13	17/07/13	18/07/13	19/07/13
Air temperature (°C)	Mean	25.2	24.6	23.9	24.5	27.0	27.7	26.3
	Max	27.2	29.3	26.4	27.3	32.3	31.9	29.0
	Min	22.0	18.9	20.2	20.7	21.1	22.3	22.1
	SD	1.5	3.4	1.4	1.7	2.9	2.6	2.0
Humidity (%)	Mean	40.6	44.5	49.2	47.2	36.4	38.0	35.3
	Max	52.8	59.5	65.5	55.9	54.2	55.9	44.3
	Min	34.1	33.0	32.8	37.3	18.5	26.8	29.4
	SD	5.6	8.5	7.2	4.5	11.3	8.4	4.8
Air speed (m/s)	Mean	3.42	1.57	1.71	1.90	1.46	2.07	4.22
	Max	4.78	2.43	2.66	2.95	2.60	3.43	5.58
	Min	2.24	0.56	0.75	0.95	0.63	0.58	2.59
	SD	0.63	0.43	0.46	0.46	0.42	0.56	0.64

Table 5 Outside environmental parameters during field study in WMC in winter.

		Winter						
		12/02/13	13/02/13	14/02/13	15/02/13	16/02/13	19/02/13	20/02/13
Air temperature (°C)	Mean	2.3	4.4	8.4	7.7	6.0	6.8	3.5
	Max	2.8	5.1	9.5	9.9	8.7	8.8	5.1
	Min	1.7	2.8	7.4	2.7	2.2	2.7	1.2
	SD	0.2	0.8	0.6	1.9	1.8	1.9	1.2
Humidity (%)	Mean	64.2	80.0	72.1	68.0	80.0	59.4	76.8
	Max	72.5	85.1	78.8	84.8	89.0	72.2	85.0
	Min	60.6	72.1	65.3	55.3	73.4	48.0	63.8
	SD	3.1	4.3	3.4	8.1	5.0	8.0	6.4
Air speed (m/s)	Mea	2.24	3.50	2.72	1.63	1.12	1.95	3.82
	Max	3.32	4.82	5.03	3.12	1.98	2.99	5.40
	Min	1.18	1.85	0.28	0.57	0.42	0.90	1.88
	SD	0.45	0.65	1.15	0.64	0.39	0.48	0.77

Table 6 Outside environmental parameters during field study in WMC in summer.

		Summer					
		12/08/13	13/08/13	14/08/13	15/08/13	16/08/13	17/08/13
Air temperature (°C)	Mean	17.4	17.5	17.7	20.1	19.9	17.6
	Max	19.2	19.6	18.7	22.2	21.8	19.7
	Min	15.0	13.6	15.8	18.3	16.1	16.3
	SD	0.8	1.3	0.8	1.0	1.6	0.8
Humidity (%)	Mean	49.1	58.4	81.4	70.4	64.5	75.3
	Max	65.3	68.8	84.9	83.2	83.6	84.8
	Min	38.6	52.6	71.1	60.3	56.4	59.9
	SD	5.4	4.0	2.6	6.1	7.8	8.4
Air speed (m/s)	Mean	2.47	2.71	2.27	2.99	2.73	3.30
	Max	3.92	4.18	3.43	4.83	4.68	5.27
	Min	1.01	0.85	1.06	1.31	0.97	1.65
	SD	0.69	0.61	0.50	0.87	0.73	0.70