Understanding Users' Comfort Levels in Homes Designed Based on the Principles of Vaastushastra in Dubai

THIS THESIS IS BEING SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF PHD

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Dedication

To my mom and sisters

Thank you for always being there for me and supporting me through my journey

Acknowledgement

I would like to thank my supervisor Professor Phillip Jones for his continuous support of my PhD research, for his understanding, patience and an open mind towards my selected topic.

My thesis has been a long journey and I would like to thank Dr John Alexander Smith, who supported my inquiry into this topic from undergraduate college and encouraged me to pursue my doctorate and for the tough discussions around my research.

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Abstract

Vaastushastra is a vernacular architectural practice that is commonly associated with mythology, luck, health and prosperity. Many people follow the rules mainly because they fear bad luck, even though most users don't fully understand why they are following it. The theory of *Vaastushastra* is linked to the ancient Sanskrit scripts of the *Vedas*, which were followed by common people even though there were no explanations provided behind these theories. The word '*Veda*' translates to 'knowledge' and '*shastra*' translates to 'science', the meaning of the word science is different to the way it is currently understood. In the past people were happy following theories that were passed on from generations, as opposed to empirical evidence-based science which needs verification through experiments and proof.

In this thesis the popular beliefs of *Vaastushastra* will be understood in relation the current scientific understanding of indoor comfort in residences. Since *Vaastushastra* is linked to the *Panch Maha Bhutas* (five elements) which are linked to the five senses, this study will examine if the rules of *Vaastushastra* have an impact on the comfort experienced by residents in homes that follow the principles. Users' comfort is easily understood in residential spaces compared to commercial spaces where temperature, light and sound can't be personalised.

Dubai was selected as the location for the thesis because many Indians living here follow the principles of *Vaastushastra* and want their houses to be compliant. The thesis aims to investigate if there are any links in temperature and humidity, which represent touch, light which represents sight, sound and smell recorded in houses that follow the principles.

The main outcomes of the thesis show that the rules of *Vaastushastra* have an impact on comfort levels in residences. North side of the house stays cooler compared to the south side, from which the southeast corner records the highest temperature even with the use of minimal windows. This supports that the functions of the house should be based on their use- so that the northeast corner which is cooler is used more often and the southeast corner is for warmer functions such as the kitchen.

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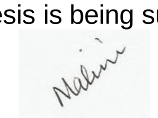

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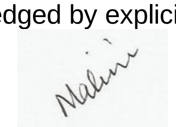

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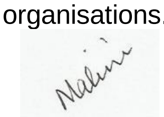

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Vaastushastra Case Studies On Comfort in Residences In Dubai in 53rd International Conference of the Architectural Science Association (ANZAScA) November 2019

Vaastushastra Case Studies On Comfort Residences In Dubai in IJAUS Vol 4, No 2 2019

'Vastushastra and its place in Sustainable design' in 8th Annual Dresden International Doctoral Colloquium "AESTHETICS IN ARCHITECTURE & URBAN DESIGN" 2016

'Understanding Vernacular: Vastu Shastra and Carl Jung's theories of Psychology' in ISVS Vol 3, April 2014

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Glossary

Aakasha – space

Agni- fire

Andhikasur- a mythological demon character

Aryans- describes the people who migrated to north of India during the Vedic times

Atharva Veda- is the fourth *Veda*, which describes occurrences daily life

Aya- gains

Ayadi/ aya formulae- a set of formulae used to determine the dimensions of the building

Ayurveda- traditional Indian medicine

Dravidians- is a term for natives of India and those who speak the *Dravidian* languages

Jala- water

Mahabharata- an epic tale of a battle between the great *Bharata* dynasty and is the one of two significant cores of Hinduism

Mandala- in the context of *Vaastushastra* is a cosmic grid which is used as a basis to create built spaces

Maya- master architect of south India

Mayamatam- original *Vaastushastra* manuscript written by *Maya*

Nakshatra- asterisms

Pancha Maha Bhutas- five elements

Prithvi- earth

Ramayana- a tale which portrays the struggles of Prince *Ram* and his wife *Sita* and is one of the two epics of Hinduism

Rig Veda- is one of the four *Vedas* and includes hymns written in praise of deities

Sam Veda- is similar in content to *Rig Veda* and is a collected of chants

Shad Varga- a set of formulae used to calculate the proportions of built spaces

Shastra-

Shiva- one of the holy trinity of Hindu gods and is the one who destroys

Sthapati - master builder or architect

Sthapatya Veda- is a supplementary Veda of *Atharva Veda* and discusses the rulebooks of built spaces.

Sutragin – surveyor

Takshaka- carpenter

Tithi- lunar days

Vaastushastra- the science or knowledge of dwelling spaces

Vaastu Purush Mandala- cosmic grid

Vara- solar days

Vardhaki- expert at painting

Vayu- wind

Vedas- knowledge or to know

Vishwakarma- master architect of north India

Vishwakarma Prakash-original *Vaastushastra* manuscript authored by *Vishwakarma*

Vyaya- losses

Yajur Veda- is a collection of chants that are recited by the priest when rituals are performed.

Yoga- traditional Indian exercise

Yoni- matrice

Chapter One: Introduction

1.1 Introduction

Vaastushastra is a traditional Indian system of architecture which was documented in the ancient scriptures and was meticulously followed by the masses at the time (Grover, 2008). The word *Vaastushastra* consists of two smaller words, in which *Vaastu* means dwelling space and *Shastra* means knowledge or science. Over the years for various reasons *Vaastushastra* lost its significance amongst its followers, which could have been due to lack of understanding of the original text, or the mysticism associated with it, or the lack of adaptability that was widely associated with the original text (Bubbar, 2005). Recently however, in the past 25 to 30 years there has been a renewed interest in the subject area both within India and internationally in countries such as UK, USA, Singapore and Germany (to name a few) where many different aspects of *Vaastushastra* are currently being researched (Messias, 2002 ,Pegrum, 2000).

The original text of *Vaastushastra* was written thousands of years ago, when science as we presently know it in the Western world didn't exist. The principles of *Vaastushastra* haven't been explained in any of the original manuscripts and therefore it is difficult to decipher which rules should be followed and which ones should be abandoned (Chakrabarti, 1998). *Vaastushastra* constitutes of many principles from which some might be outdated and therefore are irrelevant. This thesis aims to identify which of the main principles of *Vaastushastra* are prevalent by evaluating whether these principles create comfort in spaces that are designed based on its principles. The underlying factors that connect both these ideologies are the human senses of touch, sound, sight, smell and sound. In

Vaastushastra the five core elements are based on the five senses and comfort in spaces is about the user being comfortable in a space through sensory feelings. Thermal comfort and adaptive thermal comfort can both be used to evaluate how the users feel in these spaces. Some historical buildings in India are known for thermal comfort that the users experience in them (Nicol, et al., 2012). This thesis will examine if contemporary buildings built on these principles can provide a similar experience.

Vaastushastra aligns with the principles of passive design in which the built environment is designed in response to the site conditions. Homes that are built in hot and humid climates are built so that they mitigate the heat and manage to keep internal spaces cooler through natural means. When the built space is designed to fit into the surroundings the internal spaces will feel more comfortable to the users. This thesis will examine homes designed by the rules of *Vaastushastra* and whether or not users' comfort in them.

1.2 Research Scope and Focus

The core philosophy of *Vaastushastra* deals with proportions, scale, orientation, placement of windows, placement of various functions, materials used, and construction techniques used in architecture, sculpture and furniture design. The bigger purpose is to understand the impact the principles of *Vaastushastr*a have on built space, especially the impact these principles have on the comfort that residential users experience. The buildings that were constructed, attempted to use proportions found in nature, human scale, indigenous materials and adequate construction techniques to blend into the environment (Nathan, 2015). Following the principles of *Vaastushastra* creates spaces that are in harmony with nature and therefore should be aligned with the environment around and help to create spaces that are comfortable for their users.

The word *shastra* is translated to science but the word had a different connotation at the time it was written. The reference to the science in the historic and current context is similar in reference to organization of knowledge but is very different because science as we understand it today has testable explanations whereas in reference to *Vaastushastra* explanations were not provided. The word "*shastra"* loosely translates to science but is not used in the same context that it is used in today, it refers to a set of principles which are the basis of the philosophy

This thesis identifies the key principles of *Vaastushastra* which are used for residential design and examines if these can create users' comfort in homes in Dubai. This is one of the ways in which scientific understanding *Vaastushastra* can be created. Many Indians in Dubai check for the principles *Vaastushastra* when they are selecting a house, even if it is a rented property.

One of the fundamental aspects of *Vaastushastra* is the concept that there are five elements (*Pancha Maha Bhutas)* and these elements are linked with the human body. Five elements are earth, fire, wind, water and space (ether) and are linked with the five human senses as such – earth is connected to smell, fire is connected to sight, wind is connected to touch, water is connected to taste and space (ether) is connected to hearing or sound (Table 1.1). All the *Vedas* refer to the fact that the human body was created using these five elements (Dagens, 2000) (*Pancha Maha Bhutas)* which is the principle in practices such as *Ayurveda* (traditional Indian medicine) and *Yoga* (traditional Indian exercise). In order to be comfortable in a built environment the user has to experience comfort through their senses. Sometimes in hot and humid environments indoor spaces tend to be colder than required which makes the users uncomfortable. It is important to design spaces that can maintain comfortable indoor temperatures majority of the time so that its users are comfortable.

Element	*Sensory*	*Direction*
Earth	Smell	Southwest
Fire	Sight	Southeast
Wind	Touch	Northwest
Water	Taste	Northeast
Space (Ether)	Sound	Centre

Table 1.1- Elements and their connection with the senses

Correlation between the elements and the senses isn't explained in the *Vaastushastra* text but is explained in the other *Vedas* which is not discussed in this thesis as it would deviate from the main subject of user's comfort. Four of the elements are linked with a sub cardinal direction and the central space relates to the element of space (Table 1.1). The association of the elements with the directions has not been explained in any of the original text of *Vaastushastra*. It is suggested that this connection with the elements and direction represents the quality of the indoor space of each direction and is loosely based on the geographic location of India and its' climatic conditions.

The scope of this research is to examine if there are any notable differences in the user's experience of the four directions in a residential space that is designed based on the principles of *Vaastushastra*. Since the homes selected for the thesis do not have a central courtyard the fifth direction which is the center of the house, is not considered in the study. The concepts of architectural comfort include the senses of sight, sound, smell and touch, since spaces can't truly be experienced only by one sense, as discussed in Thermal Delight in Architecture (Heschong, 1979). All four senses play an important role in comfort of built spaces, but sound, taste and smell are fairly constant in residential spaces. Sight is based on natural and artificial light. Quality of natural light in a residential space varies through the year since hours of daylight and angle of the sun keep changing which changes the users comfort levels. There are two parts to the sense of touch, one is constant in terms of finishes and furniture used in the space and the other is temperature and humidity which can vary based on geographic location of the city and time of the year. Sound is another important factor for comfort in a house even though it is typically created by the residents. The right level of sound is important in making residents comfortable. Smell is another factor that is important for comfort. With the right amount of air circulation and ventilation a building can have a pleasant smell at most times making the users comfortable. The focus of the research is to examine if houses that are designed on the principles of *Vaastushastra* provide comfort to its occupants with an emphasis on senses of touch, sight, sound and sight. The quality of light in the room and the sensation of the space in terms of temperature and humidity determine how comfortable users feel in the room, therefore these two qualities are studied in this thesis.

1.3 Research Context and Contribution

1.3.1 Topic Relevance

Indians have migrated to many parts of the world and have taken their culture and rituals with them which include languages, food, clothes, movies and many others (Anon., 2000). Awareness and influences of Indian culture is easily spotted in Dubai, many people speak Indian languages, variety of Indian specialized foods are available and traditional Indian clothes are commonly worn both by Indians and people from other nationalities. *Yoga* is recognized as an alternative fitness or wellness regime which is growing in popularity around the world. *Yoga* is practised in Dubai and people from different nationalities follow these alternate methods. Similarly, *Ayurveda* is an alternative health system that was used traditionally in India and has an increasing acceptance especially in Dubai.

Vaastushastra is also practiced by people in Dubai, though this is not as easy to identify as the popularity of *Yoga* and *Ayurveda*, since buildings that are designed based on *Vaastushastra* appear the same as any other contemporary building. Ornamentation of residences is not a mandatory feature of this theory, though proportions of the buildings are recommended. Temples which are designed based on this philosophy follow the ornamentation and are easily identified due to the details used. Traditionally residences were split into many categories, from which the palaces would use ornamentation, but the common persons house would have minimum to none.

There is a suggested debate on whether *Vaastushastra* should be followed outside India because it suggested that the principles are designed for Indian climatic conditions and therefore should not be followed in other countries (Bubbar, 2005) (Acharya, 1934) (Chakrabarti, 1998). Rules of *Vaastushastra* differ based on which region in India they are written for. Dubai has a climate (fig 1.1) which is similar to Kota, Rajasthan (fig. 1.2) which is in India, since both are desserts they are hot and humid throughout the year with the exception that in Rajasthan it rains through the summer which the hottest period in Dubai. Since these two cities have similar climates the key principles of *Vaastushastra* that are discussed in this thesis are based on the those written for Rajasthan, mainly from *Mayamatam*.

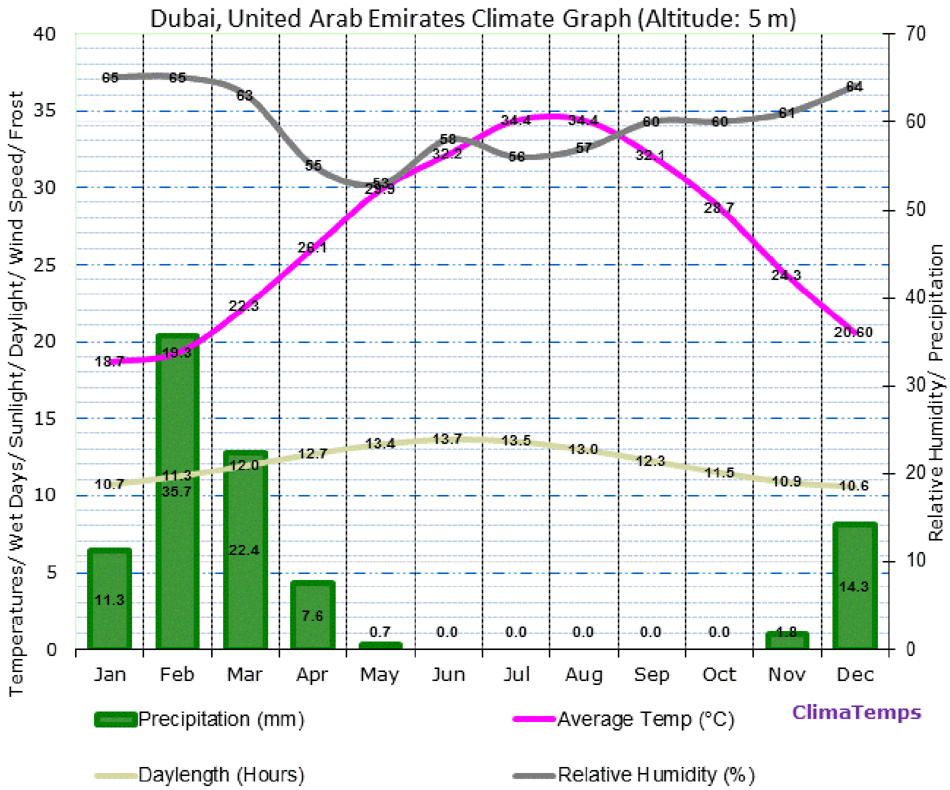

Figure 1.1- Annual Temperature and Humidity UAE

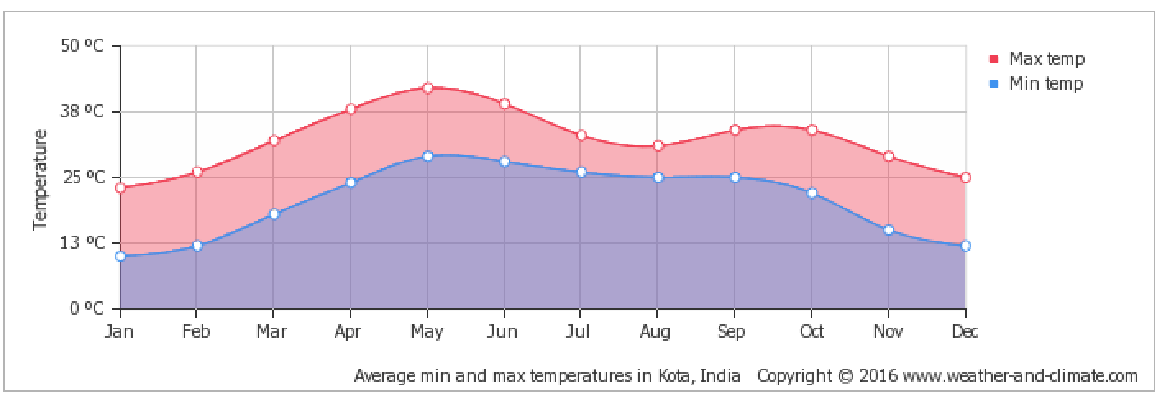

Figure 1.2- Average Annual Temperature in Kota, India

1.3.2 Intended Contribution

The intended contribution of this thesis is to examine if the principles of *Vaastushastra* have an impact in built spaces and on the comfort levels of the users. Residential spaces have a limited number of users, so the internal space should be maintained at levels that are comfortable for them. These spaces are of a reasonable size that the space can be easily monitored to measure the various factors that affect the occupants' comfort or lack of it. Users comfort in the space will be measured through various methods to try and understand the impact the design of the house has on their comfort.

The principles of *Vaastushastra* influence the design of built space because the rules mention orientation of the site, proportions the plot, proportions of the house and the rooms, locations windows, courtyard and use of materials. These principles align with the principles of passive design and therefore should create spaces that are comfortable for the users.

The intent of this thesis is to establish the connections between passive design and user comfort and *Vaastushastra.* There have been some studies that connect two of the three topics, but there is very limited research on all three topics combined. Comfort is central amongst the three theories and the factor that connects all three topics. A space that is designed to suit its environmental conditions should be comfortable to use and that is the basis of *Vaastushastra*.

1.4 Research Aim & Objectives

The overall aim of the thesis is to analyse if the principles of *Vaastushastra* have an impact on the quality of indoor space experienced by residents. By following these principles while designing the house, the space should be naturally cool in the winter months, even in a hot climate such as Dubai; which can reduce dependency on air-conditioning needs.

- To explore which scientific (as we know it today) rules could the basis to understand the key principles of *Vaastushastra*
- To identify key principles of *Vaastushastra* that are applicable in hot and humid climate of India (Rajasthan) which has a climate similar to Dubai
- To investigate if there are any benefits of applying the principles of *Vaastushastra* to homes built in Dubai

1.5 Research Questions

This research investigates the possible connection between Indian vernacular architecture (*Vaastushastra*) and the users experience of the space by asking the following questions -

- Was *Vaastushastra* successful in addressing the sensory connections between the user and the built space?
- Which principles of *Vaastushastra* helped in creating comfortable internal spaces? (if any)
- Is there a significant temperature difference in the four sub-cardinal locations in a house?
- Can the principles of *Vaastushastra* be adapted into Dubai homes to support user's comfort in architectural spaces?

1.6 Research Methodology

Three methodologies that were used for this thesis are data collection from case studies temperature and humidity (quantitative), questionnaires (qualitative) and simulation software (quantitative). The case studies were used to understand the application of the principles of *Vaastushastra* to homes in Dubai. Principles were written in an abstract manner and might appear rigid at first, but those who study these understand that there is an amount of flexibility suggested in them. Questionnaires were used to identify how the residents experienced the spaces. Various devices can record physical attributes of a space, but this doesn't always equate to end users feeling comfortable. The questionnaires were given to all the residents of the house to understand how each one of them felt in the space at different times of the year. None of the houses identified as case studies completely complied with the rules of *Vaastushastra.* Simulation software was used to recreate one of the case study houses, to investigate the impact of using all the rules in one house.

The first methodology used is to understand the comfort level of touch in a space, which is associated with temperature and humidity and the feel of the space in terms of furniture and finishes used. The latter is constant in a space as the feel of the furniture and finishes remains the same till it is replaced. Individuals try to maintain the former at levels that suit themselves and since there are few people in residential spaces this is easier to achieve. Since UAE has two major seasons, internal measurements were taken using data loggers, twice in each of the five case study homes. This is the quantitative data that would show the temperature differences between internal and external temperatures during summer and winter months. The case study homes are all different and comply with different principles of *Vaastushastra*, the data collected will help determine the impact these rules have on the internal comfort level of temperature and humidity.

The second methodology is to ask the occupants of the tested houses to fill in questionnaires about how they felt in the space. Temperature and humidity vary the most in a space, therefore data loggers were placed to monitor these. Sight is dependent on daylight which changes throughout the day, but these changes are consistent in the same season. The duration when the temperature loggers were placed in the house, the quality of light would have repeated the same cycle daily. Similarly, the other sensory connections of smell and sound should be reasonably constant within residential spaces therefore loggers were not placed to measure these. However, it is important to know how the occupants feel about these sensations and were asked about them through the questionnaires. Meeting temperature requirements of a space doesn't always mean that it is comfortable for the users. The occupants were also asked how they felt about the temperature of the space in the questionnaires and the collected data will help to understand the comfort of the users in the space. This will help in understanding the impact the principles of *Vaastushastra* might have on the five case studies.

And finally, the third methodology used is to test variations of one of the case studies through simulation software to examine the impact of applying all the principles of *Vaastushastra*. There are many different simulation software available, based on the requirements of this thesis which was to study the internal temperatures of a specific house design, the IES (Integrated Environmental Solutions) was selected. This software simulates real life condition based on external conditions that are taken from weather station data and uses properties of the building materials used to calculate the internal temperatures of the built space. To work out the accuracy of the simulation model one set of data recordings were taken from the site to match against the findings of the simulation model.

1.7 Reason for Selecting Dubai, UAE

Many Indian traditions have been accepted by the world and are being practiced internationally. *Vaastushastra* is gaining popularity and is being researched by many different people who want to be able to understand if it should be used in contemporary buildings and outside of India. *Vaastushastra* is a traditional Indian architectural system therefore is it fit to be used in contemporary context, and/or outside India? Within India there are many different views about *Vaastushastra*, mainly those who believe the rules can't be modified and those who think the rules are guidelines and can be modified based on location of the site. Those who believe in the latter think that *Vaastushastra* is written for the range of climates seen in India and therefore cannot be used outside, while other believe that the essence of the rules can be extrapolated and used as a guideline outside of India.

There are many different climates around the world, many which are similar to India and many which are dissimilar. The author's opinion is that if the weather conditions match to the Indian conditions then the principles of *Vaastushastra* could be used as a guideline, with modifications made to suit the local climate. Principles of *Vaastushastra* should not be thought of as being inflexible as the biggest evidence of the flexibility is that these change within India itself and the adaptations are based on climatic changes seen.

The climate of Dubai is similar to that of Rajasthan in India, both are dessert regions with the exception that in Dubai it rains in winter and Rajasthan typically sees monsoon rains in July and August. The latitude of Dubai is 25.2048° N and of Rajasthan is 27.0238° N. With a strong Indian population, Dubai is selected to carry out the research because the author has worked on a couple of projects which used the principles of *Vaastushastra*. Along with residential projects there has been interest by architects and developers to understand and apply these principles to projects in Dubai. This research aims to understand if there is a positive impact of applying the rules of *Vaastushastra* to residences in Dubai.

1.8 Research Organization

This thesis is divided into three parts, it starts with theoretical background, then goes on to the investigation and finally the analysis of the findings (Fig 1.3).

The first part is the theoretical background which identifies the principles of *Vaastushastra* and the key factors of users' comfort that relate to residential spaces. *Vaastushastra* has many different applications and therefore has numerous principles, this first part will explain the rules predominant for designing residences. Since India has many different climates, one of which is a dessert climate of Rajasthan, the rules followed in this climate will be studied. In the authors opinion the rules of *Vaastushastra* have an impact on the users' comfort levels which will be explained. Literature review looks at the existing opinions on both these topics which is followed by the methodology chapter that elaborates the techniques used in the thesis.

The second part is the investigation of the key principles of *Vaastushastra* by testing these in case study homes in Dubai. The case study homes are selected based on the key principles identified in part one. Within this investigation there are two parts-first is the data collection of temperature and humidity from these homes and second is data collected from the questionnaires filled by the residents. Out of the five sensory factors that have an impact on user's comfort levels, touch which is based on temperature and humidity vary the most, therefore have been selected as the measurable factor in the thesis. Other factors of sight, smell and sound are understood through the users' experiences of the space.

The third part of the research is further testing of *Vaastushastra* principles through simulation modelling to study the impact these have on the internal comfort levels of temperature and humidity. All the data is compiled to understand the impact the principles of *Vaastushastra* have on homes in Dubai.

Introduction	•Chapter 1 - Introduction
Theoratical Framework	•Chapter 2 - Literature Review •Chapter 3 - Methodology
Investigation	•Chapter 4 - Understanding User Comfort through Case Studies •Chapter 5 - Understanding User Comfort through Questionnaires
Analysis of the findings	•Chapter 6 - Modifications to Case Study through Simulation Software •Chapter 7 - Data Analysis
Conclusion	•Chapter 8 - Conclusions and Recommendations

Figure 1.3- Thesis Framework

1.9 Overview of Chapters

Chapter 1 outlines the need to research *Vaastushastra* which is a traditional theory primarily used within India and examine if these principles can be used in contemporary architecture in Dubai. It also lays out the research objectives, research questions, intended contribution of the thesis and structure of the chapters.

Chapter 2 outlines the key principles of *Vaastushastra* and identifies those that could be utilized in contemporary architecture and those that might be predominantly linked with superstitious believes. It then looks at the impact these rules might have on the user's comfort levels in the space. It reviews existing literature on the both of the subjects and recognises the existing information on each which lends to the connectivity between both.

Since *Vaastushastra* is a traditional architectural system, user's comfort of the space is one of the scientific ways in which this traditional system is understood in this thesis.

Chapter 3 explains the three different methodologies that are used in this thesis, which are briefly laid out in 1.6 above but are explained in detail in this chapter. The chapter specifies the details of case study selection, set up of the loggers in the case studies, the basis for the questionnaires for the residents and the selection of the simulation software.

Chapter 4 is the collection and initial analysis of all the data from the loggers placed in the homes. The data was collected twice in the year, once in summer and then during the winter months which looks the trends in the differences between indoor and outdoor temperatures.

Chapter 5 reviews the user's comfort of all the five residential spaces by analysing the data collected from the questionnaires filled in by the occupants. The data is understood in the context of the house and both the user's opinions and the author's opinion as an architect help to synthesize the gathered information.

Chapter 6 takes one of the case studies and modifies it further to align with all the principles of *Vaastushastra*, since the case study homes did not align with all the principles. Simulation software was used to adapt the house using several different options, which tested impact of various combinations of the principles to understand which had the maximum impact.

Chapter 7 discusses the findings of chapters 4, 5 & 6 as an overview of correlating the principles of *Vaastushastra* with user's comfort levels in a space and alignment with passive cooling techniques. Some of these principles align with the findings of the case studies and help to provide a possible explanation to the traditional principles of architecture.

Chapter 8 concludes the research and establishes the scientific theories that could be behind the principles of the vernacular architecture. It also outlines the recommendations and areas of further research that can develop this research further.

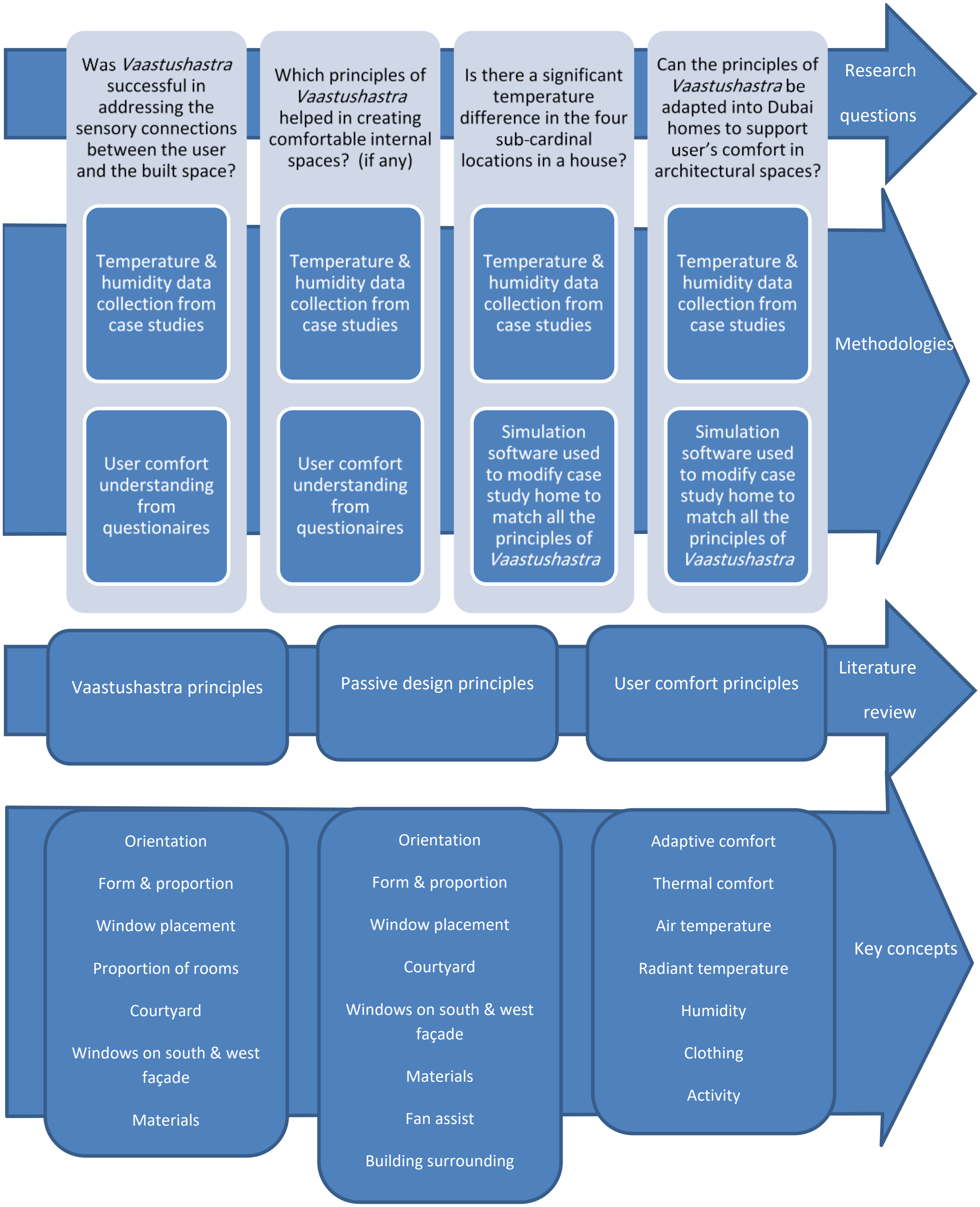

Figure 1.4- Research framework

Chapter Two: Literature Review

2.1 Introduction

This chapter will look at the traditional principles of *Vaastushastra* and theories of users' comfort. It starts by discussing the contribution that this thesis will make to existing body of knowledge of *Vaastushastra* and understanding the common aspects with users' comfort. It goes on to explain its origins in Hinduism, original manuscripts, core concepts of *Vaastushastra*, main principles used to design residential buildings, a couple of concepts that are obsolete and provides a few examples of buildings that are designed on its principles. Current literature of *Vaastushastra* will be discussed understanding the content that has been researched and the gaps that still exist.

Second half of this chapter starts by understanding the importance of thermal comfort. It then goes on to discusses the underlying principles of thermal comfort. This is followed by concepts of the adaptive approach. Users comfort is usually based on the theories of thermal comfort or adaptive thermal comfort. The principles of both are discussed in the second half and the relevance and use of adaptive comfort is discussed. There is a discussion about which method is appropriate to evaluate the comfort of the users of the case studies of this thesis. This thesis refers to comfort only to examine whether the buildings designed by *Vaastushastra* are comfortable for the users.

The principles of *Vaastushastra* are not explained in any text which makes it difficult to know why they were written the way they were and moreover to know how they can be modified or updated (Sinha, 1998). Manuscripts of *Vaastushastra* specify rules and mention dangerous consequences of sidestepping them, which would scare the average person enough to follow them verbatim (Chakrabarti, 2000). Since these texts were written at a time when fear of unknown powers such as gods and demons was enough to convince people to follow them, no explanations were documented in the text. It could also mean that these rules were written to be flexible and therefore were meant to be adapted and updated with changed in technology (Tillotson, 1998). There are many scientific theories which could be used as a basis to understand the logic and reasoning behind the traditional approach to architecture. The basis for this thesis is understanding the principles of *Vaastushastra* through the impact they may or may not have on comfort in residential spaces.

Users' comfort in spaces can be measured in many ways and there is a lot of research carried out in this subject area, but there isn't any link of it with *Vaastushastra*. This chapter will establish the possible connections between *Vaastushastra* and users' comfort levels in residential spaces. The common aspect between both subjects is the human senses, since both subjects deal with sensory perceptions. According to *Vedas* the human body is made of five elements and these are linked to the five senses, therefore the principle is that any space built based on these principles should make the occupants feel comfortable. Many aspects can be measured to understand the comfort levels of the occupants, but for this thesis the following aspects are studied (Table 2.1). –

Element	*Sense*	*Measurable factor*	*Measurable unit*
Air	Touch	Temperature and humidity	°C and RH%
Earth	Smell	Odor	ouE/m^3
Fire	Sight	Light (day light and/ or artificial)	Lux
Space	Sound	Noise levels	dBA

Table 2.1 - Measurable aspects of the selected four senses

2.2 *Vaastushastra*

This part of the thesis discusses the origins of *Vaastushastra*, the key principles, use of materials and plausible scientific explanations. There are many rules and regulations written in the manuscripts, this part of the thesis will list and explain the core principles. It will specify the principles that were used to select and test the case studies. Since there is no explanation provided in the original text (where the rules are stated) the author has mentioned scientific theories that might be the basis for these ideologies (Acharya, 1934) (Dagens, 1994). Similar discussions took place in interviews with consultants, one who currently practice *Vaastushastra* in Dubai and the other who is a professor and author of textbooks on *Vaastushastra*. (See Appendix)

2.2.1 Origins of *Vaastushastra*

Vaastushastra is a traditional vernacular architectural theory which has been practiced in India since 1500 – 1000BC and is an integral part of the *Vedas* (Patra, 2006). India is a diverse country in various aspects ranging from cultural diversity, which is seen in its numerous sub-cultures, language diversity since each sub-culture has its own unique dialect all of which results in diversity in customs and traditions. This diversity is also seen the in the adaptations and application of rules of *Vaastushastra* for different regions of India (Bubbar, 2005). Regional diversity is an important aspect of understanding *Vaastushastr*a as it links with the variations that are seen in the applications of rules (Achari, 2016). There isn't one complete handbook of *Vaastushastra* but has different original manuscripts that belong to different regions. Which suggests that the multiple versions were written for specific geographic locations and the rules laid in each version addresses social, cultural, climatic and other such aspects of the region (Acharya, 1934). The traditional houses developed in the north of India are strikingly different to those built in the geographic south in terms of architectural style and ornamentation, however they are most likely unified by the underlying principles such as proportions, grid, orientation and use of local materials (Chakrabarti, 1998). Various texts including original manuscripts and other contemporary author's interpretation of the original text, both are mentioned later in this chapter, these facilitate the understanding of the principles from traditional and contemporary viewpoints.

2.2.2 Historic Literature on *Vaastushastra*

Vaastushastra is a part of the *Vedas* which date back to 1500- 1000BC (Patra, 2006) these *Vedas* lay down the core fundamentals of Hinduism. There are four parts to these *Vedas* which are *Rig Veda, Yajur Veda, Sam Veda* and *Atharva Veda ;* the word *Veda* translates to 'knowledge' or 'to know' and each text divulges various aspects of spirituality, natural forces, and philosophical theories (Juyal, 2010). Each of *Vedas* has supplementary texts that explains the rules of specific topics in further details. *Vaastushastra* is a part of *Sthapatya Veda*, which is a supplementary *Veda* of *Atharva Veda* (Patra, 2006), and is one of the many sources for literature on *Vaastushastra*. The *Vedas* teach the basic principles and philosophies of life, out of which *Vaastushastra* lays the guidelines on architecture (Acharya, 1934) (Dagens, 1994). Ideally, *Vaastushastra* should not be read and practiced on its own but should be understood as a part of the *Vedas* and therefore should be understood as a part of a whole.

Information on *Vaastushastra* can be found in various ancient scriptures, it is not found in one "easy to use" guidebook. The knowledge of this subject is split and forms a part of many scriptures, each dealing with different aspects of building construction in detail. Apart from the text mentioned above, other original text on *Vaastushastra* are *Samaraagana Suutradhara Narad Samhita, Brihat Samhita, Vasturatnavali, Brihadvastumala, Aparaajithaprccha, , Vishvakarma Vastu Shstra, Vastumanikya Ratnakara, Griharatna Bhushana, Nutana Lagu Shilpa Sangrha, Shilpasshastram, Vedha Vastu Prabhakara, Brihadvastumala, , Vishudharmoothara Purrana, Pramaana Manjari, Vastu Vidya, Maya Vastu*, *Vastu Prabhandha, Vastu Sarni, Vastu Parakana* and *Bhrigu Samhita* etc are all referred to for detail descriptions that aren't covered in the *Mayamatam or Visvakarmaprakasha* (Chakrabarti, 1998) (Acharya, 1934).

Manasra is written by *Mansar Rishi*[1] in the Gupta period of Indian history 450-550AD (Chakrabarti, 1998). This text is also originally written in Sanskrit and the version referred to in this research is translated to English by P. K. Acharya (1934). The content is divided into seven volumes, which covers all the details about architecture from town planning to house design to joinery details of furniture. It provides *mandalas* (grids) that can be adapted for town planning, building a palace, a temple or even a house. These books get into the details of measurement and proportion systems, which is a vital aspect of *Vaastushastra* and therefore is unique. The volume and complexity of the book makes it difficult to understand as it constantly cross references itself and other books, amongst which one is Vitruvius's ten books of architecture (Acharya, 1934).

Mayamatam is the other treatise, which is south Indian in origin, along with *Manasara* mentioned above. The author of *Mayamatam* is *Maya* and the scripture was written sometime between the 11th and 12th Century (Dagens, 2000). While there are many similarities between both the texts (*Manasara* and *Mayamatam*), it should be noted that

[1] Rishi is a saint or sage, who would meditate for hours and in meditative state he would write the shlokas (verses) of the scriptures.

there are slight variations which could be because they belong to two somewhat different branches of South Indian School of architecture (Acharya, 1934). Both scriptures have the same structure, but *Manasra* explains the measurement and proportion systems in more detail then explained in *Mayamatam* (op. cit.). The author observed that both books have illustrations that help to understand town planning as well as residential plans, but there are more illustrations in *Manasara*. At the same time *Mayamatam* is written in 2 volumes and is easier for a beginner to read, as it provides an overview of the entire subject. It is a suggested read for anyone who wants to refer to an original manuscript in order to understand all the basic guidelines.

Visvakarma Prakasha is written by Visvakarma, who the architect of Gods in Sanskrit (Pegrum, 2002); the version studied for this research has been translated to Hindi by Eng. Acharya Shivprasad Varma. Vishvakarma is the divine architect mentioned in the scriptures of *Ramayana* and *Mahabharat* [2], who designed royal palaces and towns based on the principles of *Vaastushastra*. The text *Visvakarma Prakasha* is of importance as it is one of the simpler texts of *Vaastushastra* which is compiled in one book consisting of 13 chapters. The content covered by the book includes residential, temple and fort architecture and is therefore unique. The aim of *Visvakarma Prakasha* as described by the author is for the welfare of the world. It covers all the aspects of residential *Vaastushastra* in a simplified and written in an easy to follow manner. The other books that cover these topics look at various other areas such as town planning, *mandalas* (basic grid layouts), placing of the gnome, etc. *Visvakarma Prakasha* is the only north Indian book studied for this research. The author of this thesis has read all three text of *Vaastushastra* and understood that the

[2] *Ramayana* and *Mahabharata* are two epics works of Indian Literature. In *Ramayana Visvakrama* built the Golden City of Lanka and in *Mahabharata* he built Dwarka, at the end of both stories these cities get destroyed and hence there is no trace of them.

core principles of *Vaastushastra* are the same in all the different scriptures, the rules that vary are adaptations for regional suitability which is similar to the discussions by Chakrabarti in her book (1998).

All these texts discuss *Vaastushastra* but there is a distinction between them, which is the document's place of origin. At the time these scriptures were written people in India were divided into two large groups, *Dravidians* and *Aryans* (Chakrabarti, 1998). The major difference between *Dravidians*[3] and *Aryans*[4] is that they belonged to different geographic locations within India. Both races followed similar fundamentals while establishing guidelines of *Vaastushastra*, the differences in the principles highlight adaptations that were made to accommodate the local environment (Sinha, 1998). *Visvakarma Prakasha* originates from north India and therefore is associated with *Aryans*, while *Mayamatam* come from the south therefore are *Dravidian* (Acharya, 1934).

For the purposes of this thesis the key elements of *Vaastushastra* will be understood from two original manuscripts, *Mayamatam* which is the most acclaimed south Indian text and *Vishwakarma Prakash* which is the north Indian equivalent. *Mayamatam* is dated 11th -12th Century CE (Vatsyayan, 2000) and *Vishwakarma Prakash* predates it because it was argued to be written before the 6th Century (Bhattacharya 1963, cited in Chakrabarti 2000) by *Vishwakarma*. *Maya*[5] who is the master architect for south India wrote *Mayamatam* which lays the rules for every type of dwelling space that can be built for gods and men. *Maya* explains at the beginning of the first chapter that he asked God some questions and after listening to Him the treatise of *Mayamatam* was written (Dagens, 1994). *Maya* is the

[3] The people who speak *Dravidian* languages and are primarily live in the southern part of India.
[4] *Aryans* where the Indo-Iranians who had faith in the Vedic deities and followed *Vedic* rules.
[5] *Maya* is mentioned as *Asura* which has different implications based on the context it is used in. Most of the people understand *Asura* to mean evil especially when it was used in the Vedic period, but in this context, it refers to someone who is engaged with worldly pleasures more than virtuous deeds.

architect that is related with *Ramayana*[6] which predates the *Mahabharata* whose connected master architect was *Vishwakarma* who was also the author of *Vishwakarma Prakash*. *Vishwakarma* is the master architect for north India but is also the "god of architecture and engineering" (Das, 2014). Since *Vishwakarma* is the authority on the subject he has therefore written the treatise himself, unlike *Mayamatam* which was created after *Maya* asked the Supreme Being some questions. While the original manuscripts of both were written in Sanskrit, the text that were referenced for this thesis were the translated versions, *Mayamatam* which was the 3rd edition and was translated to English by Bruno Dagens in 2000 and *Vishwakarma Prakash* that was translated to Hindi by Eng. Acharya Shivprasad Varma in 2011. For this thesis only two of these texts have been selected as the core concepts are significantly established by these selected pieces. They both capture the diversity of the social, cultural and climatic differences seen in the application of *Vaastushastra* principles in the North and South of India.

2.2.3. Core principles of *Vaastushastra*

Vaastushastra deals with all aspects of architecture, from urban design to buildings planning, construction and furniture design (Ananth, 1998). The core aspects of this theory are, *Panch Maha Bhutas* (5 elements), *Vaastu Purush Mandala* (Cosmic Grid), *Shad Varga* formulae and use of materials (Ananth, 1998) (Bubbar, 2005) (Chakrabarti, 1998) (Craze, 2001). These aspects are interlinked and therefore should not be examined in isolation. All these topics are discussed in all the ancient manuscripts, each manuscript provides different levels of details for each topic. The manuscripts simply list the rules that the

[6] The *Ramayana* and *Mahabharata* were both ancient Indian heroes' tales that continue to be a predominant part of Hinduism and were both written in the traditional language of Sanskrit.

architect should follow and do not provide any explanation for it. There are many contemporary architects and researchers who are investigating plausible scientific reasoning behind these rules and their views and findings are discussed later in this chapter.

2.2.4 *Panch Maha Bhutas* and their connection to the senses

The *Panch Maha Bhutas* (5 elements) are *aakasha* or space, *vayu* or wind, *agni* or fire, *jal* or water and *printhvi* or earth. The explanation provided is based on traditional Indian scriptures and isn't supported by current scientific rationale but forms the fundaments of understanding the theory.

Aakasha or space – this element incorporates all the cosmic energies such as gravitational forces, magnetic fields and heat and light waves. Its main characteristic is known as *shabd* which could be translated as 'sound'.

Vayu or wind – this element is the atmosphere around us, what causes movement and what transmits *prana*- universal breath. Its main characteristic is *sparsh* - touch.

Agni or fire – this element represents the heat and light of the fires, lighting and volcanoes, as well as the heat of fevers, energy, passion and vigour. Its main characteristic is sight.

Jala or water- this element represents everything liquid, rain, rivers, the sea, as well as steam and clouds. It also represents all living plant material and its main characteristic is ras - taste.

Prithvi or earth- this element represents all solid matter, as well as everything we stand on – the Earth itself. It is also the element of *gandh*- smell. (Craze, 2001, p. 44)

Element	Sense	Architectural feature
Space (ether)	Sound	Auditory
Air	Touch	Tactile
Fire	Sight	Visual
Earth	Smell	Atmospheric (partially)
Water	Taste	

Table 2.2- Elements of *Vaastushastra*, the senses of human body and link to architecture

According to Hinduism the human body and the universe are made of these 5 elements (Vir Singh, 2005). Therefore, it is suggested that the subconscious mind connects to the balance or imbalance of these 5 elements in the built space. Each of these elements connects with one of the 5 senses – space connects with sound, air connects with touch, fire connects with sight, water connects with taste and earth connects with smell (Pegrum, 2000). Table 2.2 above lists the possible connections between the elements, sensory organs and architectural features. This shows that taste is the only sense that doesn't directly connect with any architectural feature. Therefore, this thesis will attempt to evaluate the comfort levels of the four senses and if evaluate if these help users feel comfortable in residential spaces that follow the rules of *Vaastushastra*.

2.2.5 Vaastu Purush Mandala (Cosmic Grid)

There is a mythological story behind the creation of the '*Vastu Purusha Mandala'* which relates to *Shiva*[7] who was in battle with a demon named "*Andhikasur*" (Thirumalachar, 1998). During the battle, *Shiva* began to sweat, and from his exertions, a man was born who helped *Shiva* win the battle and therefore was granted a "boon"[8] that he could devour all the

[7] In Hindu mythology, the holy trinity comprises *Bramha*, *Vishnu* and *Shiva*, of which *Bramha* is the creator, *Vishnu* is the one who sustains, and *Shiva* is the destroyer of the Universe.
[8] A devotee will worship any one of the holy trinity to try and appease them, upon which the devotee's wish is granted, that is, a boon.

three worlds (Earth, Heaven and Hell). When the other gods and goddesses found out, they were terrified that this man could attack all the gods and goddesses and cause complete chaos. The 45 deities pinned this man (*Purusha*) to the ground, by sitting on his back. Since this demon was created to consume the worlds, he had a tremendous appetite. After surrendering to the deities, the *Purusha* asked what he could feed on, as his appetite was not satisfied. The deities then said that he would be known as "*Vastu Purusha*" and he was free to devour or irritate those people who did not follow the rules of *Vaastushastra* in construction of the built environment[9]. This story is mythological but that does not however diminish the value of the meanings of the *Vaastushastra*. Its basic aspects possibly appear to have a greater meaning and value in everyday life to the extent that people practice the *Shastra* in order to benefit from its potential values in organizing spaces.

The above mentioned five elements (*Panch Maha Bhutas*) are placed onto a grid of 3x3 squares which is an example of the *Vastu Prush Mandala* Fig.2.1 (Bubbar, 2005). This grid constitutes of three components, *Vastu*, *Purusha*, and *Mandala* that mirror the threefold nature of existence in terms of mind, body and spirit (Pegrum, 2000). There are 32 types of *Mandalas* ranging from a single site/plot to a combination of 100 sites/plots on a grid. For the purpose of this thesis the (3x3) *Mandala* is the only one that will be discussed. This is a simplified grid that shows the locations of the elements on the grid. The elaborate 81 grid shows each square representing divine forces, demonic forces, animals, plants and other qualities/ adjectives (Op. cit). "The names of the forces or the processes involved in the evolution of the spatio-temporal cosmos are the *Devas* or *Devtas* (wrongly translated as gods because they are not personified)" (Bhatt, 1979). The principles behind all the grids

[9] This is a mythology that explains the existence of the demon that will bring misfortune to your family if the rules of *Vaastushastra* are not followed.

mentioned are the same; there is a specific corner of the grid allocated to each element. Fig. 2.1 below shows how the *Mandala* represents the five elements of nature, which can be used to the advantage of creating positive spaces. The element mentioned in each intermediate corner is supposed to represent how the occupants of the space may feel or how the functions of the house might be allocated. There is no explanation behind the placement of these elements given in the ancient text, but the author has tried to work out an explanation through this thesis.

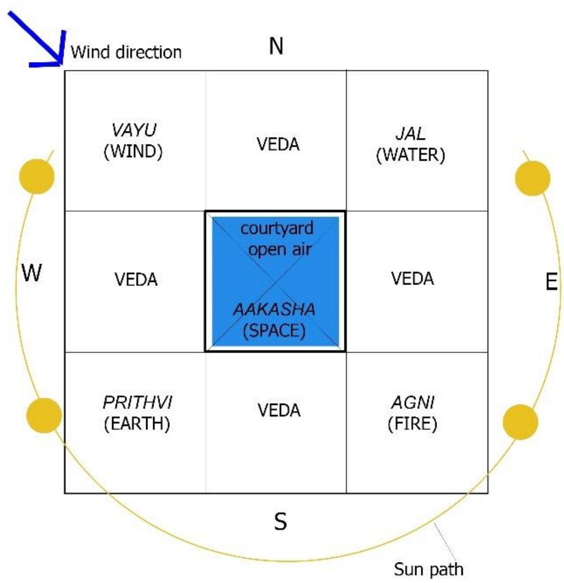

Figure 2.1- 3X3 Mandala with the 5 elements

Northeast corner is associated with water; therefore, the water features of the house can only be placed in this corner. The possible explanation could be that water feature placed in this corner would be outdoors and mainly exposed to the early morning sun when UV rays are the least and the sunlight is beneficial for people. This doesn't mean that water can't be placed in other corners such as the southwest or other northwest, the optimal direction for placing water is the northeast. Due to the combination of water and early morning sun, the northeast space is suggested for prayers (which usually happen at sunrise) or any similar activity that occurs in the morning (Chakrabarti, 1998).

Southeast is the fire corner this is possibly because it is exposed to maximum heat gain. It can be argued that the south side (both southeast and southwest) are equally exposed heat gain so why is the south east associated with fire? This thesis will test if there is a noticeable difference in the temperatures recorded in both southeast and southwest sides. Since it is the fire corner it is said to be the best place to locate the kitchen as it is the warmest location of the house. The southeast corner can be used for other purposes, but since it could be the warmest space of the house it is best suited for the kitchen (Pegrum, 2000).

Southwest is considered to be associated with the earth element. It is difficult to establish a link between the element and the direction in this case. Traditionally this corner is supposed to have minimal or no windows and is physically associated with heavy weight. The reason for the weight association could be because it is linked with the earth element which is a heavy material. Since the southwest direction is exposed to the setting sun it can make the internal space significantly warmer, which is the possible reason for minimal, small windows or no windows on the walls. An alternative way in which windows can be provided on this side is if these are overhangs or other similar methods which avoid heat gain (Bubbar, 2005).

Northwest is the wind corner because it is the predominant wind direction in many parts of India, especially in Rajasthan since it is the selected city for this thesis. This is an example of the element reflecting the physical environmental condition of wind direction. The house should be designed so that this side should allow for wind circulation by either placing adequate windows or by ensuring that air circulation can be achieved through placement of opening throughout the building. The sun has least impact on the North (west and east) sides which is a possible reason for the space to be linked with the wind element (Ananth, 1998).

Central space is associated with the element ether or space. The thought behind placing the element of space in the middle of the house is so that the centre is kept empty. In a house which is of an average size and larger the empty space means that this central location should be a courtyard. Based on the proportion of the site and the way in which the architect wants to include the courtyard its specific location can be altered. In a house that is smaller and doesn't allow for a courtyard, it means that the central space should be free of any structural column or wall (Craze, 2001).

After understanding the *Vastu Purusha Mandala* and the elements that link with it there is a possible reasoning behind the allocation of spaces based on the association with the elements. Table 2.3 shows the connection between the intermediate direction, element and the suggested function of the space and a possible connection with users' comfort

Direction	Element	Function	Suggested time of use	Users' Comfort
Northeast	Water	Meditation	Early Morning	Adequate natural light and comfortable temperature
Southeast	Fire	Kitchen	Mid-Morning	Warmest space in the house therefore used for kitchen
Southwest	Earth	Master bedroom	Night	Cooler space since minimum windows are located here
Northwest	Wind	Bathroom	Various times	Wind direction allows for natural ventilation
Centre	Space	Courtyard/ empty		Allows for natural light and ventilation in the space.

Table 2.3- Elements of *Vaastushastra*, the link to direction and function and comfort

Since the northeast corner is associated with the water element the ideal function of the space should be a meditative space, or a prayer space (Ananth, 1998). Similarly, the southeast is linked with the fire element and the ideal functional use is the kitchen (Chakrabarti, 1998). The southwest corner relates to earth and therefore suggested functional use is the master bedroom (Craze, 2001). The northwest is connected with wind element and the functional use suggested is the bathroom and lastly the central space is connected with space and therefore should be used as a courtyard or an empty space (Bubbar, 2005). These are the ideal functional uses for each of these spaces, but it doesn't mean that these are the only functional uses of the spaces. For example, the kitchen could be placed in the Northeast corner in a house where the occupants consider food to be a very important function of the house. The functional use of these spaces can change based on the preferences of the occupants of the house (op. cit.). Relocating the functions of the house is based on the importance the function has for the user or based on the time of the day when the occupant is likely to use the space. Any function of the house that occurs during daylight hours should be located where there is ample natural daylight, for example if the food is prepared during day light hours it should be placed where there is ample day light available (Whelan, 2002).

After reading all the above-mentioned manuscripts and contemporary text, the authors understanding of this is as follows. Any function that is carried out in the northeast corner should be based quality of light that is available at that time of the day. When these texts were written people relied mainly on natural day light and started their day at dawn and ended their day soon after dusk as there were minimal artificial light sources available. The functions of the house were laid out around the house to follow the suns path and the kitchen was placed in the southeast corner which was the warmest space within the house. Even though the southwest corner receives a lot of sun it is mentioned as a bedroom space because it is recommended that this corner of the house has minimal or no windows which will support the function of sleep. The northwest space is not the only location to place the bathroom, but it suggested as it allows for any unpleasant odours to escape the house especially when mechanical systems of exhaust didn't exist.

2.2.6 Orientation and grids (Mandalas)

It is important to know the orientation of the site whether it is for planning a town, village or a building so that the grid (*mandala*) can be applied the right way around. A square piece of land which is six feet (one pole)[10] in dimensions is marked out in the middle of the plot. The gnomon which off specific dimensions[11] is placed at the centre of this square piece of land around which a circle is drawn of which the diameter is double the length of the gnomon. The shadows cast in the mid-morning and mid-afternoon (marks A and B) are marked on the circle from which the east- west axis is determined; arcs are drawn from these points to determine the north- south axis Figure 2 (Dashiell, 2014). Since the compass is readily available to us to determine the cardinal points, it has replaced this procedure. Orientation is important because of the use of the *Mandala* (grid) system as each grid is designed for a specific orientation which is the ideal direction (Dagens, 1994) (Acharya, 1934).

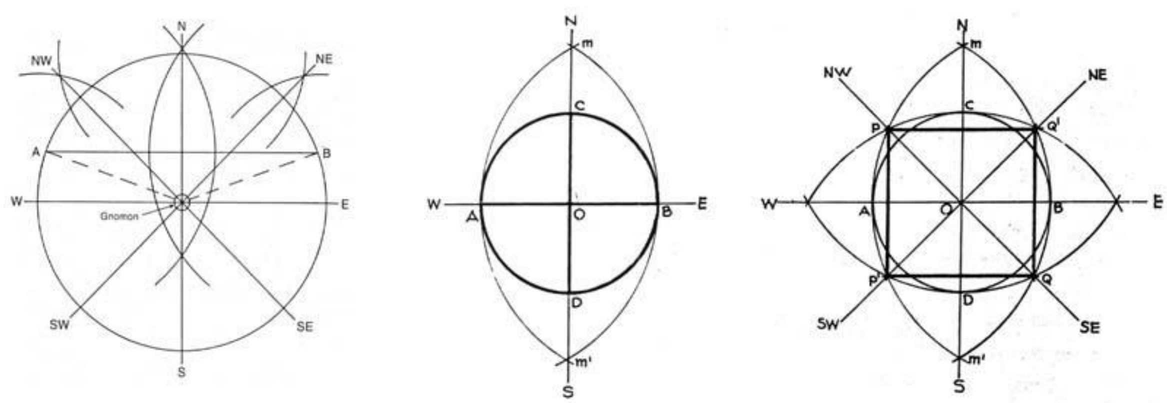

Figure 2.2- Traditional method of determining orientation *(Dagens, 1994)*

[10] The units mentioned in the original text have been converted to feet and inches, the original dimensions are mentioned in Fig. 2

[11] It is one and a half feet (one cubit) in length, has a diameter of ¾" at the top (one digit) and 3 and ¾" at the bottom (five digits), with different sizes for medium and small gnomons specified (Dagens, 2000, p. 29)

Traditional unit of measurement	Conversion unit	Feet and inches
8 grains	1 *Angula* or digit	¾ inch
12 *Angulas*	1 *Vitasti* or span of hand	9 inches
2 *Vitasti*	1 *Hasta* or forearm	18 inches
4 *Hasta*	I *Danda* or pole	6 feet
2000 *Danda*	1 *Kosha*	12,000 feet
2 *Kosha*	1 *Gavyuti*	24,000 feet
Gavyuti	1 *Yojana*	48,000 feet
100,000 *Yojana*		Earth

Table 2.4- Conversion from traditional units to feet and inches

Mandala provides a basic grid which used for planning and is scalable ranging from building to village up to towns (Dagens, 1994). The most popular form of a *mandala* is square grid which is consists of 9 squares laid in 3x3 and is most commonly used (Chakrabarti, 1998). Other forms used are rectangular, triangular or circular from which the latter two are less frequently used. There is a total of 32 different *mandalas* and each grid is used as an underlying geometric shape for the plan of a particular building based on its end use (Bubbar, 2005). For example, one grid could be used as a base for temple, residential and educational which another grid might be used only for temple design. Each *mandala* is a line drawing that has a prescribed minimum and maximum dimension in two dimensions, along with values at which these proportions can be increased (Chakrabarti, 1998).

2.2.7 *Shadvarga* formulae

The word *Shadvarga* translates to six-fold division and refer to a group of six proportions or six formulae which are used at the design stage when the volume of the house is created.

The most important factor is perimeter of the building, i.e., the length and the breadth of the site must be in harmony with each other. The *Shadvarga* formulae are a series of simple calculations that use the length, width or perimeter of the plot to calculate whether the site is auspicious or inauspicious. When these rules were written, most people would comply with the rules without questioning them (Chakrabarti, 2000).

Based on the location of the site, the formulae are modified to accommodate the variations in climate conditions. Similar to the *Shadvarga* formulae is the *ayadi/ aya* formulae, which have different equations are used to calculate different aspects of the site. The names of the six formulae each describe which aspect of the site it will calculate. The description of each formula is provided in brackets in English after the Sanskrit name which are as follows *Aya*, (gains), *Vyaya* (losses), *Nakshatra* (asterisms) *Yoni* (matrices), *Vara* (solar days) and *Tithi* (lunar days) (Acharya, 1934). The results of these calculations should be within a specified range of numbers otherwise the measurements of the site are considered inauspicious. If the measurements don't give the desired outcomes by using the formulae, the perimeter size is adjusted so that desired outcomes would be achieved (Dagens, 1994).

The scientific explanation behind the purpose of these formulae has not been documented anywhere. Therefore, further research is required to find a scientific explanation about what is meant by gains, losses and so on that the formulae are titled.

> The most common way of determining Aya is as follows: first calculate the area of the site, using *Hasta* or *Danda* as the unit of measurement, and rounding off to the nearest whole number; then divide the sum by eight. Eight represents the main directions (east, south-east, south, south-west,west, north-west, north, and north-east). The key result is the remainder of the calculation, for it is the remainder that detects the directional propensity of the considered space. (Chakrabarti, 2000)

These formulae are used to calculate the ideal site proportions which in the authors opinion connect with the five core elements. The author's understanding is that these calculations were stipulated in the rules because they create guidelines for the proportions of the site. These guidelines underpin the proportions recommended for the site without having to specify every single combination.

This thesis will try to understand the connections between the preferred proportions and the impact these have on the comfort of the users of space. This formulae and proportions aspect of *Vaastushastra* is concerned with orientation through principles that prescribe the correct placement of rooms and functions in relation to each other and to the eight major directions (the four cardinal and the four intermediary directions). Based on these principles the orientation emphasises auspicious location through good and bad effects, which are derived from the various associations of the eight directions (Chakrabarti 2000, p.45)

2.2.8 Selection of materials

The choice of materials is another essential part of *Vaastushastra* (Pegrum, 2000). The main resources used for construction are described in the texts as timber, stone and bricks. There is also an acceptance of the importance of knowledge of other popular materials that might have been used. Earlier, buildings were built with natural materials (Ananth, 1998). A typical building had thirty to forty percent organic materials, derived from vegetation, like wood, straw, leaves. The other materials were inorganic, derived from the earth like loam, brick, stone and lime (Bubbar, 2005, p.113). The materials used in a project were most likely to be sourced locally rather than for other cities. This meant that the stone or timber or brick had properties that suited the local climate (Dagens, 1994). The materials that are suggested in *Vaastushastra* change based on the region the text is written for. For the northern regions materials that protect the inside space from the outside cold temperatures are used such as brick and stone. The southern regions use a combination of stone, timer and palm leaves (Chakrabarti, 1998).

The materials mentioned in the text could be limited because there were limited options available. With advances in technology many new materials have been developed which have enhanced build environments as we can build structures that are taller, wider and more dynamic. A strong contrast is seen between traditional buildings and modern buildings in numerous ways, one of which is the internal temperatures. Many parts of traditional buildings maintain comfortable internal temperatures for some time of the year. The properties of the natural materials helped in maintaining the internal temperatures at comfortable levels. The thickness of the natural material helped prevent rapid heat gain or heat loss from the internal spaces (Nicol, et al., 2012). The impact the use of materials has on the comfort levels of the internal spaces will be measured in this thesis.

2.2.9 Superstition verses Plausible Scientific Explanation

As mentioned earlier there are numerous original *Vaastushastra* manuscripts. These manuscripts have one aspect in common which is that the rules in each manuscript are very descriptive rather than prescriptive which leaves them open to interpretation by the reader but does not provide any reasoning behind the rules. For example, a verse from *Mayamatam* states–

> "If water falls on the wall around (the house) this brings ruin to the family and, consequently, the edge of the roof (of the house) is not to abut onto this (wall) for, if that should happen, then all chance of success if spoiled, no matter for what class the house is intended." (Dagens, 1994)

The above statement is an example of a rule stated in *Mayamatam* (chapter 27 verse 125b-126) which does not provide any reasoning but only states that there will be no chance of success if it is not followed. The era in which most of these manuscripts were written was when most people where happy to abide by rules and regulations that were stated by people with religious authority which included religious *guru,* priest who quoted original text of the *Vedas*. Since this was an era without science as it is known today, it's questions or it's evidence based understanding, it is assumed that the common person either did not question their faith or did not seek these answers possibly because of the lack of basic knowledge. The word "*shastra"* loosely translates to science but is not used in the same context that it is used in today.

If we examine the rule stated above, there can be a couple of interpretations of what is meant by "wall around (the house)" could be the exterior wall of the house or the compound wall of the house. At the time this was written there was probably very little available in terms of water-proofing the house. This means that if water would fall on the wall directly or from the roof it would most likely damage the wall of the house and therefore the house and eventually cause trouble for its occupants as a result there would be no success for them. It is now a given that every building incorporates water proofing as the damage caused by lack of it is known to most and can be explained through science (Similar to the example given by Dr. Atuchan in Appendix).

2.2.10 Site selection based on principles of *Vaastushastra*

The above points describe the basic vocabulary of *Vaastushastra.* The core aspects of designing homes will be discussed in this part of the chapter. When the architect starts to design a home, the selection of the site is the first aspect that needs to be checked (Dagens,

1994) (Acharya, 1934) (Chakrabarti, 1998). The criteria for selecting the site are – colour, odour, flavour, form, orientation, sound and tactility. Based on the caste that the user belongs to, there are different criteria that the architect will check for selecting the site (op. cit.). Based on all the descriptions provided in the various *Vaastushastra* manuscripts table 2.7 has been developed by the author which produced a snapshot of all the different criteria specified. Table 2.5 below has many characteristics most of which are outdated today and only few can be considered significant.

The manuscripts of *Vaastushastra* provide the colour and odour, amongst other aspects, when they list the specifications of dwelling site for each caste (op. cit.). These texts were written before science as it is known today existed, therefore the text could not mention chemical composition, formula or names of the composition that should be available in specific sites.

It is the authors interpretation that the specification of colour could link to the chemical composition or names of the chemicals that should be present in sites based on the end user and their needs at time these written. Caste system is formally abolished in India which makes this an outdated aspect.

The trees were suggested based on the composition of the soil and the local climate conditions. This is a principle that needs to be adapted for local climates where it is applied. A natural slope to the site is preferred in India as most cities have natural rain therefore draining the water naturally is helpful. Slope on the site can be adapted based on the local climatic conditions. Basic form and proportion of the site are important factors that should be followed in contemporary residential designs because the site proportions usually dictate the building proportions.

Color	Flavor	Suggested Mineral	Formula	Site Suitable for	Tree that can be planted[12]	Site should slope towards	Basic Form/ shape of site	Length to Width ratio[13]	Result of such a site
Yellow	Sour	Goethite	FeOOH	vaisya	plaksa	East	rectangle	length is 1/6 more than width	beneficent
Strong Brown	Sour	Goethite	FeOOH	vaisya	plaksa	East	rectangle	length is 1/6 more than width	beneficent
Red	Bitter	Hematite	Fe2O3	king	asvattha	East	rectangle	length is 1/8 more than width	success
Red	Bitter	Hematite	Fe2O3	king	asvattha	East	rectangle	length is 1/8 more than width	success
Red	Bitter	Lepidocrocite	FeOOH	king	asvattha	East	rectangle	length is 1/8 more than width	success
Dark Red	Bitter	Ferrihydrite	Fe (OH)3	king	asvattha	East	rectangle	length is 1/8 more than width	success
Black	Pungent	Iron sulfide	FeS	sudra	nyagrodha	East	rectangle	length is 1/4 more than width	riches and gain
Black (metallic)	Pungent	Pyrite	FeS2	sudra	nyagrodha	East	rectangle	length is 1/4 more than width	riches and gain
Pale Yellow	Sour	Jarosite	K Fe3 (OH)6 (SO4)2	vaisya	plaksa	East	rectangle	length is 1/6 more than width	beneficent
Black	Pungent	Todorokite	MnO4	sudra	nyagrodha	East	rectangle	length is 1/4 more than width	riches and gain
Black	Pungent	Humus		sudra	nyagrodha	East	rectangle	length is 1/4 more than width	riches and gain
White	astringent and sweet	Calcite	CaCO3	brahmins	udumbra	North	square	length is equal to width	good fortune
White	astringent and sweet	Dolomite	CaMg (CO3)2	brahmins	udumbra	North	square	length is equal to width	good fortune
Very Pale brown	Sour	Gypsum	CaSO4× 2H2O	vaisya	plaksa	East	rectangle	length is 1/6 more than width	beneficent

Table 2.5- Site selection criteria *(Karani, 2012)*

[12] These are Indian names of the trees as specified in the original manuscripts.
[13] Links to the Aya formulas as these establish the orientation of the building, courtyard size and location, opening sizes and location and so on.

2.2.11 Planning the layout of houses

Once the site is selected there are many prescriptive procedures about creating the foundation of the building, laying the plinth and the base of the building (Sabharathnam, 1998). These describe methods that are similar to rule of thumb of structural calculations which are currently carried out with greater precision. The foundation deposits prescribed by *Vaastushastra* also mentioned that precious and non-precious items should be laid in them (Acharya, 1934) (Dagens, 1994). The text prescribes these deposits as ways to appease the gods and goddesses which is based on faith and therefore outside the scope of current scientific explanation.

The house and its design are detailed in all the various text of *Vaastushastra*. The rules begin with the layout of all the buildings on the site because the site can be small enough to accommodate one building or large enough to accommodate up to ten built structures (Chakrabarti, 1998). Overall planning of the buildings does not mention direction; however, it is understood that the directions recommended for the site are followed through. The author of this thesis agrees that directions are an important aspect of *Vaastushastra,* but the importance is in terms of connections with elements of nature such as light, water, wind and air which will be tested in thesis. Another correlation of the elements is with the supernatural aspects it is associate with, which is not considered in this thesis.

The house is first classified into number of buildings it can comprise which are one, two, three, four, seven or ten main buildings (*sala*[14]). In concept a house with these building would look like Fig. 2.3

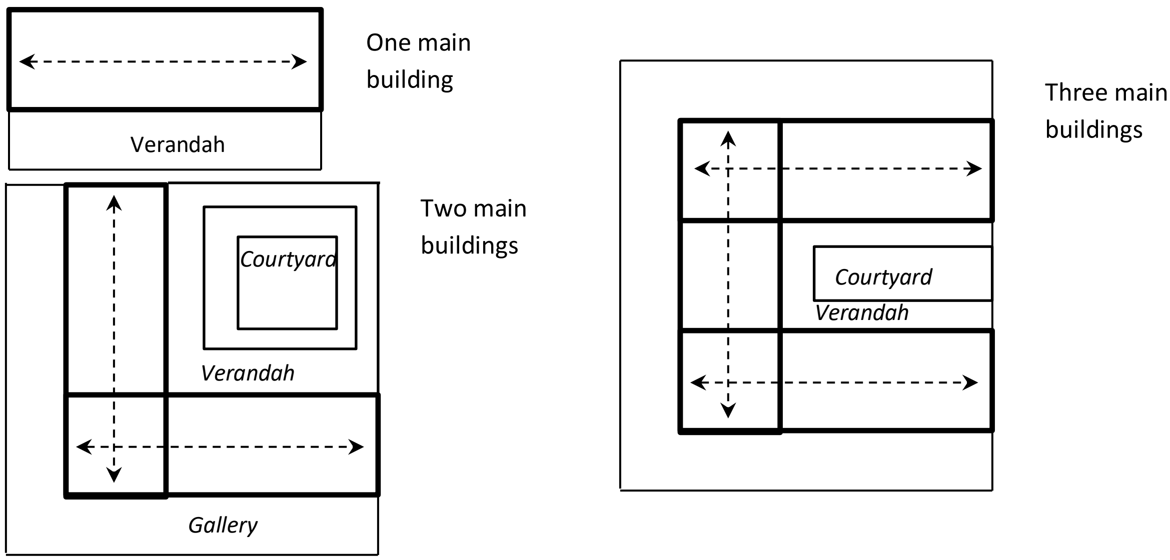

Figure 2.3 -Basic blocks for residences (Acharya, 1934)

[14] A detailed description of what a building can comprise off is given in *Manasara* Series No: 1- A Dictionary of Hindu Architecture pp. 580- 587. In general it refers to a hall, a room, an apartment, a house, a stable and a stall.

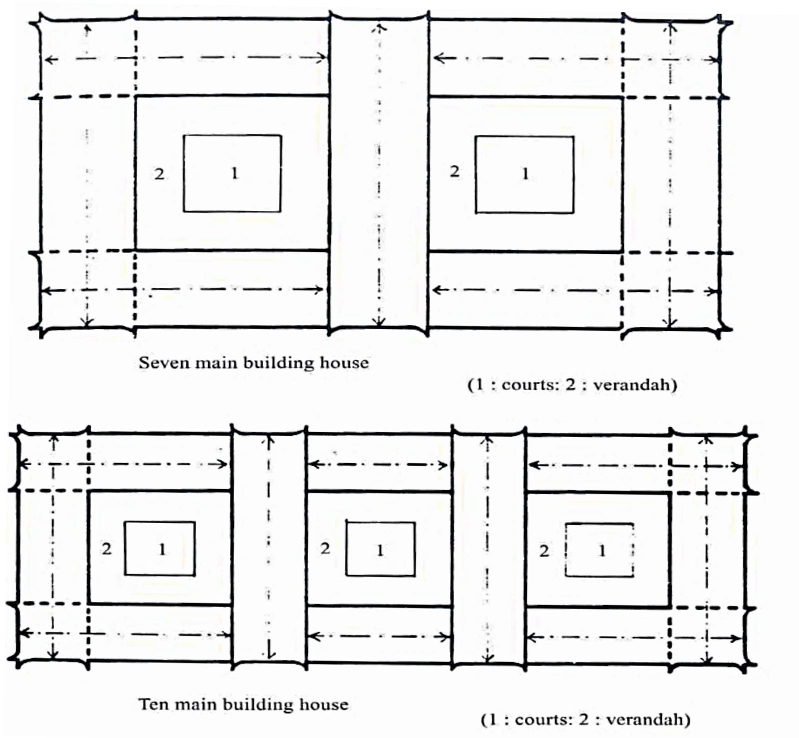

Figure 2.4- Basic design of larger residences (Acharya, 1934)

The above diagrams are conceptual in terms of planning the main buildings[15] (built forms) and the verandas and courtyards (voids) fig 2.4. The application of them will vary based on the site and the use of the building and therefore the buildings that are constructed based on *Vaastushastra* look different from each other. The dimensions of these buildings are specified in *Mayamatam* which states the minimum and maximum dimension and how to calculate the variations in between (Chakrabarti, 2000). Based on the calculations of the site and the *Aya* formula, the architect can calculate the dimensions of each building (Bubbar, 2005).

The heights of the buildings are also specified in the text with the maximum mentioned height of 12 floors (op. cit.). All the dimensions of the buildings are also specified based on the caste system, which is probably linked to the affordability of building the house based on the income of the earning member, typically male (Chakrabarti, 1998). The links to the caste system is

[15] More examples of these diagrams are shown in the introduction chapter of *Mayamatam* Vol. I

considered outdated as it has no established link with the architecture other than affordability. The height is suggested in relation to the length and width of the plan (Sabharathnam, 1998). The author's understanding of this is that it the volume of the space should be proportionate with reference to the site and human scale. The elevations that are given in *Manasara*, *Vishwakarma Prakash* and *Mayamatam* support the understanding of proportion. All three also mention specifically where the doors should and should not be placed, the reasoning behind this is that good fortune will fall upon you if you follow the rules and if you do not follow them you will be faced with misfortune (Acharya, 1934) (Dagens, 1994).

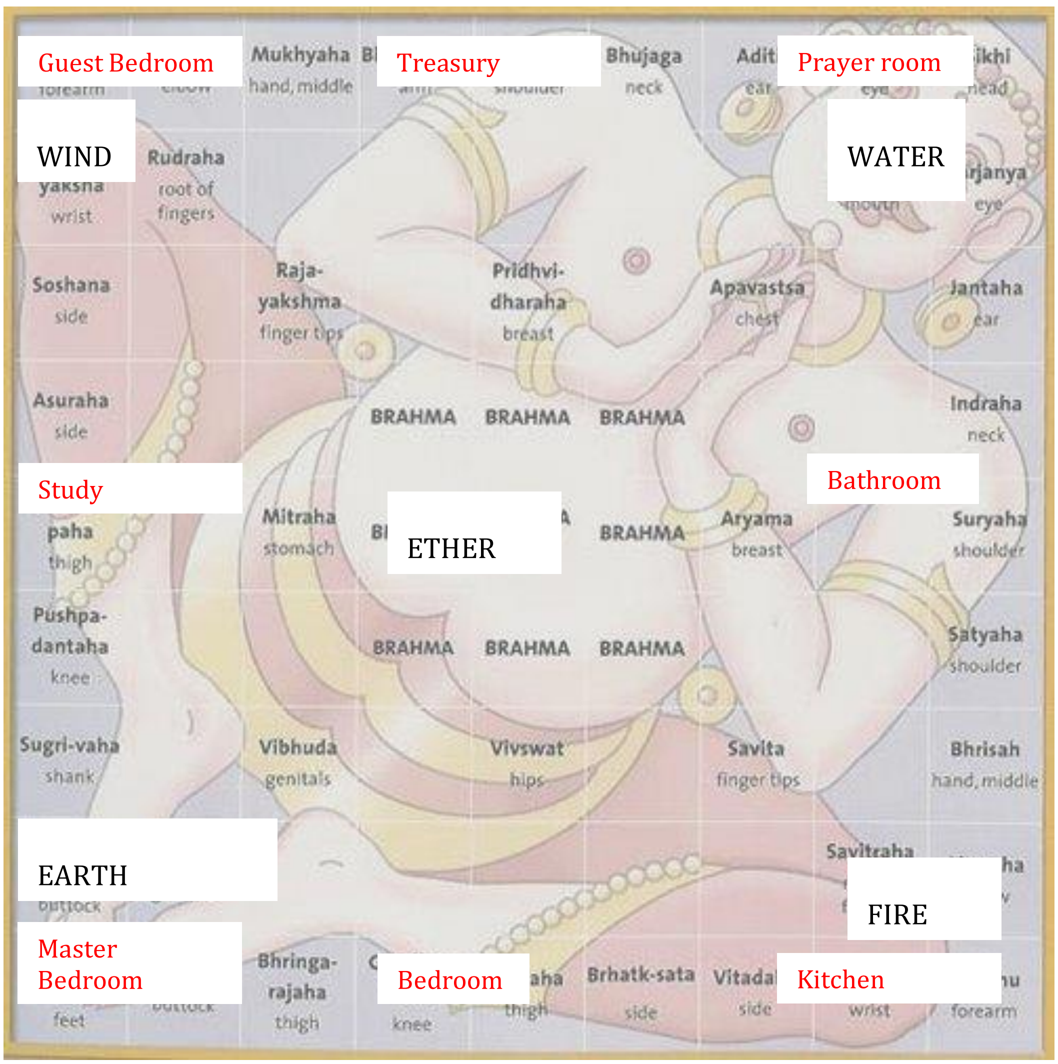

Figure 2.5- Elements and room locations on Mandala (Pegrum, 2000)

The internal layouts of the house are also specified in *Vaastushastra*, these are the most popular and well-known aspects of *Vaastushastra*. Figure 2.5 shows the relationship between the elements, deities of the *mandala*, the directions and allocation of rooms (Pegrum, 2000) (Chakrabarti, 1998) (Craze, 2001). The deities of the *mandala* create superstition in *Vaastushastra,* and the common understanding is that if you place things under the appropriate deity it will be successful.

The elements and architectural features connect the building with its surroundings. The north and north-east side of the building should have maximum number of openings to allow for natural light and for ventilation, especially in relation with the central courtyard. The south side should have minimum openings as it keeps out the solar heat gain (Bubbar, 2005). The building is oriented based on the geographic location of the house (Chakrabarti, 1998). All the buildings of the site should allow for verandas and courtyards which allow for natural ventilation.

2.2.12 Traditional and Contemporary Examples of *Vaastushastra*

Many cities in India were laid out on the basic grid of *Vaastushastra*, such as Chandigarh and Jaipur (Patra 2009, Chakrabarti 1998). In the master plan of Chandigarh, the following features link with *Vaastushastra* – capital complex, where the government buildings are located symbolizes the head since the government buildings are the metaphorical head of a city in the northeast. Similarly, Punjab University represents education and therefore is in the north. Sukhna Lake occupies the east/ north east corner which is an example of a water element located in the north east and east region. The city centre occupies the heart or the physical centre of the city which is usually left with open with landscape elements which helps with air circulation and acts a control for the city's urban density. The creation ground is placed in the Northwest;

industrial zone is located in the southeast and the southwest, south and west zones are for living purposes which links to the earth element which is nurtures growth (Patra, 2009). In the planning of a building or a city, the most important considerations is that two dimensions, i.e., the length and the breadth must be in harmony and must belong to each other, which allows the space contained in them would be harmonious (Bubbar, 2005).

In the ancient times the first step in designing the house was to identify the architectural team, which constituted of four experts who were *Sthapati* or master builder or architect*, Sutragin* or surveyor is the son or disciple of *Sthapati , Takshaka* carpenter or sculptor *and Vardhaki* expert at painting and helps the *Takshaka* (Acharya, 1934) (Dagens, 1994). Once the team was in place the site was selected through a rigorous check for matching the guidelines that examine the size, shape, sound, taste, colour, smell, vegetation and topographical features which shows that the site can be used to build a home. The orientation of the site is determined after which the appropriate *Mandala* was identified after which the *Vastu Purusha Mandala* was laid on top of the established grid (Nathan, 2015). The house is built around a central open space, ruled by *Bramha*, as depicted on the *Mandala* (Achari, 2016). Each side of the square courtyard holds one wing of the house which is known as the main building. Depending on the scale of the house, additional grids are added to make it seven or ten main building house (Chakrabarti, 1998). An example of the seven-range house which shows the length, width and verandas that use the prescribed proportions described in the text (Figure 2.6).

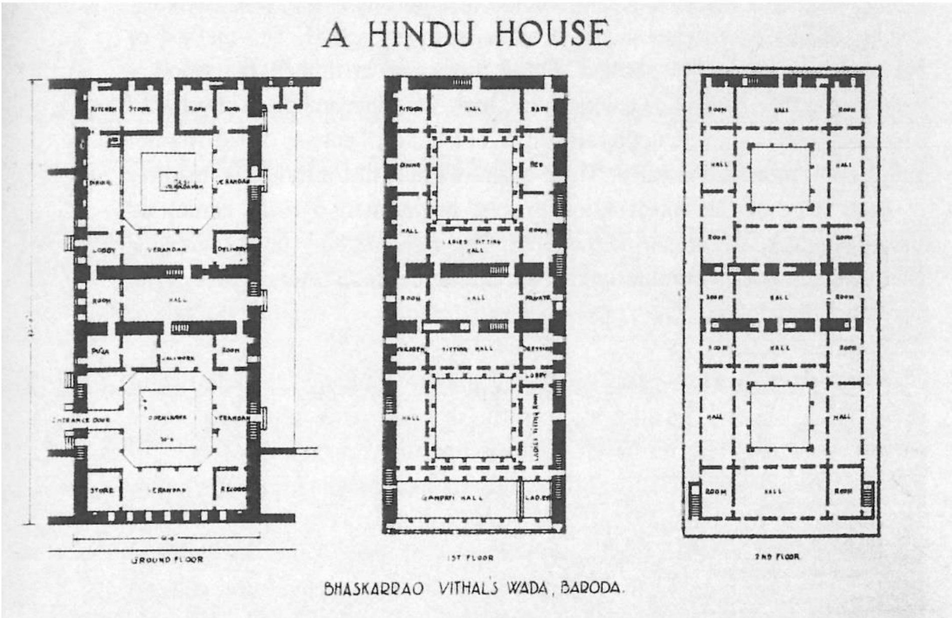

Figure 2.6- A seven range house with two courtyards (Batley cited in Chakrabarti, 1998)

The *Mandala*s also provide detailed instructions regarding individual houses which specifies details about planning of the house, location of the courtyards, placement of doors, windows, furniture and other household items. (Nathan, 2002). *Vaastushastra* connects orientation with the correct placement of rooms and functions in relation to each other and to the eight major directions (the four cardinal and the four intermediary directions). The orientation principles emphasise auspicious location, which are thought to have good and bad effects for functions that are in them are derived through the associations of the eight directions (Chakrabarti, 2000). The functions of the house would be placed in various directions based on the lifestyle of the family as discussed in 2.2.4. Those functions that would be carried out during the early morning would be placed so that there would be access to natural daylight. Therefore, if the family would cook its meals early in the morning the kitchen would be placed in the northeast corner. Also, if the family thought the function of eating was important the kitchen would be placed in northeast corner.

Mandala grid is associated with the *Vaastu Purusha* Fig.2.5 and is figuratively linked with the human form known as the *Purusha* in Hindi (Nathan, 2015). Regardless of the scale at which the *mandala* is used it always represents the human form. The activates are therefore laid out accordingly. Whether it is used to plan a city, village or individual house the *mandala* represents the body parts and the *marmasthan* (vital points). The main function of house or village is placed at the head which is the northeast region. Similarly, the centre is known as the heart, even though biologically the centre of the human body is the stomach, in this case it is referred to as the heart. The central space is metaphorically the heart and is suggested to be left open or free from structural loads such as columns and load bearing walls (Thirumalachar, 1998).

Although the various texts on *Vaastushastra* are similar in the in terms of basic layout of the building, the application to different regions dictates variation according to the region to which it is applied. The regional variation occurs in terms of incorporating the physical form determinants like climatic, topographical and cultural parameters could be compared to show how *Vastu Purusha Manadala*, the basic design grid, for instance, presents two different solutions suitable for each region (Chakrabarti, 1998). A house that is built in Rajasthan (Fig 2.7) is built to suit the hot and arid climate and the house in Kerala (Fig 2.8) is built for wet and humid climate (op. cit.). The house built for Rajasthan is rectangular and the is longer in the east to west axis and shorter in the north to west axis. This aspect helps prevent heat gain in hot climates, based on the sun angle especially during the summer months. Rooms are placed around the courtyard of the house and the same proportions are maintained for all the rooms. Larger rooms are a multiple of the base square which is then added on in one direction (length or width). Proportions of the courtyard are similar to the overall house; both are rectangular in shape and length and width proportions are maintained. The house designed for Kerala is square in geometry as the climate is wet and humid. The main courtyard is square which is proportionate to the overall square of the house. Since the weather is tropical the key feature of the house is the pitch roof which provides overhangs around the house. Rooms in this plan are based on a square in geometry and are an extension of the room in one direction only. These examples show the same rules of *Vaastushastra* can be applied differently to accommodate different requirements of the region and the users.

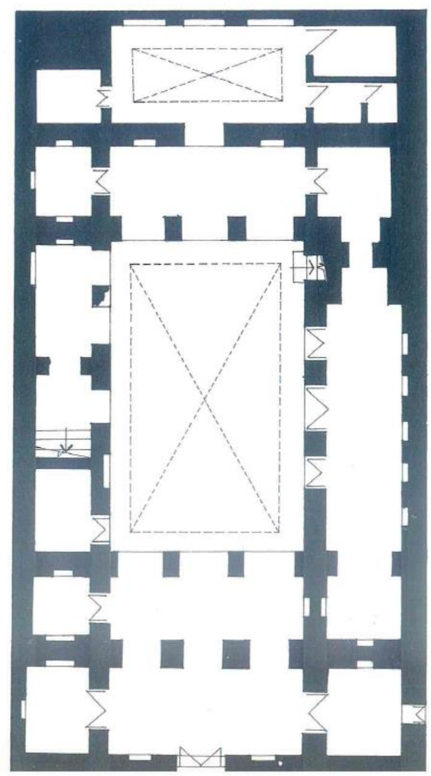

Figure 2.7- A Haveli in Rajasthan (Chakrabarti, 1998)

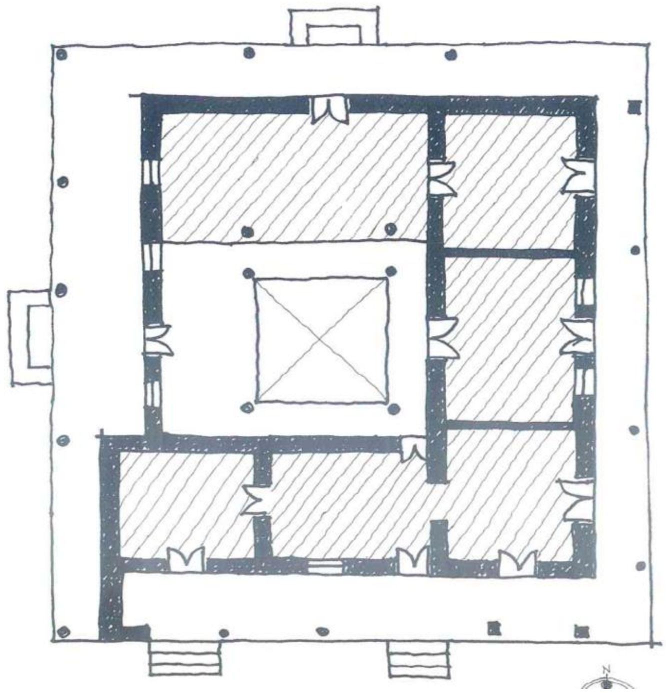

Figure 2.8- A house in Kerala (Chakrabarti, 1998)

Following are some unconventional applications of the principles of Vaastushastra and the *Vastu Purush Mandala* grid. First is the creative application of the 3x3 *Mandala* on the IIT campus in Bombay (Fig. 2.9) and the final plans (Fig. 2.10). The plan of the campus is based on the 3x3 grid in which the grid is pulled apart and creatively placed back together. Three stages of the plan are shown in Fig.2.9 which show how an architect can use the *mandala* in a creative and unique manner (Chakrabarti, 1998).

In the example of IIT campus it is important to understand which of the original characteristics are maintained in the contemporary application of the *mandala*. The orientation of the plan is the along the north- south axis which is one of the traditional characters. The rooms on the right side of the plan do not conform to the orientation which illustrates that some of the rooms can vary from the main grid as long as the grid is maintained in the majority of the building. Another character is that the courtyard is maintained at the centre of the building the main understanding is that the central space is without structural walls and columns. The proportions of the rooms are maintained throughout the building which is a key feature that is maintained from the original text. There are minimal windows on the south façade of the building and the windows on the west façade are covered by an architectural overhang which protects these openings.

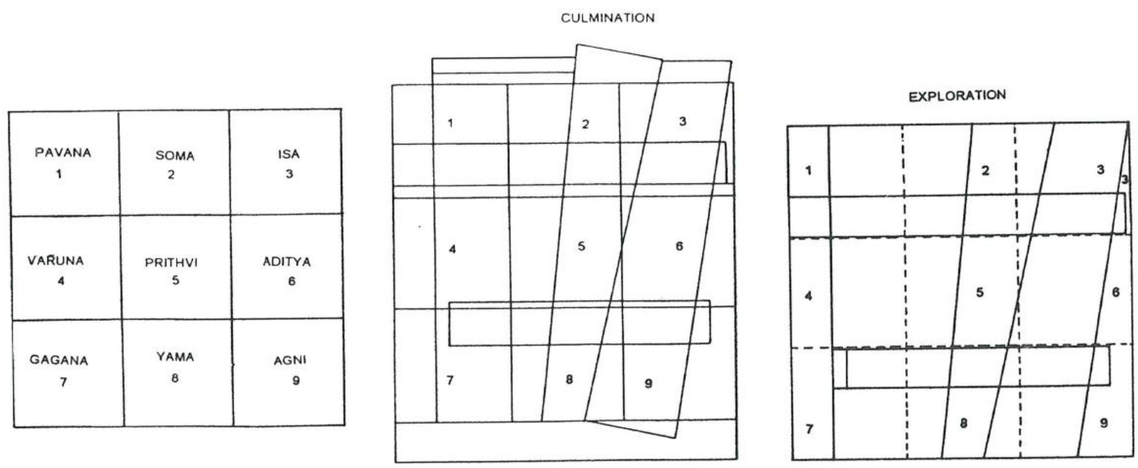

Figure 2.9- Play of the 3x3 Mandala, IIT, Bombay (Indian Architect and builder cited in Chakrabarti1998)

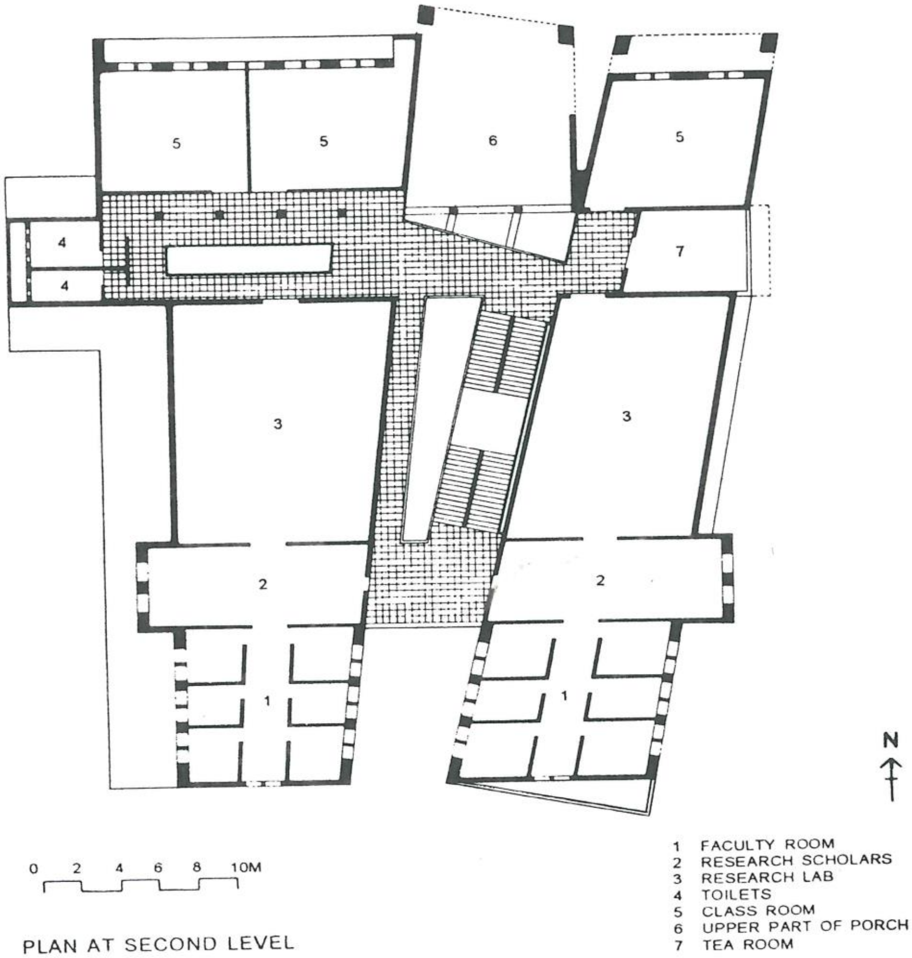

Figure 2.10- Plan of IIT Bombay (Indian Architect and builder cited in Chakrabarti1998)

Another example of unconventional use of the rules is Jawahar Kala Kendra in Jaipur, which was designed by Charles Correa in 1986. It is based on a grid of 9 squares, with each of the squares associated with functions derived from the given planetary associations (Figure 2.11).

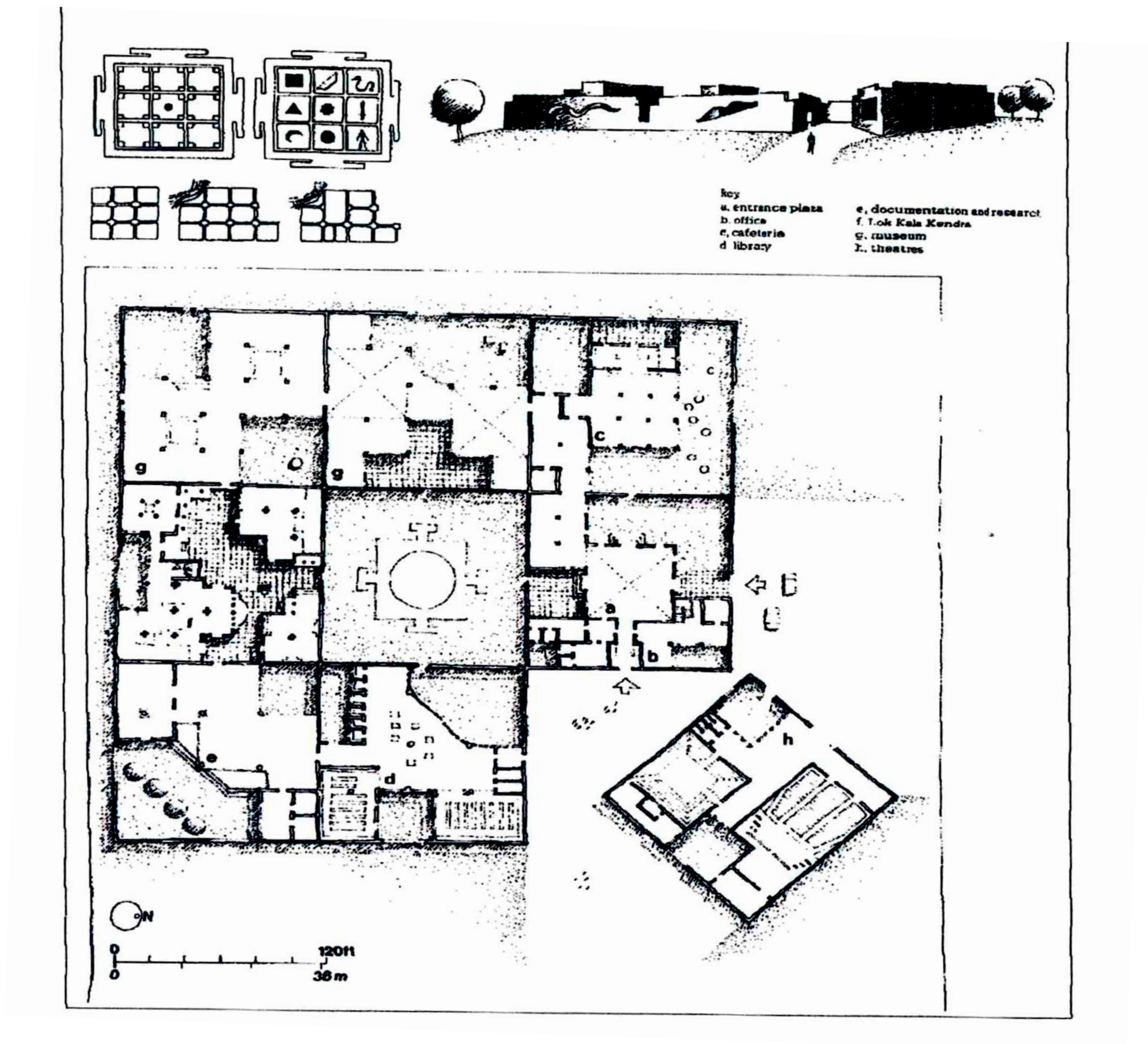

Figure 2.11 - Charles Correa's plan for Jawaher Kala Kendra, Jaipur 1986 (Chakrabarti1998)

2.2.13 *Vaastushastra* in and around India

Vaastushastra is a part of the *Vedas,* which is followed by Hindus, therefore its examples can be seen in countries that practice Hinduism. Some examples of *Vaastushastra* are discussed in chapter 2.2.10, these show examples of building plans to understand how these planned are laid out. These are other examples of buildings that are built on its principles and can be seen both within and outside India (Acharya, 2006). *Vaastushastra* is used at a variety of scales and planning cities is one such example (Pegrum, 2000). Some cities were initially planned based on the principles of *Vaastushastra*, these later changed as the cities developed and the additional expansions didn't always follow the principles of *Vaastushastra*. The city of Jaipur in Rajasthan, also Jaisalmer in Rajasthan, the master plan for Chandigarh and the concept of *Vidyadhar Nagar* are examples of such cities (Ananth, 2001) (Chakrabarti, 1998).

Vaastushastra was used to design and build many different types of buildings across India. It is predominantly associated with temple architecture, but it was used to design palaces that were used by kings, *havelis* that were dwelling spaces for nobles, gateways, pavilions & halls and houses (Dagens, 2000). Examples of buildings that are made based on the principles of *Vaastushastra* can be seen all around India. Each region has a specific style of architecture, but it can be broadly divided into two styles, one from the north which was influenced by Aryans and the south which belongs to the Dravidians (See Chapter 2.2.1).

Examples of such temple architecture can be seen in *Pattadakal*, *Bhuvanesvara*, *Cuttack*, *Jaspur*, *Benares, Vrindavan, Khajuraho,* etc. which have been identified as Indo-Aryan architecture. Whereas temples at *Pattadakal*, *Dharwar*, *Mamallapuram, Conjeevaram, Tanjore, Tiruvalur, Srirangam* and others are examples of Dravidian architecture (Acharya, 2006). Majority of the palaces in Rajasthan, were designed based on the principles of *Vaastushastra*. Examples of these palaces include, Udaipur City Palace, *Bikaner* Palace, *Amber* Palace, *Chitor* Palace to name a few (G.H.R.Tillotson, 1999). Similarly, Rajasthan has examples of *havelis* such as *Purohit Hav*eli in Udaipur, *Begun* Fort in Mewar, *Bhatt Paliwal Haveli* in Udaipur, *Pandit Shivdin Haveli* in Jaipur and many others (Shikha, 2004).

2.2.14 *Vaastushastra* outside India

Manasara is one of the original manuscripts of *Vaastushastra* which is used to understand the principles and their application as mentioned in Chapter 2.2.1. *Manasara* constitutes of seven volumes which were written by Prasanna Kumar Acharya. The sixth book in this series is titled

Hindu Architecture in India and Abroad. The book starts with a chapter that takes account of *Pre-Vedic Architecture*, which is the period before the Hindu *Vedas* were written. In this chapter PK Acharya surveys the architecture in Mohenjo-Daro, Harappa, Jhukun, Johi, Sehwan, Kohistan, Baluchistan and Waziristan and includes the insights of Sir John Marshall who was in charge of the archaeological survey of India (Acharya, 2006). This chapter discusses the materials that were used in the construction of the buildings, the height of the building, number of courtyards included and in some cases the similarities that these structures might have with the various text of *Vaastushastra*.

PK Acharya then looks at *Vedic* Architecture which refers to the period after various text of *Vaastushastra* were written. He mentions that there are references to *Vaastushastra* in other text such as the *Atharva-veda* and that the architecture found in Mohenjo-Daro and Harappa which predates this text does embody the rules of *Vaastushastra* (op. cit.).

Next are examples of architecture that were built based on *Vaastushastra* and were seen in the cities that are very close to India, such as Tibet, Sikkim, Nepal and Ceylon as well as Kashmir and Kangra. In Tibet, there are rare examples of *Siva* temples, but these were built in the principles of *Vaastushastra* with small local changes. The monasteries in Tibet were established by Indian teachers and therefore the architecture was reminder of 'Indian or origin and style' but they had roof structures that were of Chinese style (op. cit.). Examples of structures that follow principles *Vaastushastra* can also be found in Khotan. The structures use different proportions, but the basic geometric shapes are a consistent with the elements in Indian architecture.

Other cities in which examples of Hindu architecture can be seen are Burma, Siam, Cambodia, Sumatra, Bali, Borneo, China and Japan (op. cit.). According to Acharya, architecture in Burma "borrowed many of the Indian forms of architecture" (Fergusson, 1910, p. 339). Pyramidal roofs that are seen in temple structures in Burma replicate the setbacks in heights and similar curvilinear *sikhara* (mountain peak) seen in Hindu architecture (Fergusson, 1910).

“The principle variations made in the design of the Zedi (*chaitya* means shrine) are those of the relative proportion of the bell to the east of the structure, the outline of the same and its superstructure, and the decoration employed” (Fergusson, 1910, p. 343).

Siam has very few architectural remains that have Indian origins, compared to Champa and Camboadia (Acharya, 2006). The text mentions temples such as *Dong Duong*, *Po Nagar* to be designed based on design suggested in *Manasara*. Similarly, cities of Cambodia, Sumatara and Bali have temples that resemble the architectural style seen in India. Acharya then gives a detailed description about the architectural style found in China.

“These rules were distinctly taken from the architectural texts of India. In the *Manasara Silpa-sastra* the rules regarding the length, breath, height and number of stories of buildings for people of different ranks are discussed in great detail” (Acharya, 2006, p. 376)

The architecture in Japan “owes its origins to Chinese sources” (Fergusson, 1910, p. 487). Temples in Japan regardless of whether they belong to Buddhist or Shinto faith “are all of Chinese Ting type” (Acharya, 2006, p. 369). The plans of homes in Japan are similar to those seen in India and follow the principles outlined in *Manasara* (Acharya, 2006).

The above shows that the principles of *Vaastushastra* have been applied outside of India. Its application doesn’t mean that the buildings have a similar appearance. The above examples show that the principles of *Vaastushastra* can be applied and the buildings can also maintain local features. The important ideas that need to be maintained are the key principles that have been identified in chapter 2.3.8.

2.2.15 Literature review of text on *Vaastushastra*

It was in the early 1990's that *Vaastushastra* became popular amongst architects (Tillotson, 1997). The Fist All India Symposium on *Vastu* was held in Bangalore in June 1995. The papers from it were published in *Vastu, Astrology and Architecture* (Vasudev, 1998). The focus of the symposium was to understand the relevance of *Vaastushastra* at that time. There were three main topics at the symposium, *Vastu and its relevance to modern times, Vastu and Jyotisa* (Astrology) and *Vastu and Temple architecture*. The findings of the papers discuss the rules from the original Sanskrit texts, in English which can be read and understood by those who don't know Sanskrit. The findings made it relatively easier for more people to follow *Vaastushastra* rather than trying to read and understand the original text even though these are available in English. Various articles explain key aspects of orientation, proportions, appropriate heights of buildings and use of materials in designing buildings. The articles also include discussions on temple architecture in relation to *Vaastushastra*. Many authors such as Adam Hardy, Alice Boner, Sadāśiva Rath Śarmā and Pamela Scott to name a few have written extensively about Temple architecture.

Vibhuti Chakrabarti wrote her book *Indian Architectural Theory and Practice: Contemporary Uses of Vastu Vidya* in 1998. Her work is widely referenced in all research publications. This book introduced the concept that the variations between the different manuscripts were related to the geographic location for which the were written. Chakrabarti also explains this by showing two different plans from different regions in India shown in 2.2.10. Her explanations are based on the concepts of deities and astrology. *Manadala* is the cosmic grid (see 2.2.5) on which the deities reside and placing the wrong function in it can bring misfortune. This is one plausible explanation for the theory, this thesis is exploring another way in which this theory can be verified. Chakrabarti then wrote a paper about the formulae that are used in *Vaastushastra* which is also widely referred to in academic research papers.

Reena Patra is another author who has written about *Vaastushastra*. Her first paper was titled *A Comparative Study* on *Vaastu Shastra* and Heidegger's *Building, Dwelling and Thinking* was published in 2006. She finds similarities between both pieces of writing and highlights the fact that "it establishes a relationship between man and nature" (Patra, 2006, p. 199). She introduces the concept that homes should be a place where people "should live comfortably" (op. cit.). This paper is about the spiritual concept of comfort, it doesn't go though the theory of thermal comfort. Another paper by Patra looks at the similarity between *Vaastushastra* and sustainability (Patra, 2009). D K Bubbar published his book *The Spirit of Indian Architecture* in 2005. In his book her explores the idea that *Vaastushastra* can be applied to countries outside India. This can happen by modifying the rules to suit the local climate in which it is applied. He is a practicing architect and he has examples of spaces that he has designed based on these principles. G.H.R. Tillotson, Amita Sinha and Vini Nathan are other contemporary authors who have written papers on *Vaastushastra.*

Juliet Pegrum's *Vastu Vidya the Indian art of placement*, Richard Craze's *Vaastu the Indian spiritual alternative to feng shui* and Sashikala Ananth's *Vastu A path to harmonious living* are all coffee table books with lots of illustrations to explain the basic facts. These are similar in approach to Chakrabarti's writing and they all explain the theory from a spiritual approach. Other known authors include N.H. Sahhasrabude, R.D. Mahtme, Derebail Muralidhar Rao, A.R. Tarkhedkar and others who try to provide scientific explanations for *Vaastushastra*. They discuss that the north side is positive because it is the source of energy and the south is negative because it is the sink zone. Other concepts include referring to 'energy' from 'gravitational waves, geomagnetic flux' and other. These concepts can be looked at it further detail to understand their scientific reasoning.

2.3.1 Sick building syndrome and Comfort

"The design of our built environment affects our health and well-being and can have long-term implications for quality of life" (Steemers, 2016). The World Health Organization defines health as "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2016). "To a large extent, factors such as where we live, the state of our environment, genetics, our income and education level, and our relationships with friends and family all have considerable impacts on health" (op.cit.). Another aspect of understanding built spaces is the impact that buildings can have on the health of the users (Mujdem & Balanh, 2011).

Sick building syndrome was primarily understood as a problem that was faced only in office buildings from the early 1970's, but it affected up to 30% (WHO, 2016) of the newly constructed buildings in the west which included homes and nurseries. In the early 1970's buildings were designed so that they were sealed shut, this was thought to help maintain the internal temperature of the building as the enclosure of the building would not allow for the building to lose or gain heat. As a result of which many users of the building started experiencing biological or psychological health problems that would begin soon after entering the building and disappear shortly after leaving the building (Mujdem & Balanh, 2011). After which building regulations were created that stipulated various indoor conditions to ensure that the users of buildings do not suffer from any of these ailments.

All types of built spaces should include comfort for its users and prevent sick building syndromes especially factors that apply to residential spaces. A combination of both creates spaces in which the users are more likely to feel comfortable. Both the subjects have been written and researched and there are many common aspects between them. Architects are the ones who are responsible for the making of a building, from its concept, to its technical support up to execution. The characteristics which relate to sick building syndrome are-dimensional and spatial features, visual features, auditory features, tactile features and atmospheric features and are applicable to residential spaces (Mujdem & Balanh, 2011).Understanding the users' needs and requirements is an important factor for the architect especially since this will help in creating the appropriate spaces in terms of technical needs and comfort factors. The form of the building is created by the architect incorporating various aspects such as, urban setting, site analysis and users' needs.

There are many comfort factors that are considered while designing spaces, especially homes as they are very personal spaces and there are many aspects that vary based on user's personal choices. There are some factors that are quantifiable and those are the main factors that will be considered in this thesis and those are temperature, humidity, light, sound and IAQ levels (Alshaikh, 2016). Each of these factors is quantifiable and has a range of data that is considered to create comfort within residential spaces but achieving this data within residential spaces doesn't guarantee that the residents will all be comfortable, personal preferences need to be incorporated in the design too. The comfort factors should be thought of while the house is designed and therefore the spaces created are more likely to have a positive experience. Architectural features and engineering details are the aspects of the building that should help a building achieve reasonable amount of comfortable habitable spaces.

2.3.2 Comfort

It was earlier thought that user satisfaction of indoor spaces was based on two factors 'right temperature' and 'air freshness' (Nicol, et al., 2012). Various studies showed that most people were not satisfied with their thermal environment. Indoor climates are either too hot in the winter in cold climates where heating is used or too cold in the summer in hot climates where air-conditioning is used. The human body must main its core temperature which is done either by spending energy to warm up or dispelling energy to cool down (Pallubinsky, et al., 2019). When the core temperature rises the body sweats to cool down through the process of evaporation or by shivering when the temperature is too low. Extreme temperatures have a severe impact on the people's health as discussed on 2.3.2.

There was further research into understanding comfort and how it can be achieved. We are capable of experiencing more than satisfaction through our thermal sense and in some situations are able to experience delight (Heschong, 1979). This created a shift in understanding that finding comfort could be more than just achieving specific temperatures. The ways in which we achieve delight are the factors that enable us to return the body to thermal state of equilibrium (de Dear, 2011). This finding was based on the groundbreaking research by Cabanac, which explained *thermal sensation* and *thermal comfort* are as different as sensation and perception (de Dear, 2011). Existing guides for determining appropriate indoor temperatures for functions within a building are provided by various CIBSE and ASHARE guidebooks.

Engineers seem to be tasked with the accountability of the indoor environment which could be harmful for architects and potentially for buildings that they design (Nicol, et al., 2012). International standards are now available for tropical climates in *Buildings for extreme environments: Tropical climates* (2017); cold climates, *Buildings for extreme environments: Cold climates* (2017) and for arid climates, *Buildings for extreme environments: Arid* (2014). From these *Buildings for extreme environments: Arid* (2014) includes the use of air-conditioning and indicates the desirable indoor temperatures in Fig. 2.13 below. There are many factors that need to be considered in understanding people's interaction with their environment, this includes "time, climate, building form, social conditioning, economic and other factors as well the immediate physical environment" (Nicol, et al., 2012).

2.3.3 Impact of extreme heat

Scientific studies have shown heat waves cause the highest number of deaths from all-natural hazards. The temperature of the environment has an impact on the thermal comfort, health and wellbeing of people and can be the cause of death in some cases (Hansen & Soebarto, 2019). Heat waves can occur in conjunction with high levels of humidity or with low levels of humidity which makes the environment hot and dry. Dubai is as hot and humid city, with average temperatures in the mid 40°C and known to peak at 50°C and humidity levels in the range of 90% (See Fig 1.2 in Chapter 1). During the summer months temperatures are high during the day but the humidity levels aren't consistently high. The humidity level increases at night and mechanical cooling is required to create useable indoor spaces (CIBSE, 2014). During extreme temperatures people tend to spend most of their time indoors (Loughnan & Tapper, 2015). The impact of high temperatures on the health of people can be eased by the spaces that we build (Hansen & Soebarto, 2019). Indoor temperatures that are very high are known to have a negative impact on people's health (Ormandy & Ezratty, 2016).

2.3.4 Underlying processes of thermal comfort

There are different processes that take place for the human body to maintain its internal temperature at around 37°C. Thermal comfort is related to the need to maintain this almost constant internal temperature irrespective of the heat that the body produces or the environment it is in (Nicol, et al., 2012). This process of maintain internal body temperature is known as 'thermoregulation' and is studied by thermal physiologists, psychologists and sociologists. The architect and engineer create buildings that address the user's thermal needs in the best way possible (op. cit.).

Physiology is the understanding the heat we generate mostly comes from the food that we eat. Different levels of heat are generated by the body based on the activity it is engaged in, for example sedentary activities generate less heat as compared to active ones or running or cycling. If the core temperature drops the body restricts blood circulation to parts of the body (usually the hands and feet) by contracting blood vessels on the surface. If the core temperature is too high the opposite happens known as vasodilation. In this the blood vessels close to the skin expand and increase the supply of blood to the periphery (Nicol, et al., 2012).

The study of the stimuli received by our senses and the way our brain reads them is known as psychophysics. Studies by Cabanac showed that a strong sensation is felt when the skin experiences a sudden change in temperature, but this only lasts for a short time (Nicol, et al., 2012). Therefore, we will either feel pleased or displeased with an experience based on whether the experience makes us move closer, further away from restoring to the core internal temperature. When the body is overheated then a cold feeling is welcome, but a experiencing a cold feeling at that time is unfavorable and vice-versa (Nicol, et al., 2012). Our response to the environment can be measured on a scale from +3 to -3 (ASHARE scale) or from 1 to 7 (Bedford scale). There isn't a direct relation between physical conditions that people feel in it. There are a variety of environments when people can feel comfortable. A person who grew up in tent in Iraq will have a different reaction to temperature than a person who was raised in a tent in the Russian Arctic. Similarly someone who lies and work in an air-conditioned environment reacts differently to temperature than someone who live and works in a naturally ventilated building and both live in the same neighborhood (Cândido, et al., 2010).

Through physics we understand that the body loses heat to its surroundings primarily in three different ways – radiation, evaporation and convection and on some occasions through conduction. When the body is lightly active the metabolic heat produced is low and is balanced out with the heat that is lost to the environment. This means that it takes time to change people's metabolic state. The heat lost from the body should be similar to the heat produced within the body over long period of time. The body achieves this by three different processes, "convection (heat lost through the body heating the air surrounding us); radiation (heat radiated to the surrounding surfaces); and evaporation (heat lost by evaporating sweat and moisture)" (Nicol, et al., 2012, p. 13).

Clothing is an important factor in understanding thermal comfort as well as adaptive comfort. It is treated as a uniform layer of insulation that protects the body from the environment. Clothing also plays a role in heat loss by evaporation, since it provides one extra layer for the dispersal of water away from the skin. Sweat can also be absorbed by the cloth. Both factors depend on the type of fabric used and the construction of the garment. Behaviour is another factor that influences our thermal interaction with the environment which includes, additional clothing, taking off clothing, posture change, movement, taking shelter and others. (Nicol, et al., 2012)

2.3.5 Adaptive comfort

Adaptive comfort studies have increased over the past years, ever since research showed that the heat balance theory was not always successful. Nicol mentioned in his view on current practices in the editorial to Building research & Information, " A number of field studies had shown that existing approaches to comfort based on heat balance theory failed to explain the range of temperatures that people found comfortable in buildings with the variable indoor temperatures characteristic of naturally ventilated buildings". Adaptive standards were added to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHARE) only in 2004 (Nicol, 2011). For this thesis, the standards of comfort were referenced from Buildings for extreme environments (CIBSE, 2014). The definition of adaptation is "the gradual lessening of the human response to repeated environmental stimulation" (Halawa & Hoof, 2012, p. 102).

Adaptive comfort supports that users can be comfortable in a variety of indoor temperatures when there are options available for adaptation. "The overall understanding of how to design for adaptation in relation to the outdoor conditions, hence how to translate the adaptive principles into a design culture and concepts for operating buildings is still limited" (Hellwig, et al., 2019)

2.3.5.1 Principles of adaptive comfort

In the 70's and 80's Auliciems (1969a, 1969b, 1981b, 1981a), Nicol and Humphreys (1973) and Humphreys (1976, 1978) set the meaning of thermal comfort as "as a self-regulating system and relate thermal perception to prevailing indoor and outdoor conditions" (Hellwig, et al., 2019). There are three reasons to study thermal comfort which Nicol J F (1993) explained as the following, firstly so that people are content by their conditions, to identify standards that can be followed and lastly to control the consumption of energy (Taleghani, et al., 2013). It was found that being neutral to the thermal conditions in the space might not always be the users' preferred choice (Halawa & Hoof, 2012; Brager, G.S., and R.J. de Dear. 2001). The user is seen as an inactive receiver of the temperatures in a space which is not always the case.

Adaptive comfort models give the user the flexibility to adapt to the thermal environment in order to feel comfortable (Mishra & Ramgopal, 2013). Adaptive comfort studies found that there might be gaps in ASHARE thermal comfort scale which is used to measure users' comfort in a space. Principles that capture the main concepts behind adaptive comfort which are broadly categorized as behavioral, physiological, and psychological (de Dear, R., & Brager, G. 1998). There is limited knowledge about these three categories and the impact that each of these adaptive principles have on the comfort of the users, but the basics are well-known (Schweiker, et al., 2012). The other factors that have an impact on the users' comfort are "cultural, climatic, social, and contextual factors" and these are not considered in comfort studies which leads to an increased dependency of air-conditioning (de Dear, R., & Brager, G. 1998).

The following facts are known about the three concepts of adaptive comfort. Behavioral were further divided into three parts, personal (changing the amount of clothing worn), technological (controlling the air-conditioning) and cultural (break during the warmest part of the day) (de Dear, R., & Brager, G. 1998). Recent studies by Marcel Schweiker mention that behavioral changes include changes to heat balance such as "changing clothes, opening windows, or using fans" (2012). The factors mentioned by Schweiker can be measured and the actions usually depend on internal and external temperatures. The availability of such changeable functions and the occupants' access to changing them controls the amount change the occupants can bring to the space. Studies show that when the users' feel that they can change their environment they feel more comfortable in the space.

Physiological aspect of thermal adaptation can be broken down to "genetic adaptation (intergenerational) and acclimatization (within the individual's lifetime)" (de Dear, R., & Brager, G. 1998). Genetic adaptation is passed on from generations and therefore isn't considered in the discussions. When an individual is acclimatization to heat the body changes to adjust to the conditions, this is done with by lowering the metabolic rate or by increasing the amount of sweat and reducing the loss of salt. There are limited studies that show the effect of long-term acclimatization to hot and humid environments. (Schweiker, et al., 2012). The psychological aspect of thermal adaptation refers to “an altered perception of, and reaction to, sensory information due to past experience and expectations” (de Dear, R., & Brager, G. 1998). There are three types of psychological adaptive processes “habituation (if found to be important), expectation, and perceived control” (Schweiker, et al., 2012).

2.3.5.2 Methods to measure comfort

There are two ways in which thermal comfort has been measured, climate chamber studies and field studies. Climate chamber studies are held within a controlled environment and the occupants can’t change their environment, and field studies allow for cultural and psychological factors (Taleghani, et al., 2013) (Schweiker, et al., 2012) (Enescu, 2017). The climate chamber is used for air-conditioned spaces and is based on the heat balance model of the human body and was developed by Fanger in the 1970s. This model calculates whether the users the space are satisfied with the thermal environment and is calculated based on six variables of metabolism, clothing, indoor air temperature, indoor mean radiant temperature, indoor air velocity and indoor air humidity. In simulation indoor studies show that when the users have control over different aspects of their environment (fans, sun shading devices and windows), they feel more comfortable. Field studies combine the use of questionnaires with recording indoor variables, in some cases outdoor if these are required. (Ruppa, et al., 2015). Though many categorize simulation studies along with field studies and refer to them as field studies (Taleghani, et al., 2013).

Another method to understand thermal comfort indoors is to map the indoor and outdoor temperatures concurrently next to each other. This creates a “cloud” of information over time (Nicol, 2017) (Nicol, 2019). These “clouds” can be used to measure the indoor temperatures of rooms in a house in relation to the outdoor temperatures which shows the connection to the construction of the building, occupants' behavior, use of mechanical systems and passive systems. "Indoor temperature will also be a response to a wider measure of the outdoor conditions such as solar gain and wind patterns not just at the time but also in the recent past that influence the actual 'core' temperatures of the building and may take time to react to the outdoor environment" (Nicol, 2017). Traditional Indian Havelis maintain different temperature indoor than the ambient outdoor temperatures. The lower floors such as the basement maintain the temperature for almost a month whereas the higher floors see temperature changes in time periods as short as an hour (Nicol, et al., 2012).

Studies were carried out in homes in Saudi Arabia, to understand users' comfort in mechanically ventilated indoor spaces in a hot country. The temperature clouds for mechanically ventilated buildings shows that the indoor temperatures vary from 20 to 35°C when the outdoor temperatures vary from 29 to 48°C. Each home maintained an average temperature which was unique from the others. The mean temperatures of the homes ranged from 22.4 to 31.5°C and remained fairly consistent in each home. Variations in the temperatures suggest that there are variations in the mechanical systems used in each house and that the occupants can adapt their environment to achieve comfort. The studies show that the occupants suffer more from extreme heat than extreme cold. (Nicol, 2017).

2.3.5.3 Comfort studies in traditional *Vaastushastra* home

It is important to investigate whether traditional spaces that were designed based on the principles of *Vaastushastra* were comfortable for their occupants or not. A.S. Dili, M.A. Naseer and T. Zacharia Varghese have written various research papers on comfort levels achieved in a traditional home in Kerala. The authors have tested the comfort levels of a traditional house using five different parameters and all the results show that house achieves users comfort (Dili, et al.,

2011) (Dili, et al., 2010). Principles of *Vaastushastra* were followed while designing the traditional homes in Kerala (Dili, et al., 2010). The house has an open courtyard and four blocks built around it and the buildings have a pitched roof on them. The building used for the case studies (*Puthiya Kovilakam*) is nearly 300 years old. The house is made from traditional materials "mud, laterite, granite stone and lime mortar for walls, wood and bamboo for roofing, and coconut palm leaves and clay tiles for roof covering" (Dili, et al., 2010, p. 1135). Temperatures of the house were monitored through winter and summer, specifically from December 2008 to May 2009. Loggers were placed at the top and bottom of the courtyard, in the semi open space around the courtyard and a bedroom adjacent to the courtyard (Dili, et al., 2010).

One of the papers investigates the temperature difference between outdoor and indoor temperatures during the summer and winter periods. During the winter months the outdoor temperatures vary between 18°C to 36°C, but the indoor temperatures are maintained between 23.5 °C to 28°C (Dili, et al., 2010). Outdoor summer temperatures vary from 25°C to 38°C and the indoor temperatures are recorded at 28°C to 32°C. Even though the outdoor temperatures vary significantly between the summer and winter; indoor temperatures are maintained at acceptable levels. The authors of the paper conclude that thermal comfort is achieved because the building has an insulative envelope and allows for controlled and continuous air flow (op. cit.).

In another paper by the same authors reviews the qualitative and quantitative aspects for the same house. Climate of Kerala is warm- humid with moderate temperatures, high relative humidity and heavy rainfall. For the qualitative analysis, they look at orientation of the building, internal arrangement of spaces, use of the internal courtyard, openings and their use for natural ventilation and thermal protection (Dili, et al., 2010). The building has a rectangular form and is oriented around the cardinal directions as it is stipulated in *Vaastushastra*. Internal functions are laid out so that they maximize the local climate conditions, which means that functions used during the day are placed on the north and south and those used at night are in the west (op. cit.). These are the main principles of *Vaastushastra* that are discussed on Chapter 2.3.8. The quantitative results show similar differences n temperature to those mentioned in the paragraph above. The same authors have investigated the comfort of the same house during the summer and rainy seasons and found that the house is comfortable for its users despite the outdoor conditions.

“The investigation has revealed that when the outside ambient temperature is below normal, the building system tries to maintain the indoor air temperature at a higher but comfortable level and when the outside temperature is above normal, the indoor temperature is maintained at a lower but comfortable level” (Dili, et al., 2010, p. 2229).

Another study of the same house compares it with a modern house in the same neighborhood (Dili, et al., 2010). The authors of the paper define the house as modern based on the materials used to construct is “20cm thick walls of brick masonry plastered with cement mortar and roof of reinforced cement concrete (RCC)” (Dili, et al., 2010, p. 654). Temperatures were recorded in both houses from February 2010 to mid-May 2010. Loggers in the traditional house were set up as explained above and in the modern house they were placed in the bedroom. The results show that there is less temperature variation in the traditional house compared to the modern house. The traditional house has better air circulation compared to the modern house and this is attributed to the characteristics of the traditional house. The authors of the paper identify that high thermal insulation and air circulation are the key factors that help to maintain the internal temperatures at comfortable levels. One of the main factors that contribute to the thermal insulation is the use of traditional materials. Traditional materials aren’t used in contemporary construction since it is easier to construct buildings using modern materials such as concrete. It is important to understand if there are other factors that helped to make traditional homes more comfortable than modern homes.

2.3.6. Passive design in Residential Spaces

Design of the building plays an important part in determining comfort of its users. Passive design principles can have an impact on the comfort levels. Key factors that are identified for this thesis are – temperature and humidity, light, sound and levels of smell. Each of these factors have both international and regional standards which are stated in CIBSE (2014) regulations and will be used as benchmarks in this thesis.

Understanding comfort factors in buildings is not an isolated topic, it is related with other topics such as sustainability and passive design systems. Some principles of *Vaastushastra* are similar to the ideology behind low tech sustainable issues. Based on the 3-tier approach to sustainable design Fig. 2.12 (Lechner, 2008) these common aspects from Tier 1 are –

- Location, site design, landscaping, form, orientation, colour, exterior shading and construction materials all contribute towards the temperature of the indoor space. Air tightness is an aspect that can help with maintaining internal temperature, but at the same time it creates the problem of stale air which then increases the reliability on mechanical systems. A regular exchange of air is required within spaces which is provided by mechanical systems and eliminates stale air at the same time. At the same time the temperature maintained through the mechanical systems should match indoor comfort levels
- The aspects of the windows orientation, size, glazing type, insulation and shading all have an impact on the internal temperature maintained. In an ideal situation the windows would only be located on the appropriate façade of the building, but this would mean that significant portion of the building might not receive natural light. This problem is usually easily remedied by the use of design solutions such as light shelves, exterior shading and use of appropriate landscape elements.

- Efficient lighting is an aspect that is related with sustainability more than it is linked with creating comfortable internal spaces. Using lighting systems that are efficient is always an added advantage but from a standpoint of achieving comfort levels it is not a requirement. Efficient appliances are directly linked with the sustainable aspects of the built space as these are not directly linked with the comfort levels of the users.

Figure 2.12- The 3 Tier Approach (Lechner, 2008)

Once the tier 1 aspects are used to design the basic plan of the building it can help with heat retention or rejection or avoidance, based on the geographic location it is placed. Elements of passive design can be selected to suit the lactation and therefore both these categories can help with creating spaces that are comfortable for the users. The third tier is about the mechanical systems used in the building which is directly linked to sustainability. It is indirectly linked to comfort, because tier 1 and 2 should be able to create spaces that are comfortable and therefore reduce the users' dependency on mechanical systems.

Comfort ventilation is a strategy used when air circulation can be used to cool a space, it allows for the heat to escape from a space and hence allows for it to be cooled. Night flush cooling is used in places where the daytime temperatures are too high, and the building is designed so that the ventilation systems help the thermal mass cool by convention. Earth coupling is another technic in which the structure is built into the ground to take advantage of the constant temperature of the earth, depending on the climate.

Based on the location of the house, heating with the use of solar exposure is very beneficial in countries which have colder climates. The feature of direct heat gain is added to the building by placing glazing on the south façade of a building which helps to heat the building naturally up to a certain extent. Similarly, trombe wall and sun space when included on the southern part of the house add naturally heated spaces.

2.3.7 Users' Comfort in Residential Spaces

One of the key principles of *Vaastushastra* is the connection with the elements. The selected comfort factors are "thermal comfort, visual comfort, acoustic comfort and air quality" (Enescu, 2017) and they are linked to the senses. These comfort factors link to the four senses because thermal comfort is linked to touch, visual comfort is linked to sight, acoustic comfort is link to sound and air quality is liked to smell. Comfort in any built environment can be assessed through many different criteria. The chosen method is a combination of quantitative methods which are collected through various loggers and qualitative that collect the users' feelings through questionnaires.

The 'cloud' method mentioned in 2.3.5.2 will be used to measure indoor temperature and humidity and this will plotted against the outdoor temperatures (Nicol, 2017). In addition, the users' will be interviewed about their experiences of the space in which they will be asked about the qualitative aspects of touch, light, sound and smell. The quantitative and qualitative aspects of a space can possibly summarize the user's comfort or discomfort levels within the space. Below are the key criteria that will be used to understand users' comfort in this thesis.

2.3.7.1 Temperature and humidity

One of the aspects of understanding comfort in spaces is the temperature and the humidity should be suitable to both the region and the activities that users are carrying out. Various regulations for example ISO 7730 (2005), CIBSE A (2006) or ASHARE Guide and Databook (2009) set these criteria (Nicol, et al., 2012). These regulations specify global standards and further details are provided in local regulations such as (CIBSE, 2014) for extreme environments -arid Fig.2.13.

Relative humidity (%)	Temperature (°C)			
	Summer		Winter	
	Range	Optimum	Range	Optimum
40	23.0–26.5	25.0	20.5–24.0	22.5
50	22.5–26.0	24.5	20.0–23.5	22.0
70	22.0–25.5	24.0	20.0–23.0	21.5

Figure 2.13 - Internal design conditions for Middle East (CIBSE)

2.3.7.2. Light

Another important aspect of comfort in residential spaces is light which includes both natural and artificial sources. The use of natural light in buildings has a predominantly beneficial impact on the health and well-being of its users (ATP & LM, 2011). Light however can have a negative impact on the health of its users through aspects such as radiation and light operating through visual systems (Boyce, 2009), the impact of these are known and they have various regulations attached to them (Boyce, 2009). Chartered Institution of Building Services Engineer (CIBSE) and Illuminating Engineering Society of North America (IESNA) both regulate the artificial light in built spaces. On an average every living space in a home should have natural light. Any room that doesn't have natural light is considered as non-inhabitable or non-living space and is used for facilities such as a storeroom.

2.3.7.3. Sound

There are a variety sounds that are experienced by people in different spaces and at different times, while all sounds are not pleasant total lack of sound is not always pleasant either. Dwellings that are in residential communities are generally perceived to be quieter than other spaces such as retail spaces, office spaces, mix use developments and mix use developments in which residences are incorporated. Most of the internal sound levels of a house can be regulated by the occupants based on their personal preferences. Ambient sounds include – "work/ mechanical noise; natural environmental sound; living environment noise; maritime environmental sound; traditional environment sound; water environment sound and regional environment sound" (Han, et al., 2009, p. 102). Mechanical systems that are used in residential spaces generate noise and therefore create stress for the users (Steemers, 2016). There are various attempts at making these sound levels as minimal as possible, but they do create some noise. On the other hand, a sound connection between neighbors and sounds from nature can be welcoming to residents. Since homes are usually quiet spaces acoustic separation is rarely used.

2.3.7.4 Smell

The air in hot and arid regions potentially carries more moisture, therefore these areas are known to be hot and humid. Relative humidity is one of the factors of thermal comfort because high levels of humidity can restrict perspiration, which makes it uncomfortable for people. High levels of moisture which are maintained over long periods of time can give rise to bacteria and fungi. Odours, allergens and toxins come from bacteria and fungi. Fortunately, an environment in which humans are comfortable is too dry for these bacteria and fungi to survive (CIBSE, 2014).

2.3.8. Understanding *Vaastushastra* through aspects of comfort

Vaastushastra has many principles, in this part the author has identified key design principles which should be used to design the building. One of the main aspects of *Vaastushastra* is that are differences between the four sub cardinal directions. Each corner has a suggested function which is based on when the space will be used by the residents. For example, if the kitchen is used the most then it can be located in the northeast corner which is recommended to be used during early hours of the day (Pegrum, 2000) (See 2.2.4, Table 2.3) This thesis will examine if the principles of *Vaastushastra* cause variations in the comfort levels of the four sub cardinal directions. Even though these key principles are not stated anywhere specifically the author has created a list of these principles which are as follows –

1. Orientation of the house
   The orientation of the house has an influence on the temperatures that are achieved in the different intermediate directions of built spaces. This is based on the principles of passive design discussed above in 2.3.6 and is also mentioned in CIBSE *Building for extreme environment Arid* (2014). It is a known fact that the north side is cooler than the south side. This thesis will examine if there are any more variations within the northeast and northwest, or southeast and southwest sides?
2. Form and proportion of the house
   Overall the geometry and proportion of the house is thought to have an influence on the internal temperatures, it is mentioned as "form" in Fig. 2.12 above. Basic geometric shapes such as square and rectangle which have the required proportions should be able to support the indoor spaces and remain at a temperature that is close to users' comfort. Passive design principles suggest that when spaces are made on the correct proportions it allows for natural ventilation through air circulation and therefore makes it more

comfortable for the users. The impact of rooms with odd shapes will be investigated through the case studies.

3. Placement and size of windows

   Windows influence the amount of heat gained by the building therefore placing them in the appropriate direction would mean less heat gain in the building (CIBSE, 2014). North and east sides are thought to favour windows and the south and west side are the unfavourable sides. Since the morning and evening sun is in the northern part of the sky, amount of glazing should be minimized and shading is required on all sides (CIBSE, 2014).

4. Proportion of the rooms in the house

   Proportions of the rooms have an impact on the temperature recorded within the space. The preferred shape of the room should be square or rectangular with the rectangular shape based on proportions of the building. The proportions of the individual rooms support the proportions of the overall house and similarly facilitates air movement within individual rooms which is a principle of passive design.

5. Use of a courtyard in the house

   Mid-size homes and above can benefit from having a courtyard located in the centre of the house, as this helps to cool the house overall. A courtyard that is placed correctly in the house can allow for natural light and facilitate air circulation which supports users comfort levels. The courtyard feature allows for most rooms to access natural daylight. The cooling effect of the courtyard is also dependant on proportions off itself and to the whole house. If the courtyard is too narrow in either length, width or height it won't have the desired impact of comfortable spaces which is also a principle of passive design

6. Windows on south and west sides

   Adding windows to the south or west side is possible if there are appropriate shading devices introduced or the architecture of the building prevents exposure on these sides. With the addition of shading devices solar heat gain in the affected rooms could be reduced. This is a method of low technology passive design which allows for the space to receive natural day light, opens up the space for natural ventilation and at the same time prevents heat gain. Massing of the building is another method of low technology passive design which helps keep the spaces comfortable.

7. Materials

Materials have an impact on the heat gain of the house because these define the external surfaces of the house. Traditional materials such as brick, timber and stone are compared to the heat gain of concrete, since Dubai is a hot climate and heat gain is a major concern. Low technology passive design stipulates that local materials should be used for the construction of houses. One of the main advantages of using local materials is that the material can sustain local climate and help to maintain comfort levels indoors.

2.3.9 Passive design for hot and humid climates

The rest of this chapter will examine how the key principles of *Vaastushastra* explained above might contribute towards creating comfort indoors. The first principle mentioned is the orientation of the house. Passive design strategies mention that orientation is a key factor for buildings designed in all climate. Orientation is important factor while designing building anywhere in the world. In the hot and humid region such as the Middle East, orientation is an important principle while designing thermally comfortable homes (Alshaikh, 2016). Preferred orientation for buildings in hot and humid climates is that the length of the building is from east to west as seen in Fig. 3.1 and 3.2 (Anon., 2012).

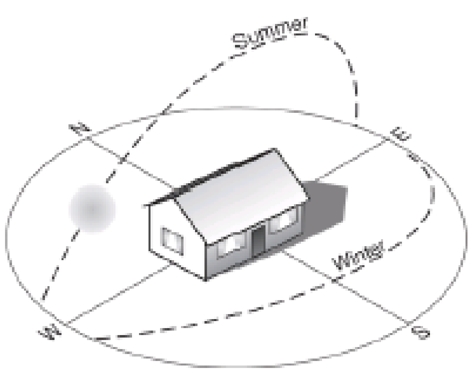

Figure 2.14- Preferred orientation for buildings in hot and humid climate (Anon., 2012)

The second key principle identified is the form and the proportion of the building. Orientation of the building is dependant on its overall form and therefore both must be looked at together. Fig. 3.2 shows ideal orientation for different building forms. Plans that are shown are indicative therefore can be scaled up or down to suit the requirements of the users. The courtyard plan is one of the suggested strategies of form for hot and humid climates, other variations include an L shaped plan and a simple rectangular form, the last of which is the most commonly used shape. Rectangular shape is the preferred shape because it allows for “minimum perimeter to area ratio” (Anon., 2010). Since the rectangle shape has the smallest perimeter its exposure to solar radiation is minimum which is preferred in the Middle East.

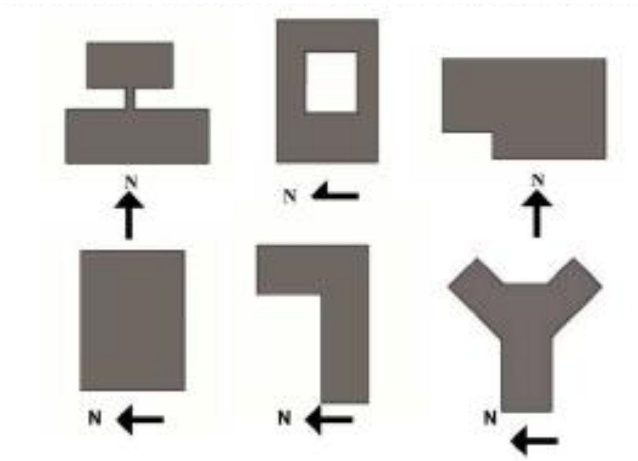

Figure 2.15- Building forms and suggested orientation (Anon., 2010)

As shown in Fig 3.2 below, orientation of buildings in hot and humid climates should be with the length of the house oriented around the east to west axis (Anon., 2012). This means that only the short sides of the house are exposed to maximum solar radiation. Summer sun is at a higher altitude and therefore makes it easier to shade the house on the south façade. The CIBSE guide for *Building for extreme environments Arid*, also mentions that there should be adequate shading to “block solar radiation” (2014, p.14). When solar radiation is managed this can lead to relatively lower indoor temperatures which can make the building feel more comfortable for the users.

The third principle is the location and the size of the windows on the façades. Location of the windows is an important aspect while designing buildings. Openings or windows on the north side can allow natural sunlight which is needed in buildings and at the same time there isn't too much solar radiation, so it doesn't cause gain in internal temperatures (Alshaikh, 2016). The sun angle is low on the east and west facades and it could be a problem to provide adequate shading for these sides (Anon., 2010).

The sixth principle is about shading the windows on the south and west sides. Various strategies can be used to shade windows on different on different sides of the house as shown in Fig. 3.3. Since the angle of the sun is high during the summer months it is relatively easier to shade the south façade and a horizontal shade can allow for some needed winter sun (Alshaikh, 2016). Other strategies to shade the windows are shown in Fig. 3.4 which include wall projections that are offset from the wall which has the window, using trees or other vegetation, use of screens or adding surface texture to the exposed walls.

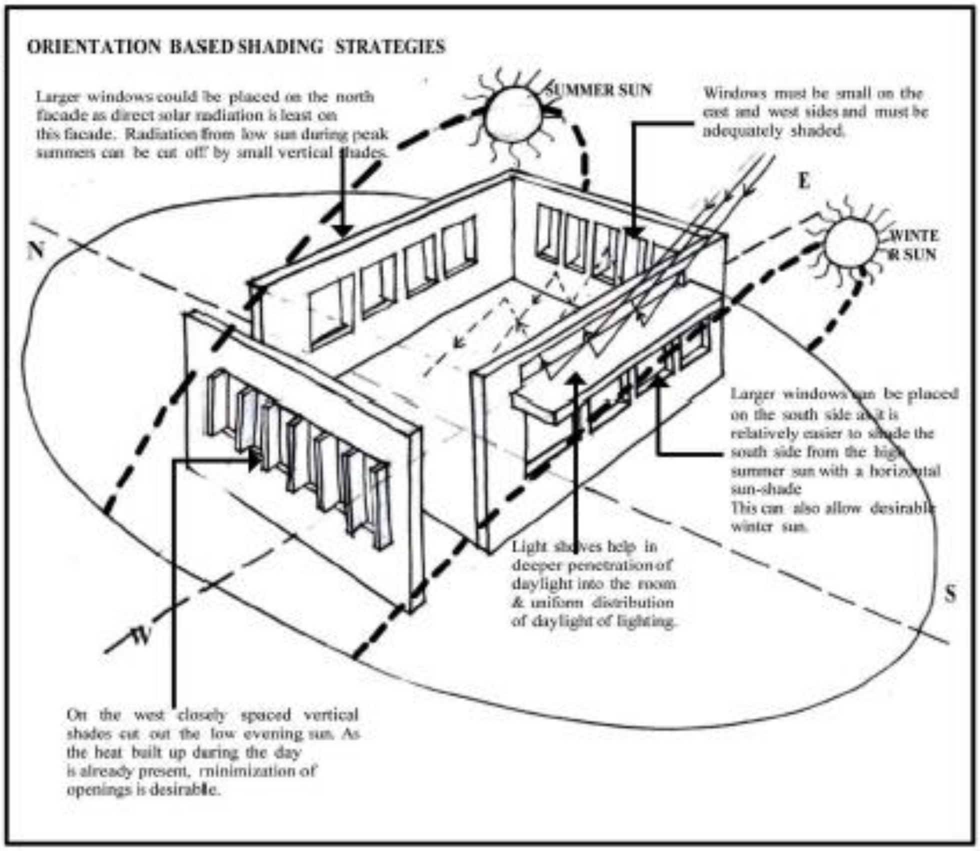

Figure 2.16- Orientation based shading strategies

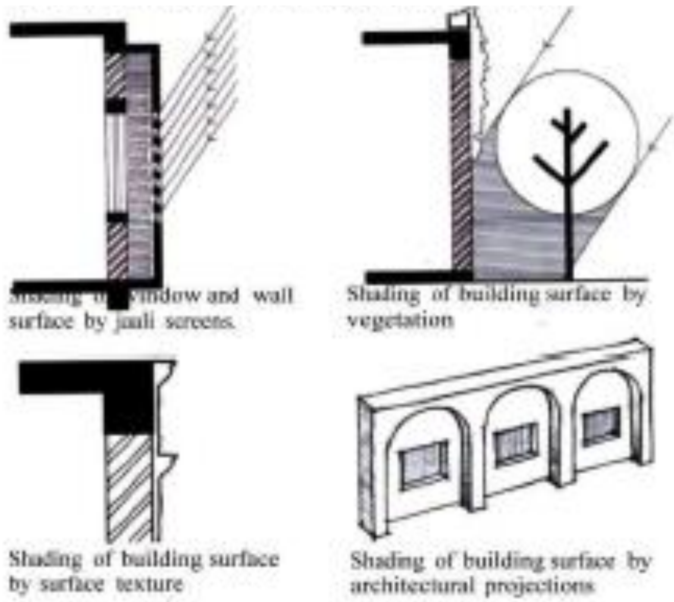

Figure 2.17- Shading strategies

Fourth principle is the use of appropriate proportions for the internal rooms in the building. Internal layout of the house is also an important factor in creating comfortable spaces (Alshaikh, 2016). Internal spaces in the building should be based on the proportions of the house. When the internal spaces use the appropriate proportions, it can allow for air circulation which can make the internal spaces more comfortable to use.

Fifth principle is the use of courtyard in the house. The courtyard should be designed so that it provides internal shading to the required facades. It can also be used to plant trees which can add to the shading that is provided by the building as shown in Fig 3.5. Placing windows at strategic places on the building can also with air circulation in the building. With the appropriate air circulation, the internal temperatures can be lower than the external temperature therefore making internal spaces more comfortable.

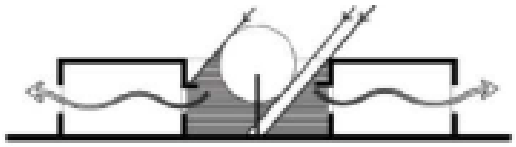

Figure 2.18- Internal shading in courtyard buildings

Use of materials is the seventh principle that is used in *Vaastushastra*. Properties of materials can help to evaluate if they are useful for the region or not. Buildings create shelter from the external environment; therefore the choice of materials is an important factor. Thermal mass and thermal insulation help to determine if the material can be used in hot and arid climates. Thermal mass refers to the materials capability to absorb and retain heat which helps to delay the heat gain inside the built space (Anon., 2010). Thermal insulation refers to the reduction of heat transfer through a material. Thermal conductivity (k) measures the insulating capability of any material. A low value of thermal conductivity means that the material has high insulating ability (op. cit.) which mean that the heat from one side won't be easily transferred to the other side (R value). Thermal transmittance (U value) is the ability of the material to conduct heat which is the opposite of R value. Dubai government stipulates that the maximum U value for exterior walls in homes should be 0.57W/m^{2}K (Anon., 2019).

Traditional materials can help maintain comfortable indoor temperatures as seen in the case study of the house in Kerala (Dili, et al., 2011). The author discusses that since the house is made using traditional materials and uses traditional techniques of construction, the house has good thermal insulation from external temperatures. The walls of the house are made of laterite masonry that are 750 mm thick and have a cavity in between which is filled with fine sand (Dili, et al., 2010). The roof system in the traditional house is a combination of wooden ceiling, clay tiles roof and a well-ventilated attic space (Dili, et al., 2011). Both the walls and roof system of the traditional building help to maintain the internal temperatures according to the authors. The use of traditional materials prevents a “time lag” between outdoor and indoor temperature which can be caused by “the highly insulative wall preventing conductive heat flow and due to the continuous air flow maintained through the building” (Dili, et al., 2011, p. 60). Whereas in the modern building doesn’t allow for continuous air flow. Concrete is the material used in the building, which absorbs heat during the day and transfers the heat through the roof and the delay in transferring the heat is referred to as “time lag” (op. cit.).

The use of traditional materials in construction has significantly dropped and we rely more on contemporary materials. Both the case studies used to compare traditional and modern buildings have differences other than the materials used in construction. The orientation of the house is different and the location of the spaces that are monitored are different. The variation in temperatures measured in the house could be due to these factors as well as the materials used to construct the houses. Homes in Saudi Arabia that used concrete for construction were also studied for comfort and it was found that other factors such as orientation, layout of internal spaces, shading devices used etc. also contribute towards the comfort levels of the users (Alshaikh, 2016).

2.4. Conclusion

This chapter reviewed the overlaps between *Vaastushastra*, user’s comfort and principles of passive design in residential spaces. Even though they are distinctly different subjects there are many common aspects between them. Seven factors that are listed above (2.3.8) are key principles of *Vaastushastra* but are also used in passive design strategies and for optimizing users’ comfort in built environment and will be used to investigate the case studies carried out in this thesis. These key principles of *Vaastushastra* align with the concepts of users’ comfort as well as passive design principles. The principles of *Vaastushastra* could possibly be connected to the behavioral, physiological, and psychological impact the space has on its users.

Orientation of the house is a key factor in designing the house, it has an impact on natural light levels, heat gain, views to the outside, noise levels and natural ventilation. Especially in hot and humid cities like Dubai orientation of the building can have a major impact on the user's comfort levels. Form and proportion of the building have an impact on the air circulation within the building and heat gain and these have an impact on the mechanical systems used inside the space therefore the noise levels caused by the excessive use of these mechanical systems. Placement and size of windows along with proportions of rooms also have an impact on natural lights levels and natural ventilation in the space and these have an effect on the user's comfort. Depending on the size of the plot and the size of the built environment courtyards can help bring in natural light and ventilation into a building and allow for users' comfort through natural means. Use of materials also has an impact on the users' comfort because appropriate use of materials can either help combat or maintain external temperatures.

Many of above factors that are key in *Vaastushastra* are also included in passive design strategies. Orientation, building form & proportions, courtyard, window placement and se of materials are common factors between both *Vaastushastra* and passive design, and passive design also includes use of fans and use of the buildings surroundings to provide shading through trees, plants and cooling by adding water bodies.

User comfort is not only about indoor temperature, but it also includes thermal comfort, adaptive comfort, air temperature, radiant temperature, humidity, clothing and the user's activity level. It is important that the user is in a space which can be adapted to suit their comfort level, for example the user can open a window for change in room temperature, or switch on or off any mechanical systems to achieve comfort.

Vaastushastra lists many principles, some of which some might be outdated because there are new ways to execute them. For example, the gnome was used to work out the north of the site, we use a simple compass. Another example is that the colour, smell and taste of the soil were checked to understand soil conditions. These are replaced by various soils tests that show the strength and weakness of the soil. These principles are stated in the text without any explanations to understand why they are stated.

The findings from the case studies will help understand if there is any direct link between the principles, the temperatures recorded indoors and how the user's comfort in the space. The selected case studies have factors that the users can adapt and therefore have an impact on their comfort levels. This is used to understand if there is a scientific connection to *Vaastushastra* principles.

If design of the space can create more comfortable spaces, then the dependency on artificial heating or cooling can be reduced. Alternative methods of cooling such as natural ventilation and use of fans can be used to maintain comfortable internal temperature.

Chapter Three: Methodology

3.1. Introduction

This chapter introduces the methodologies that were used in the thesis. The choice of the methodologies is discussed first followed by the explanation of why each method is selected. Fig, 3.1 shows the conceptual framework used for the methodology. An important part of the methodology is the selection of the case study homes. The location of these homes and the reason for selection is discussed. Chapter 2.3.8 mentions the criteria that were used to make the selection of the case study homes. There is a description about each case study home which is followed by explanations of which selection criteria are met by the house. Then there is a discussion about both methods of gathering data from the case study homes using data loggers and by users answering questionnaires. The next methodology used in the thesis is to is the use of simulation software. There is a discussion about the use of software modelling and the reason it has been included in the thesis.

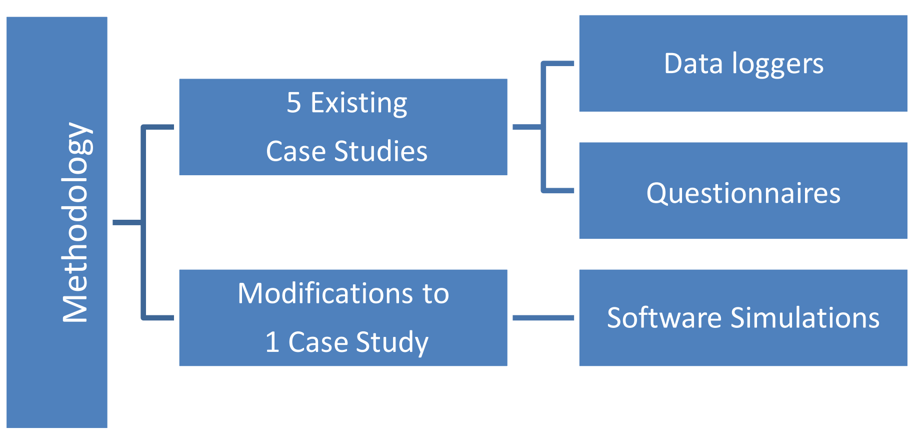

Figure 3.1 - Methodology Framework

3.2 Methodologies Used for the Thesis

Three methodologies selected for the thesis are used to understand the selected case study homes and the impact the architectural design of these homes has on the users' comfort (Dawson, 2009). The selected methodologies include, temperature and humidity collection from selected case studies (quantitative), data collected from questionnaires given to the users of case study homes (qualitative) and data collected from simulation software (Berry, 1994). These methodologies are linked to the research objectives and the correlation to these is seen in Fig. 3.2. Case study homes were selected based on the key principles of *Vaastushastra* identified in chapter 2.3.3 (Graiano, 1993). The houses that have been selected exhibit different applications of the rules of *Vaastushastra*. If the selected houses would have the all the rules applied in the same way it would be difficult to understand its impact to user's comfort because the data collected from all the houses would be similar to each other. A standard set of rules was identified (chapter 2.3.3) and the houses that were selected for the thesis study had minor variations to the identified rules.

Five case studies were identified to investigate whether the principles of *Vaastushastra* had an impact on the comfort levels of users. Many different factors create comfort for users in the spaces that they use. Home is a very personal space for its occupants. Out of all the criteria that can have an impact on the comfort of users, the criteria that vary based on the design of the building are natural light levels and temperature along with humidity. Other factors such as sound and smell should be a consistent aspect of the users experience in the specific house and therefore don't need to be monitored through quantitative data collection. The light levels in the house will vary from one season to another, but will remain stagnant through one season; therefore, this data was captured through users' experience questionnaires rather than quantitative data collection (Rubin, 2005). Questionnaires were set up to understand how the users felt in the space in terms of the quality of their own experience (Yin, 2009). In these the users were asked about all aspects of comfort in the house, natural light availability, noise levels, smell, if they felt hot or cold in the space and ventilation. These would help to understand the overall experience of the user and compare it against the temperature data that was physically collected.

The selected case studies were complaint with majority of the rules of *Vaastushastra* but they none of the houses completely compliant with all the principles. To investigate the principles of *Vaastushastra* further IES an integrated environmental solution software was used to simulate one house and modify it so that all the principles were met. Using a simulation software would allow modifications in the existing building which would investigate if the internal spaces would be more comfortable after complying with all the rules. Since the house is built it would be difficult to test the suggested modifications in the actual house.

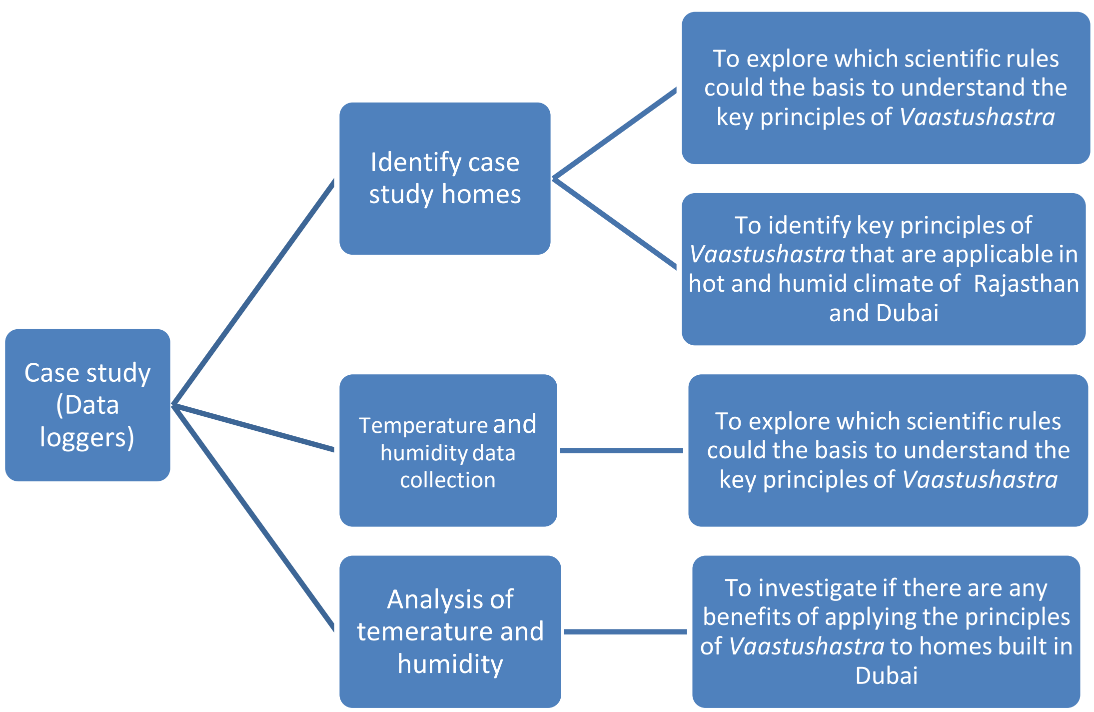

Figure 3.2- Research methods connected to the research objectives.

3.3.1 Weather and location of Dubai

United Arad Emirates (UAE) is located between Oman and Saudi Arabia and located on the Arabian/ Persian Gulf (CIBSE, 2014). The capital of UAE is Abu Dhabi, and Dubai is the second largest state and shares borders with Sharjah, Abu Dhabi and Oman (Fig.3.2.). UAE is a dessert and is predominantly a hot and humid climate, even though the humidity does not climb above the highest average level of 65% (ClimaTemps.com, 2009) it is considered humid because the RH level does not fall below 55% throughout the year. There are two seasons in Dubai, summer and winter. Summer lasts from May till October and the remaining months are relatively cooler which is the winter season. The temperatures in Dubai range between 28°C to 36°C during the summer with maximum temperatures touching 48°C in July or August (Talebn, 2014). While in the winter it is average high of 23°C and low of 14°C. These aspects of the environment have a strong impact on the research conducted and the data gathered for this thesis.

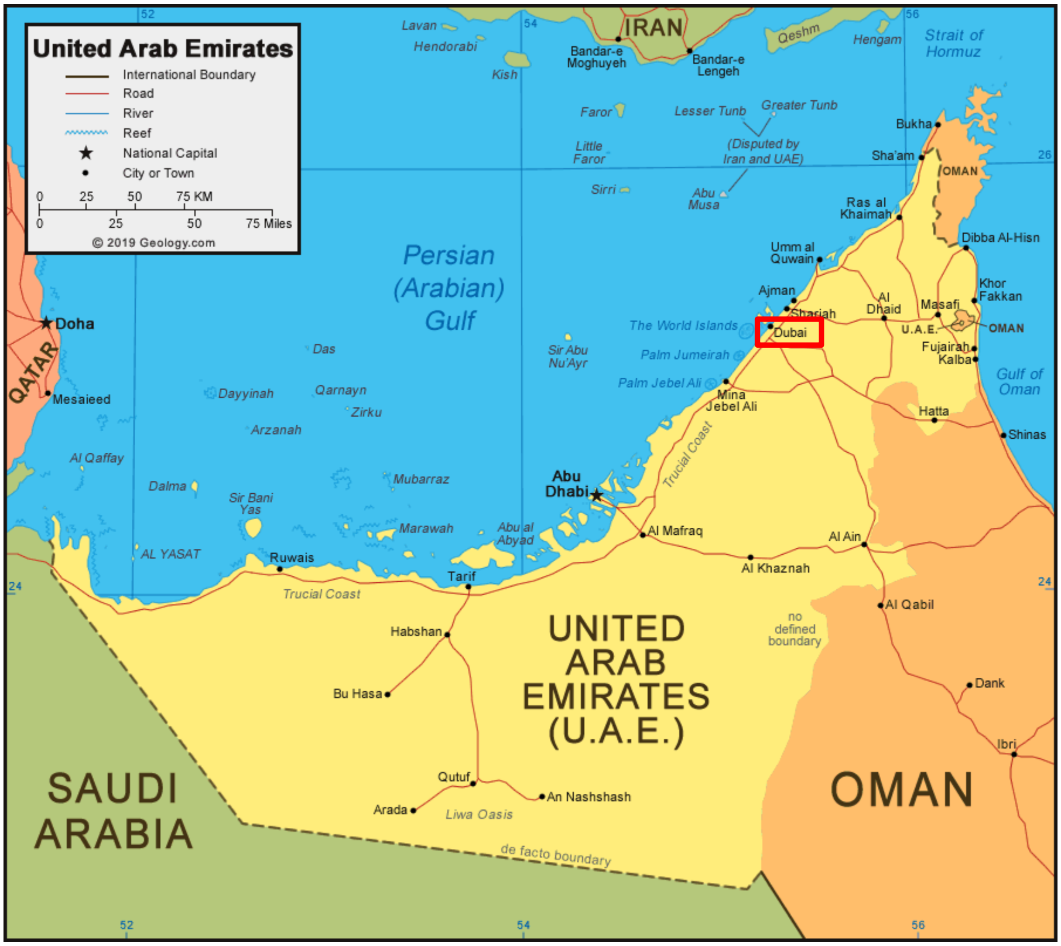

Figure 3.3- Location map of UAE https://geology.com/world/united-arab-emirates-satellite-image.shtml

3.3.2 Selection and location of the Case study homes

For the purposes of this thesis mid-sized dwelling spaces which are three or four-bedroom independent homes built on the principles of *Vaastushastra* in Dubai were considered. The reason for this selection was based on size of the house, its adherence to the principles of *Vaastushastra* and the similarity of the users' profiles. The average size of these houses was kept between 250 to 650 sqm. which should be sizeable enough to record differences in comfort factors in different parts/spaces of the house. If smaller houses were selected the space would possibly have similar recorded measurements on all sides and parts because the limited dimensions would create similar conditions in all corners of the house. Larger homes are very limited in Dubai, out of which very few are designed on the principles of *Vaastushastra* and therefore have been eliminated. The users' profiles for the different houses will be kept similar in terms of their requirement to live in a house that is designed based on the principles of *Vaastushastra*. This connects the users' in terms of accepting the requirements of vernacular design.

There was a selection criterion for the houses, which would help to identify which ones can be used for the case studies. A total of 10 homes were approached to be a part of the study. The main principles of orientation, shape of the house and locations of windows were primarily checked in all the houses. One of the challenges of the selecting the case study homes was that mid-size homes didn't have courtyards and there were not too many large houses that were complaint with the other rules of *Vaastushastra*. For this reason, the presence of the courtyard was over-looked for the purposes of this thesis. A couple of houses didn't match these criteria and therefore were not used as case studies. It was important that the residents were comfortable being a part of the study and that their home would be anonymously documented in thesis. A couple of residents were not comfortable with sharing their personal information and therefore these homes were not included in the study. One of the houses was the same layout as another home selected for the study and was in the same neighbourhood and therefore one of the houses was not selected.

Since the weather in Dubai is hot and it doesn't rain too much, all the houses have flat roofs. The material used for the construction of shell of all the houses is concrete which includes a combination of site caste concrete and concrete blockwork. The concrete brickwork used for the construction of the site is inclusive of a layer of insulation which helps maintain the internal temperature and conforms to ASHARE regulations. Since the climate is hot for majority of the months the insulation helps to prevent the loss of the cooler indoor temperature to the outdoor ambient heat. Windows can be the main source of loss of cool temperature or for internal heat gain, but most homes use double glazed glass panels which controls internal heat gain. When these windows are placed in the appropriate direction, they can prevent excessive heat gain since it is essential for homes to have windows.

All the selected homes are contemporary in appearance and therefore are not traditional in their design features in terms of ornamentation. This is because these homes follow the principles of *Vaastushastra* in terms of design theories but not in terms of ornamentation or façade treatments. The ancient text was written so that it could be adapted to incorporate the developments in technology and create built spaces that reflect these developments. Since the current style of housing doesn't incorporate ornamentation it is an accepted factor for the houses selected for investigation.

The homes were all located in residential areas in Dubai. The homes were located in three different residential areas, Al Mankhool, Al Jafliya and Jumeriah 1. These areas are highlighted in the map of Dubai seen in Fig. 3.4. Three of the five homes are located in Al Mankool, one is located in Al Jafliya and one is located in Jumeriah 1. Each of the 5 selected case studies are discussed further on in this chapter.

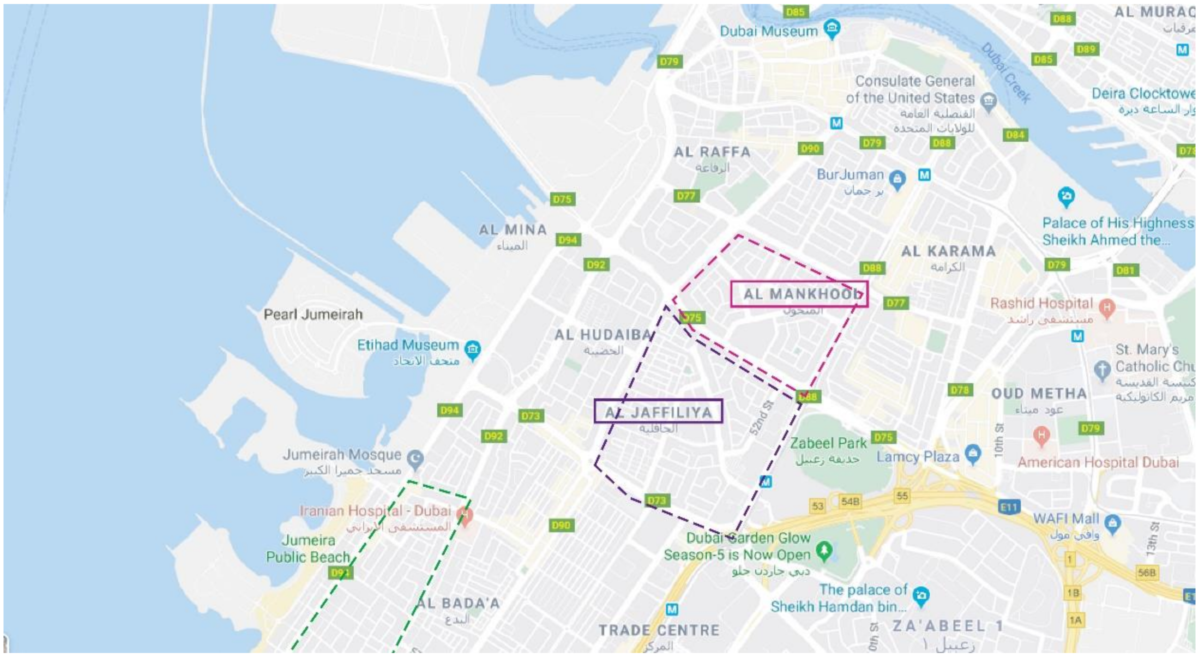

Figure 3.4- Locations of Case Study homes

3.4 Data loggers

The houses that were selected for the research complied with a variety of *Vaastushastra* principles. Principles of *Vaastushastra* can be modified which means the architect who applies them can interpret how the rules can be applied to any built space. A skilled and experienced master architect (*sthapati*) will be able to decipher the principles and apply them successfully. Therefore, the houses that were selected for the test were not all the same, there are minor variations between all of them, but they all follow the core principles.

The aim of the study was to test if the houses built on the principles of *Vaastushastra* provided comfort to the occupants of the homes. Since private homes were the main part of the study the sight, sound and smell were not measured through data loggers, but through users experience of the space by questionnaires. Two similar studies were carried out for homes in Kerala to understand the comfort levels indoors (Dili, 2009) and the model of these studies was used as a basis for the data collected from the 5 selected case studies.

Data loggers were used to monitor only the temperature and humidity of the spaces (Patton, 2002). Data loggers that were used for the study are seen in Fig. 3.5. The loggers were placed in four corners of the house. *Vaastushastra* emphasises on eight directions (four cardinal and four intermediate) of the house, monitoring all the eight directions might end up with similar data collection therefore four intermediate directions were selected. In all cases if there was a window present the logger was placed on the windowsill, if not it was placed at a similar height of 400 or 450mm. Location of the loggers can be seen in the plans of the case studies. By placing the loggers on the sill, the impact of the window on all four sides (north, east, south and west) was studied. If the corner of the house had one window, the logger was placed near the window. Heat gain might be exaggerated due to this purpose, but the windows in all the selected homes are double glazed and tinted. To overcome the concern about too much heat gain the loggers were placed at the ledge of the window and since the loggers are small in size the window ledge prevents any direct heat gain.

Figure 3.5- Data loggers used to measure temperature and humidity

There are two seasons that occur in Dubai, which are summer and winter from which the former lasts for 8 to 9 months and winter is short and lasts for 3 to 4 months. Both seasons will have an impact on the temperature and humidity levels measured in doors, therefore measurements were taken once in each season, in summer and winter. The selected homes were tested in real time, by placing data loggers at the various intermediate corners. The data loggers were used to measure the temperature and relative humidity of the spaces for minimum duration of fifteen days. The measurements were logged at regular intervals of 10 minutes in order to understand the fluctuation of the temperature and humidity in the spaces. Only one house (Case study 1) was measured three times, once in the summer without air-conditioning, once in the summer with air-conditioning and once in the winter without air-conditioning. The remaining for case studies were monitored twice. Data was collected from all five case study homes twice, once in summer with the use of air-conditioning and once in winter without the use of air-conditioning.

The data for the external temperatures was taken from the local weather station web site. Summer temperatures can be very high in Dubai ranging higher than 40°C and not dropping below 30°C. These temperatures make it very difficult for people to go outdoor or to stay indoors without the use of air-conditioning, which made it difficult to record temperatures of the house in the summer. One option was to place the data loggers in the case study houses when the occupants were on holiday, but since there were different families they would go away from the house at different times in summer. To understand the impact that the design of the house had on the internal temperature of the house the external temperature had to be a constant factor and therefore it was important to conduct these tests on the same dates. External temperature was used as the control aspect of the case studies. Each house follows the basic principles of *Vaastushastra,* and the loggers will help to understand the impact each design principle has on the collected data. The anomalies seen in some houses will help to understand the impact of variations have on the recorded data levels if any.

It was not possible to ask the occupants of all the homes to switch of the air-conditioning in the homes during the summer, so one home was set up to test summer conditions without the use of air-conditioning in the house. Case study 1 was selected as a test home as the occupants would be away for 19 days and the air-conditioning would be switched off. This test was done in June from 17th June till 5th July 2016. It was tested at this time because it is one of the warmest months of the year in Dubai. Before the temperature of the house was recorded it occupied which meant that the air-conditioning was switched on before the loggers were set up and therefore it was important to switch off the air-conditioning before the loggers were placed in the house. Loggers were set up in the house one day after the air-conditioning had been switched off, results are discussed under Case Study 1 without air-conditioning chapter 4.1. Care was taken that the loggers were placed in the at the same location when the readings were taken in both summer and winter seasons, since placing them in a different location could tamper with the results.

The loggers were placed in the case study homes during the summer and the occupants were occasionally allowed to switch on the air-conditioning. Occupants of the house were asked to maintain a log of the time that the air-conditioning was switched on and off in the house and this information was considered during the analysis of the temperature and humidity data collected. Similarly, data loggers were placed in the house during the winter when the air-conditioning was not used. But during the winter months the air-conditioning was switched off in all the houses. Both these set ups show how the internal temperature and humidity levels vary based on the climate outside, since the design principles of the house remain the same. It also shows if the use of air-conditioning has a strong impact on the collected data.

3.5. Questionnaires for Users' of Case Study Homes

This thesis will consider the both aspects of the users' comfort by measuring the quantitative aspects such as, temperature, and humidity levels. The questionnaire use a mixed approach, one from understanding users' comfort in a space (Nicol, et al., 2012)and the other from protocol to investigate indoor spaces (Richardson, et al., 2006) Even though each user's experience of a space is subject to their age and gender as these factors have an impact on the way people experience spaces; this data of age and gender was not collected as this would create too many variations in understanding the different levels of comfort that were experienced in the house. The questionnaires were used as a means to understand the levels of comfort that the users' felt in the case study homes. For the purpose of this thesis the users' comfort has been understood in a generalized manner and not investigated further based on personal preferences. The questionnaires where developed from research papers which studied users' comfort in residential spaces. One of the papers discusses comfort factors that need to be assessed in homes (Richardson, et al., 2006), from which the appropriate criteria were selected, and few others were added. Another paper discusses the quality of the indoor environment of green buildings, but some of the factors measured were suitable for residential spaces and therefore were used in the questionnaires (Ravindu, et al., 2015)). A sample questionnaire is attached in the appendix.

The data collected from the questionnaires can be used to understand the comfort levels of the users of the house based on the compliance with the rules of *Vaastushastra* (Chapter 5). Users understanding of a space is based on their sensory experience of sight, smell, sound and touch. Quantitative data that is collected through loggers doesn't acknowledge how the users feel in the space which is investigated through the questionnaires. Each of the senses were linked with useable features of the house, sight was related to natural and artificial light, smell connected with the odours in and around the house, sound is associated to noise levels experienced and touch is based on house the space feels regardless of measured temperature.

The questionnaire was divided into two sections, first was to identify the problems and the second part was to understand how occupants used the space. The first part asks the users if the face any problems with levels of natural light, noise, high or low temperature, bad smell or stale air, static electricity and humidity. The second part connected the user's actions with the sensory experiences and whether their actions and the frequency of the actions changed based on the season. For example, the users were asked how often they switched on air-conditioning during the summer and winter months. These questions are linked to the behaviour in the space which helps to understand the impact the identified design principles had on the aspects of comfort. Data collected from the questionnaires is interpreted in conjunction with the data collected from the loggers to understand the impact the identified principles of *Vaastushastra* have on the users.

3.6. Simulation Software Selected

The house selected for Case study 1 didn't apply all the rules of *Vaastushastra* but was compliant with many of the rules. It was important to understand the impact on the internal temperature and humidity if all the rules of *Vaastushastra* were adhered to. Case study 1 was an existing house and it was not possible to modify the physical house; therefore, this was tested with simulation on a software. Modifications can be easily made and tested using simulation software (discussed in Chapter 7) which shows the change in temperature achieved once the house was designed to comply with the principles of *Vaastushastra*. These modifications made to the case study house test which principles of *Vaastushastra* have an impact on in the internal temperature and humidity.

Since the tests were first carried out during summer it was difficult to judge if the data gathered was reflective of the architecture or of the fact that the homes were constantly air-conditioned. The temperature in the summer touches highs of 45°C with humidity levels of 65% and in such situation, it is impossible for people not to use air-conditioning indoors. In order to overcome this problem, a house which was going to be vacant for two weeks was identified and the data loggers where placed in the intermediate corners. Real time measurements were taken in the house when the temperature of the house was only dependent upon its design principles and features and the air-conditioning was switched off. The data collected did show some interesting findings, but these circumstances could not be recreated in other test homes since it was difficult to find homes which were built on the principles of *Vaastushastra* and would be vacant for two weeks.

The next step was to create the tested house using virtual reality software IES (Integrated Environmental Solutions). There are many software that could have been used for the simulation HEED, EnergyPlus, BeOPT, eQUEST, DesignBuilder, and IES. Out of all this software two are commonly used for Building Performance Simulation (BPS) which are Energy but since IES (Al-janabi, et al., 2019). Various factors influence the reliability of the results from BPS software such as data input quality, competence and knowledge of the user, applied methods in the simulation software and over simplification of complex technologies (Imam, et al., 2017) (Choi, 2017) (Dodoo, et al., 2017). IES is a relatively simple software which can be self-taught and similar to other software that the author has used therefore it was selected.

The results generated from the software are fairly accurate which helps to further investigate the principles of *Vaastushastra*. The software helps to replicate the conditions on site as closely as possible, so that the data generated from the model was similar to the data collected from the physical site which can be seen in chapter 7.

All 5 case studies were monitored in the winter months for a period of 10 days. Since the outside temperatures were cooler, the houses were monitored without the use of air-conditioning. These homes were then simulated using IES software to compare the differences in the temperatures of the real houses verses the simulations. Since the software has its limitations on replicating reality, it was expected to find some variations in the data generated from the software. An acceptable difference is an average of 10% variation between the data collected on site and the data generated from the virtual software (Al-janabi, et al., 2019). With the given range of temperatures of between 20°C and 40°C the variation of 10% ranges between 2-4°C, which doesn't have a significant impact on the results found from the simulation. Once this was successful it would be possible to modify the virtual model to test any changes made to improve the compliance of the house with the principles of *Vaastushastra* and test if these changes would create more comfort for the users. The virtual environment allowed for various changes to be made to the house and to test if these changes had a positive or a negative impact on the data collected (discussed in chapter 7).

3.7. Comfort factors examined in the case studies

From the various factors that can be used to measure the user's comfort in the homes, the four factors that are used in this thesis are mentioned below. These will be the factors which will be measured in all the case studies, twice in the year, to understand if the residents are comfortable in the space.

Sight is measured by the ability to be able to clearly see in a space by means of natural of artificial light. Natural daylight is an essential factor that relates to users' comfort. The design of the house can have an impact on the availability of natural light. This study will understand if the principles of *Vaastushastra* have an impact on the light levels experienced. The user of a space relies on daylight (when available) or use of curtains to block it out and similarly use of artificial light when daylight is unavailable. Light levels of a house can easily be modified to suit the occupant and their preferences based on the activity carried out. For example, some people like to sleep during the afternoon with the use of black out curtains and others prefer to read at night with artificial light. The user can easily adapt light to suit their needs in residential spaces.

Sound doesn't typically vary too much within a home as the activities that create noise within a house are usually caused by its residents. Some noise that comes from the outside is filtered by the time it can be heard by the occupants and therefore shouldn't be too high. Exceptions to this might be street or traffic noise which is dependent on the location of the house. When noisy activities are carried out in the house, in most cases, all the occupants are a part of this activity or are tolerant towards it. The sound level cannot be and should not be zero as constant silence is not always very pleasant. Some sound is needed but this sound should be minimal and nonintrusive. Sound is generated by the appliances in the house – heating or cooling systems or refrigerators or washing machines etc. and in Dubai due to the temperature outside the biggest problem of noise at home comes from the constant use of air-conditioning. This study will examine if the design on the house has an impact in the indoor temperatures which in turn have an impact on the use of air-conditioning and therefore the sound levels within the house.

Smell is the level of pleasant or unpleasant odour that the user can detect. To an extent the odours of the house are also largely controlled by the occupants since the activities in the house determine the odours. At the same time there are some odourless gasses that are also harmful for the people. These smells and gasses are typically constant in houses and the variation is usually minimal depending on the air circulation of the house. The exceptions to this would be when the house is maintained with materials that contain VOC's, if natural ventilation is not provided in the kitchen then cooking gasses and odours can be troublesome to the occupants. In the case of the latter air fresheners (which don't contain VOC's) in the house can maintain pleasant odours.

<u>Touch</u> is the aspect of the study that reflects how the user feels in the space. There are many factors that govern touch, from surface temperatures of the finishes used, to the clothing worn by the inhabitants of the space and to an extent the way in which the space is built (Nicol, et al., 2012). This thesis focuses to a large extent on this aspect, which is the way in which the built space influences how the users' feel in the space. There are many aspects about the design of the built space that have an impact on the temperature and humidity level and the comfort of the users.

The reason for the selection for the case studies was that the users feel and the experience of each of the houses was comfortable for the most part. The initial positive experience of the house was based on various comfort factors that were felt in the space without any data collection. The next stage tested the comfort parameters by recording them. Even though each of the selected houses complies with different rules but as a whole each of the houses can be considered compliant with *Vaastushastra* and was therefore selected for the testing.

Key principles of *Vaastushastra* are identified in Chapter 2.3.8. Each of the 5 case studies are discussed below in relation to these key principles. Two of the identified seven key principles of *Vaastushastra* have been identified as being the same way to all five selected houses. These two principles are, firstly none of the houses have a central courtyard present and secondly all the houses use concrete as the main material for construction. It was difficult to find mid-size houses in Dubai which had a central courtyard, due to which none of the selected houses have this feature. This is an important aspect of *Vaastushastra* and therefore needs to be tested. Both these features of use of courtyard and variation of material used to construct the shell of the building will be tested in the simulation stage of the thesis which is in chapter 7.

A brief introduction to each case study is provided below –

3.7.1 Case study 1

Figure 3.6- View of main entrance from side walk

Figure 3.7- South facade

Figure 3.8- Covered car park

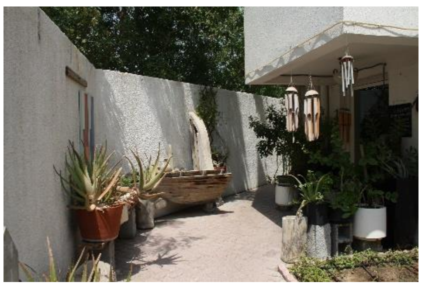

Figure 3.9- House entrance view with compound wall

Figure 3.10- View of living room doors

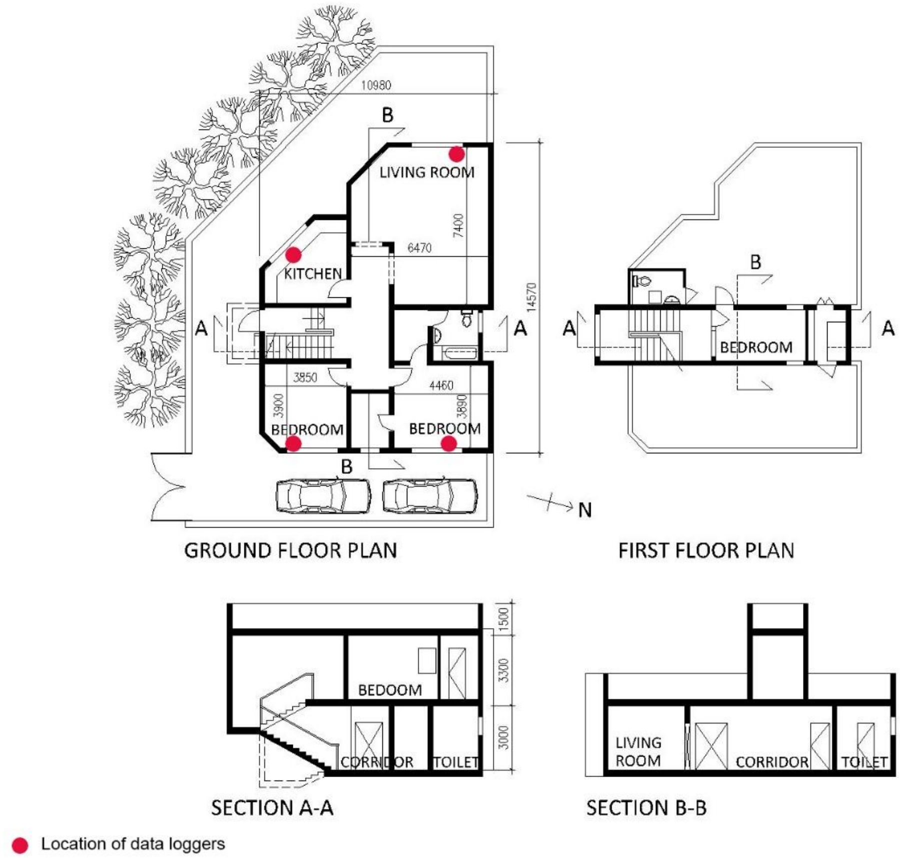

Figure 3.11- Case Study 1 Plans and Sections

The house selected for the first case study was a mid-size family home which was approximately 180m^2; it is built on two levels with an internal staircase and an open garden space. The spaces in the house include a kitchen, living room, dining room and one bedroom which has an attached full bathroom and there is a shared guest toilet on the ground floor (Fig 3.11). The upper floor has the 2 bedrooms and each bedroom has an attached bathroom and is the private space of the house. The house has trees to one side when seen from the main road (fig 3.6). The house sits very close to the fence and the trees on the south and west side provide a fair amount of shade in the front of the house. The staircase acts like a canopy to the entrance area so the space is fairly pleasant to use in the cooler months of the year (fig 3.9).

The cooling system used in the house is individual air-conditioning units. In addition to this the house has a ceiling fan in the living space and floor fans around the house and these are used in suitable weather conditions. The spaces most occupied in the house are on the ground floor which includes the kitchen, living room and bedroom. There are openable windows on both levels of the house, of which there is a sliding glass door that opens into the garden area and is used as a window.

The house is not thoroughly aligned with all the rules of *Vaastushastra* but does follow some of the crucial ones which are the following –

The orientation of the house has almost the correct orientation. The ideal orientation is that the building should be oriented with the east west axis on the length of the building. This building is oriented slightly so that the length is slightly away from the east west axis. The rotation of the angle is 15°away from the east west axis which is within the acceptable limit of variation. Any house that is rotated away from the cardinal directions isn't compliant with the principles of *Vaastushastra*.

The proportions of the house itself comply with the proportions that are established by *Vaastushastra* as the house is rectangular as an overall shape. The dimensions of the house are 14.5m by 11m and therefore the proportion of the house is 1:75. The southwest corner is cut in this house which breaks the overall rectangular shape and is used to study the impact of irregular shaped geometry.

The proportions of the house make it comfortable for the user even though it is a small space. The house has been designed well which means that the internal spaces have been laid out well, so the space is completely utilized. Even though the area is on the smaller side the house doesn't feel cramped when it is used.

Placement and size of the windows. Some of the windows of the house are placed on east wall, but there aren't any windows on the north wall. The living room is in the northwest and is the largest space in the house with the largest window that is placed on the south wall (fig 3.10). This feature is not only a window but also a door to the backyard of the house. The largest window in the house is placed on the west wall. There are a few windows on the south side too which is not in line with the principles of *Vaastushastra*. The window on the south wall is placed in the staircase (fig 3.7). It is 2m x 6 m in height and it allows for natural light in the house. There are two windows on the east wall, and these are covered by the covered canopy which covers the car park (fig 3.8). Windows on the south and west side will help determine of the impact these have on the users' comfort levels in the space.

Proportion of the rooms in the house also follow suggested proportions because each room is rectangular in shape and is based on proportions that are recommended in *Vaastushastra*. Even though the rooms are rectangular they have a proportion of 1:85 up to 1:97, with the proportion of a square room being 1:1. The concern is that some rooms are cut off at corners, this helps examine if the pure geometry has an impact on the comfort levels of the users.

The house has **windows on the south and west side** and these windows do not have any window overhangs or shading devices. This will help to determine if heat is gained from these sides of the building when shading is not provided and if it has an impact on the users' comfort factors.

3.7.2 Case Study 2


Figure 3.12- View of house from road


Figure 3.13- Front facade


Figure 3.14- East facade of house


Figure 3.15- South facade of house

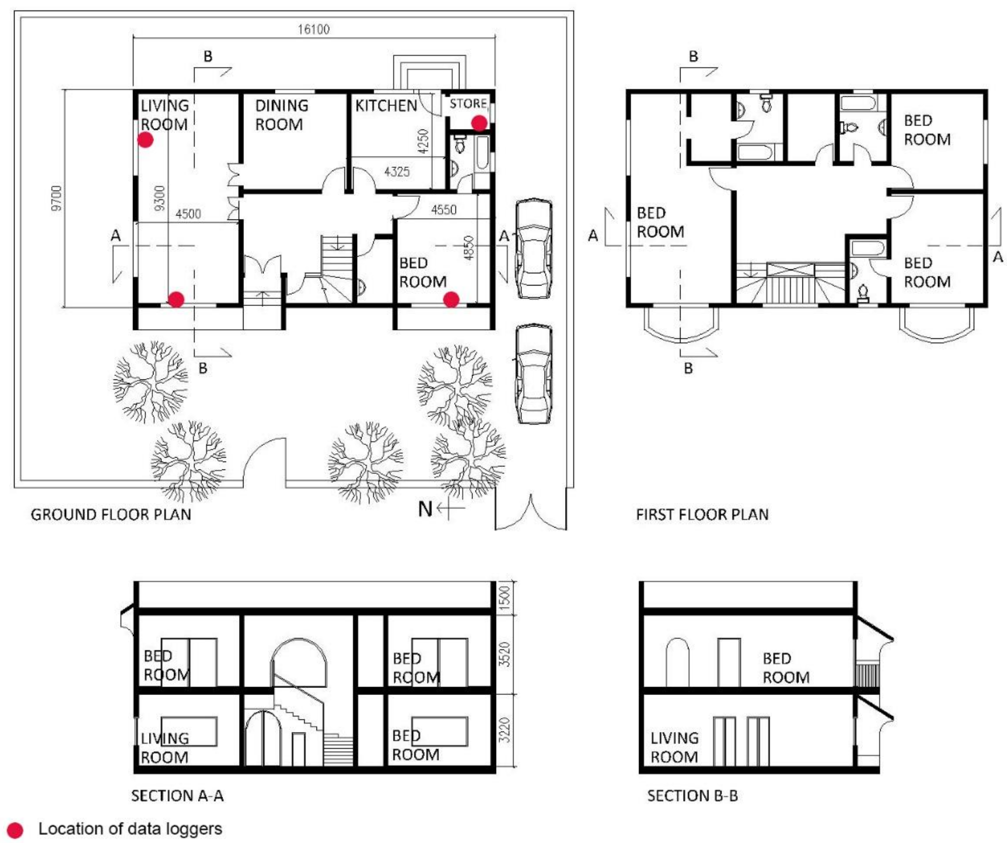

Figure3.16- Case Study 2 Plans and Sections

The second case study selected bigger than the first case study in terms of size because it was 300m² with two levels, an internal staircase and open garden space. This house is set back from the boundary wall and has a fair size garden in front of the house (Fig 3.12). there are a couple of trees located outside the boundary wall of the house. The garden is located on the west side of the house and has plotted plants as well as trees. This space is used by the occupants during the cooler months of the year and during the cooler times of the day. The space behind the house is small and doesn't have any trees, but does have some potted plants (Fig 3.14, 3.15). The spaces in the house include a kitchen, living room, dining room, a bedroom with an attached bathroom and a guest toilet on the ground floor. The upper floor is the private space and has three bedrooms out of which two have attached bathrooms and one bathroom is shared with the others.

Each of the rooms that are occupied have individually controlled air-conditioning units and the corridor spaces do not have any operable cooling systems. No other cooling systems are used in the house. The house has openable windows on both floors, with balconies on the upper floor (fig 3.13) with openable glass doors which are double up as windows allowing for natural ventilation in the cooler months. The spaces that are most occupied are located on the ground floor which are the living room, dining room, kitchen and the bedroom.

The house is compliant with the rules of *Vaastushastra* in the following ways –

The orientation of the house aligns with the cardinal directions and the length of the house lines up with the north/ south axis which is acceptable in *Vaastushastra*. *Vaastushastra* stipulates that the house should be aligned to the cardinal directions. This house will examine if the orientation to the north south has an impact on the comfort levels of the users.

The proportions of the house are based on the proportions of *Vaastushastra*; the house is rectangular in proportion which is one of the recommended ratios and shape. The house is 16m x 10.7m which gives an overall proportion of 1:66.

Placement and size of the windows. The windows in the house are on the north, east and west. Windows on three sides help to determine if these windows have the expected impact on the interior space and on the comfort levels of the users. There are two windows on the north wall, and these are both located in the livening room. These windows are 2.4m x 1.3m and allow suitable natural light into the space during the summer, but during the winter the room can be a bit darker. There is another window of the same size placed on the west wall of the living room, but this has a shading device. There are windows on the east wall which are the same size and located in separate rooms to provide adequate natural light in both dining room and kitchen. There are only two small windows located on the south wall on the ground floor of house which are 0.9m x 1.5m (Fig 3.14). By measuring temperature and humidity on all sides it is easy to compare the recorded temperature and understand the impact that the design of the house has on the internal space.

Proportion of the rooms in the house are rectangular and square and match the overall proportions of the house; with the exception of the living room, which is longer than it is wider and the proportion of this room is 1:48. The other rooms on the ground floor of the house are almost square in proportion with ratios of approximately 1:92. Use of rectangular and square geometries as the shape of the rooms and the house will help determine the impact these have on the comfort levels of the users.

Windows on south and west sides. In this house there aren't too many windows on the south side of the house, just two small windows on the south façade which don't have an overhang. The west wall of the house has two large windows, but these are recessed into the house and have an overhang which can possibly prevent heat gain. The size of these windows is 2.4m x 1.3 m. These are set back by 1m and have an overhang on them as seen in fig 3.13. The readings from these spaces will show the impact the overhangs have on the users' comfort levels.

3.7.3 Case Study 3

Figure 3.17- View from main road East façade

Figure 3.18- South façade

Figure 3.19- North façade

Figure 3.20- West façade

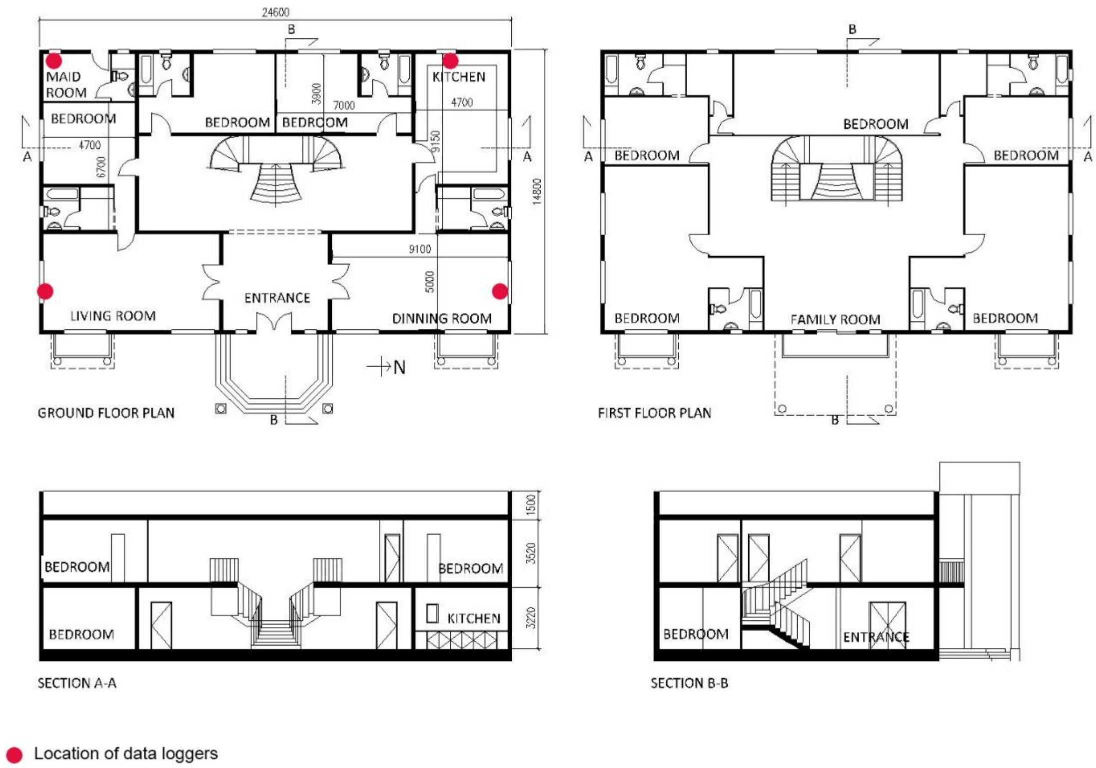

Figure 3.21- Case Study 3 Plans and Sections

The next house is larger than the first two and is 650m² in built up space. This house is also a two-storey house with an internal staircase and an elevator. The outdoor space is paved and could be used for outdoor seating for large or small gatherings and has dedicated spaces for parking cars (Fig 3.17). There aren't any elements of landscape in the yard of the house which prevents the outdoor space from being used by the occupants since it is very hot for most part of the year. This results in the space being used primarily as a car parking space. If there were some landscape elements the occupants could have used the outdoor space when the weather was conducive. This is the only house in the study that has windows on all four sides. The east façade has some shading structures (Fig. 3.17) but the other three sides don't have any shading for the windows.

The ground floor has the formal living room, formal dining room, casual dining room, guest bedroom, kitchen and storeroom. The upper level has the casual living space and four bedrooms each with an attached bathroom. There is a central void in the house where the staircase is located which makes the family room on the top floor an open space where all the sounds of the house can be heard. The house has central air conditioning units with individual controls for each room. There are no other cooling systems used in the house. The house does have openable windows that can be used for cross ventilation when the weather gets better. The spaces that are most occupied are the living room and bedrooms that are on the upper floors.

The house is compliant with the rules of *Vaastushastra* in the following ways –

The orientation of the house aligns with the cardinal directions and the length of the house lines up with the north/ south axis which is acceptable principle of *Vaastushastra*. This isn't the most ideal orientation of the house, but it is one of the options that can be used. It is important to understand the impact that orientation has on the house and it will be examined though this case study.

The proportions of the house are based on the proportions of *Vaastushastra*; the house is rectangular in proportion which is one of the recommended ratio and shape. The house is 24.6m x 14.8m which has a proportion of 1:60 which is more towards which is close to golden ratio of 1:618. This is one of the factors that is unique to this house and the data collected will check if it has any impact on users' comfort levels.

Placement and size of the windows. The windows in the house are on all sides therefore are seen on north, south, east and west sides. Larger windows are of the size 2.2m by 2.4m in height. These large windows are located on all sides of the house (Fig 3.17, 3.18, 3.19, 3.20). According to *Vaastushastra* these are acceptable on the north and east abut not on south and west facades. Many of these windows have a decorative arch on them which is representative of the architecture seen in Dubai and isn't representative of *Vaastushastra*. There are some small windows on north east and west facades too and these are mainly to ventilate the bathrooms. Smaller windows are 1m by 1.5m and are partially openable for ventilation purposes. Windows on all sides help to determine if these have the expected impact on the interior space and on the comfort levels of the users.

Proportion of the rooms in the house are rectangular and square, the rectangular rooms are similar to the overall proportions of the house and the square rooms are different in proportions. The rectangular rooms such as the living room, dining room and kitchen have the proportion of 1:5 which makes the room twice in length than in width. The length of these rooms is approximately 9m while the width is about 4.5m each. The bedrooms on the other hand have the proportions of 1:7 with the sizes of 6.5m by 4m and more. Combining both proportions of spaces on the ground floor might have an impact on the users' comfort.

Windows on south and west sides. The house has windows on the south and west side, but these windows do not have any window overhangs or shading devices (Fig 3.18, 3.20). This will help determine if there is heat gain from these sides of the building and if it has an impact on the users' comfort factors.

3.7.4 Case study 4

Figure 3.22- View from the street

Figure 3.23- South facade

Figure 3.24- South and east facade

Figure 3.25- West facade

Figure 3.26- Case Study 4 Plans and Sections

The fourth house is also larger and has a built up of 550m^2 built up space. This is a two-storey house which has two sets of internal staircases and one elevator. This house is part of a compound of three villas and therefore sharing its compound space with the other houses. The shared compound space is primarily used as car parking space and each house has its own deck space which is used for outdoor private sitting in the cooler months. The outdoor space is hardscaped for the most part with some trees, potted plants, shrubs and a small patch of lawn (Fig 3.25). There are a few trees that are seen from outside the house and these are located outside the property (Fig.3.22).

The geometry of the house isn't an exact square, but the overall proportions and shape match are close to a square shape. The house is a four-bedroom house with the private spaces on the top floor and the semi-private spaces on the ground floor. The lower floor has an entrance lobby that has a double height void, one staircase that leads to the upper floor and another staircase that leads to the basement level. The ground floor has the formal living and dining space with a guest toilet, kitchen and office and a room that is used as a temple. The upper floor has all the bedrooms and each of the rooms have attached bathrooms. Main source of cooling in the house is the central air- conditioning and each space has a control of its own. No other cooling systems are used in the house. The house does have openable windows that can be used for cross ventilation when the weather gets better. The spaces that are most occupied are the living room and the office on the ground floor and the one of the bedrooms on the first floor. The remaining bedrooms are not used as much since only one couple lives in the house.

The house is compliant with the rules of *Vaastushastra* in the following ways –

The orientation of the house aligns with the cardinal directions and the length of the house lines up with the east west axis which is a core principle of *Vaastushastra*. Since the house is close to the proportions of a square, either dimensions of the house are similar and therefore can be considered as the length of the house. For this study we will consider that the house is aligned with the east and is therefore highly recommended in terms of alignment with the cardinal directions.

The proportions of the house are based on the principles of *Vaastushastra*, especially since the house is of square proportions. Both the length and width of the house are approximately 16.5m which gives the house the proportions 1:98.

Placement and size of the windows. The house doesn't have too many windows on the north façade which shows on the plans of the house. Since the north wall doesn't have windows and it is the part of the house that connects with the neighbouring houses, it wasn't photographed. The pictures show the other part of the house that has many windows. The building looks like one big house but is 3 houses built together, part of the neighbouring house can be seen in fig.3.22. Majority of the windows are placed on the east façade (Fig 3.24), with a couple of windows on the south façade and openable glass doors on west side (Fig 3.25). The room in the northwest corner is the only one that doesn't have any window, since this is the wall that connects to the other houses.

Proportion of the rooms in the house for most of the rooms are either rectangular or square, except for the room in the southeast which doesn't follow the suggested proportions. The living room and the office are close to square proportions with proportions close to 1:98. The room in the southeast corner is longer in length compared to its width and has a proportion of 1:61 which makes it an irregular room. The kitchen is in the northeast and has a proportion of 1:4 which is also not an acceptable proportion. The placement of the irregular shaped room in the house will help determine the impact it has on the comfort levels created in the house.

Windows on south and west sides. The house has windows on the south and west side and these windows do not have any window overhangs or shading devices (Fig 3.23, 3.25). The dining room which is in the northwest corner of the house doesn't have any windows and gets light through the door that opens onto the deck. This will help determine if there is heat gain from these sides of the building and if it has an impact on the users' comfort factors.

3.7.5 Case study 5

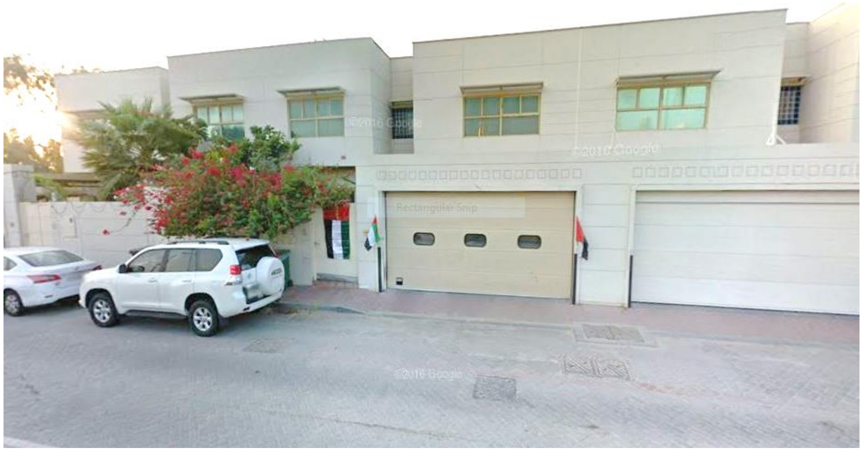

Figure 3.27- View from main road (east facade)

Figure 3.28- West facade

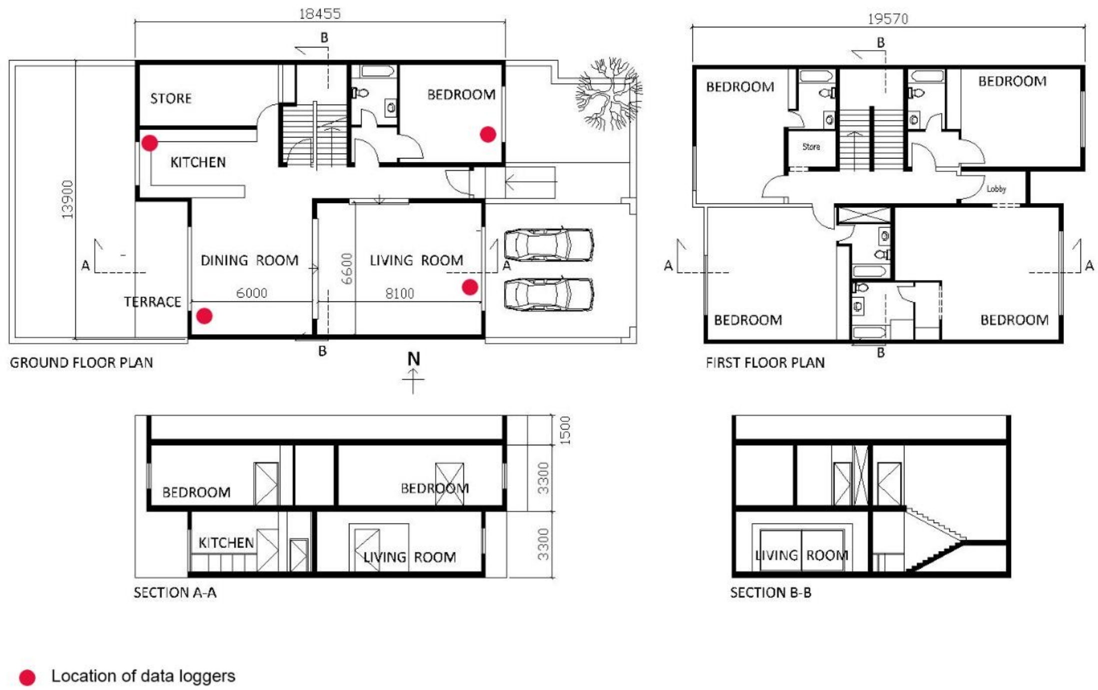

Figure 3.29- Case Study 5 - plans and sections

The last house selected as a case study has a built-up area of 450m². This is another two-storied house which has an internal staircase and outdoor green space. The house is a row house and shares compound walls on the north and south sides. The space in front of the house is used for parking and has a small front garden and a patio at the back with an outhouse. The house feels like a big open space on the ground floor because the living room and dining room open into each other. The bedroom on the ground floor and the store are not noticeable when you enter the house. The backyard space is on the west side of the house but is relatively cooler in the winter months and therefore is used as a social gathering space. This is used both by the family and by guests as a space to relax and interact. The backyard and the front garden have some trees and shrubs (Fig 3.27, 3.28). The upper floor provides a small overhang to the backyard on the ground floor.

The ground floor has the living room, dining room, kitchen and a bedroom with an attached bathroom. The upper floor has four bedrooms which each have attached bathrooms. The cooling system used in the house is central air-conditioning with individual controls for various rooms or spaces. There are no other cooling options available in the house. The space most occupied on the ground floor is the living room and on the first floor are the individual bedrooms. There are openable windows on both levels of the house, of which there is a sliding glass door that opens into the garden area and is used as a window.

The house is compliant with the rules of *Vaastushastra* in the following ways –

The orientation of the house aligns with the cardinal directions and the length of the house lines up with the east west axis which is a core principle of *Vaastushastra*. The house is rectangular in proportion and the width aligns with the north south axis which follows the principle of *Vaastushastra*.

The proportions of the house are rectangular and is in proportion the ratio suggested in *Vaastushastra*. The dimensions of the house are 18.5m x 14m which gives the house a proportion of 1:75 which is similar to the proportions of case study 1.

Placement and size of the windows. The house doesn't have too many windows and is used to study the impact this condition has on the internal conditions and users' comforts. Most of the windows are located on the east side (Fig 3.27), with a couple of windows on the west side (Fig 3.28). The windows on the east façade are 4.2m by 1.3m. On the west façade there is a large window which is also a door and has the dimensions of 4.2m by 3m. The kitchen has a smaller window which is 2.2m by 1.3m (Fig 3.28).

Proportion of the rooms in the house rooms are either rectangular or square which follow the rules of *Vaastushastra*. The living room is of rectangular proportions of 1:75 which is similar to the overall proportions of the house. The dining room has square proportions since both the length and width are approximately 6m and has a proportion close to 1:1.

Windows on south and west sides. The house has windows on the west side and one of the windows has a small architectural overhang. The other window doesn't have any overhang.

Chapter Four: Understanding User Comfort through Data Collection

4.1 Introduction

This chapter examines the data collected from the temperature and humidity loggers that were paced in the case study homes. The first part of this chapter discusses the data collected from case study 1 during the summer without the use of air-conditioning. The second part shows the data collected from all five case studies homes during the summer but with the use of air-conditioning. The third part shows the data collected during winter months and without the use of air-conditioning.

To test the principles of *Vaastushastra* five homes were selected for case studies which were compliant with the principles of *Vaastushastra* as discussed in chapter 3.7.1 to 3.7.5. The aim of the data collection is to compare the temperature and humidity readings between summer and winter months. During the winter months the houses did not use air-conditioning, which shows the impact the principles of *Vaastushastra* have on the indoor spaces. Whereas in the summer the air-conditioning was operational in the house. Data loggers that are used in the case studies are discussed in chapter 3.4. For external temperatures the data was taken from the weather station website weather underground (Anon., 2019).

The trends in temperature during both the seasons are seen in this chapter from which we can start to identify the impact key principles of *Vaastushastra* can have when applied to homes in Dubai. As explained in chapter 3, the house selected for case study 1 was studied under 3 different circumstances once in the summer without air-conditioning, once in the summer with the use of air-conditioning and once in the winter without the use of air-conditioning (Table 4.1). The first house was monitored three times because it was empty in the summer therefore could be monitored without the use of air-conditioning. Since the remaining homes were not empty at the same time, they weren't monitored without use of air-conditioning. These temperatures were then used to verify the simulation studies carried out in chapter 7. Data loggers were placed in the remaining four houses twice, once in summer with air-conditioning used by the occupants and once in the winter without the use of air-conditioning. The five were also modelled using the simulation software to verify the data generated.

Case Study Number	Summer without air-conditioning	Summer with air-conditioning	Winter without air-conditioning
1	✓	✓	✓
2		✓	✓
3		✓	✓
4		✓	✓
5		✓	✓

Table 4.1- Circumstances when data was collected in the case study homes

All the case studies were selected based on their compliance with the rules of *Vaastushastra*. The houses that have been selected for the thesis exhibit different applications of the rules of *Vaastushastra*. Criteria for selection of the case study houses is based on the variation of the rules of *Vaastushastra* which have been discussed on Chapter 3.7.1- 3.7.5.

4.2. Case Study 1 data collected without air-conditioning

The first case study was set up in a house (described in Chapter 3) that was vacant for twenty days (16/06/2016 till 05/07/2016) and therefore it was possible to understand the impact the design of the house had on the internal temperature and humidity when air-conditioning was not used in the house. Temperature and humidity data loggers were placed at the four intermediate directions of the house – northeast, southeast, southwest and northwest. The rules of *Vaastushastra* suggest that the north side of the house (northeast and northwest) should be cooler than the south side of the house (southeast and southwest) if the openings of the house are as recommended in the manuscripts.

This case study was set up to understand the impact on the internal temperature and humidity levels when the house follows most of the key principles of *Vaastushastra*. The exceptions to the principles in this house are that some of the rooms are not rectangular but with a corner that is cut off which breaks the basic geometry of the shape. The house also has windows on the south and west side which are not covered by overhangs.

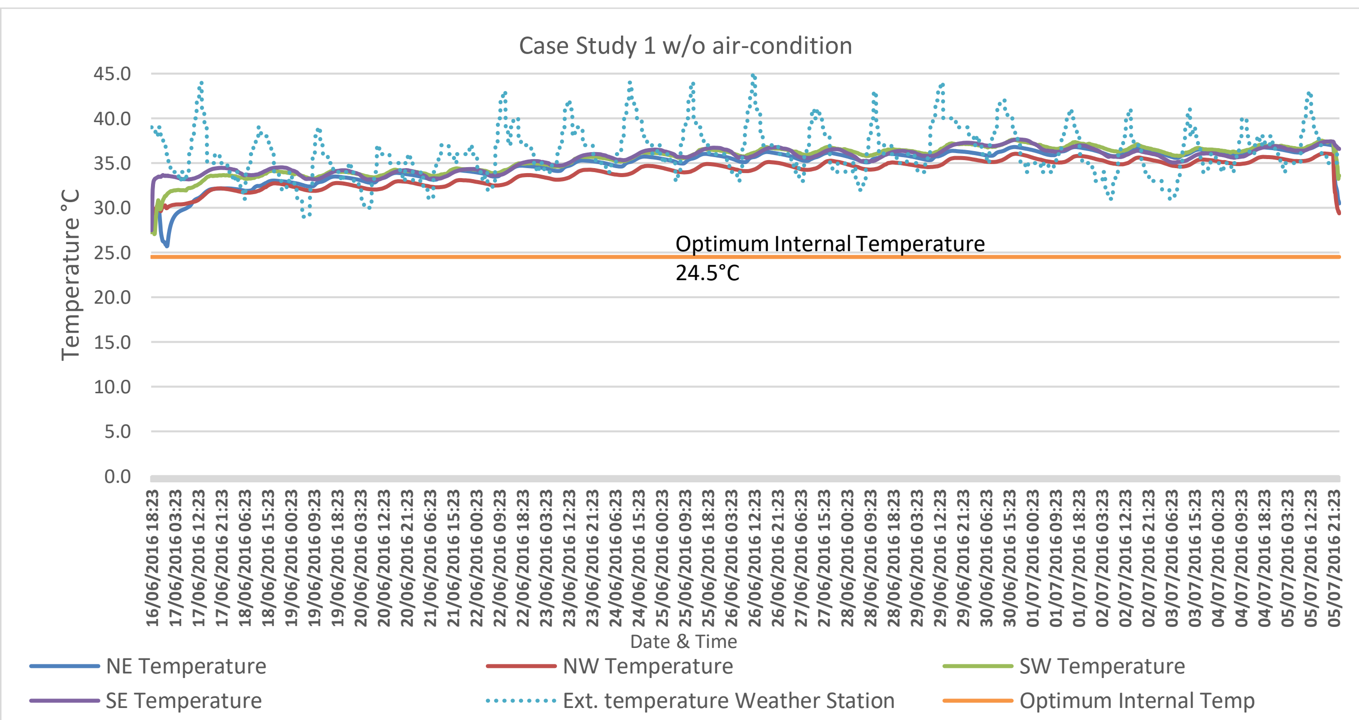

Figure 4.1- Internal temperature compared to external temperature- Case Study 1

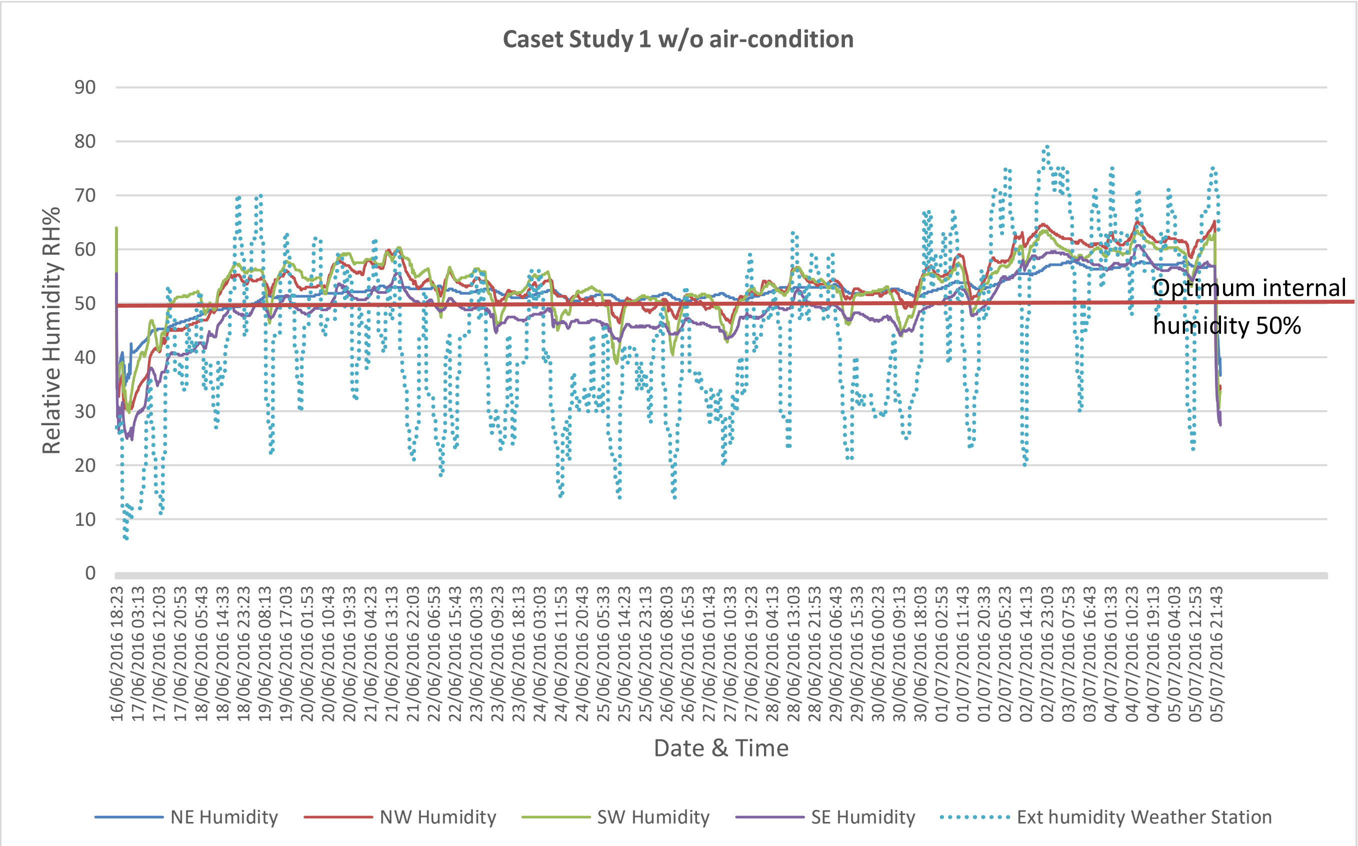

Figure 4.2 - Internal humidity compared to external humidity - Case Study 1

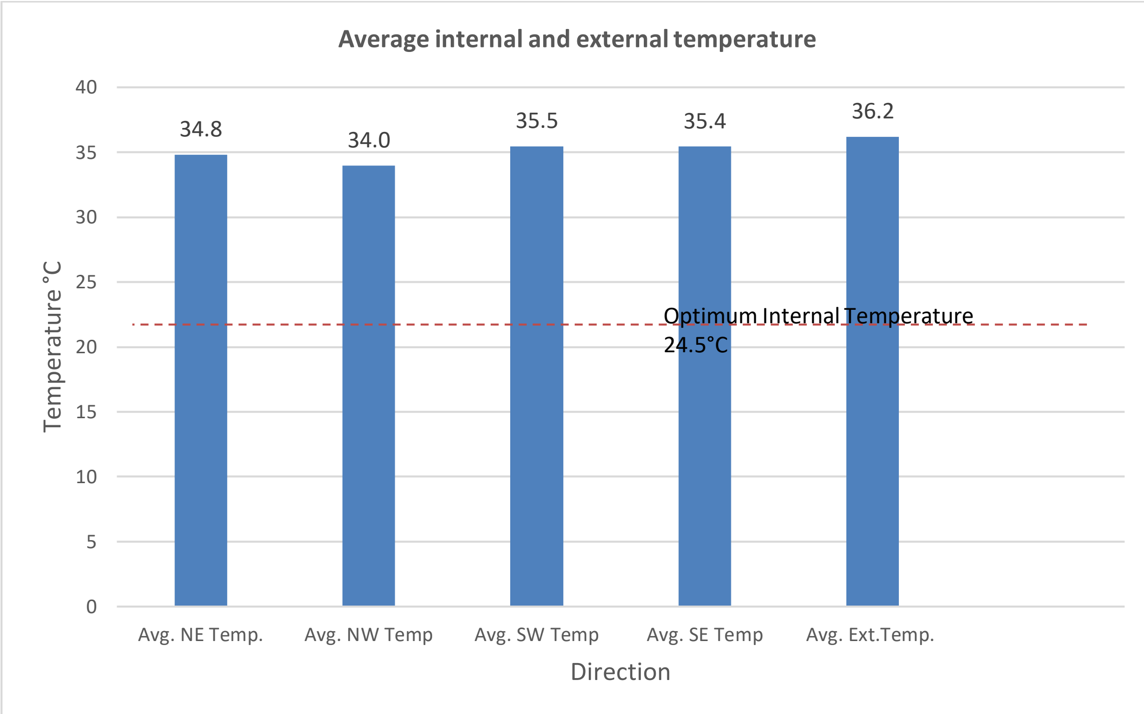

Figure 4.3 - Average internal and external temperature - Case Study 1

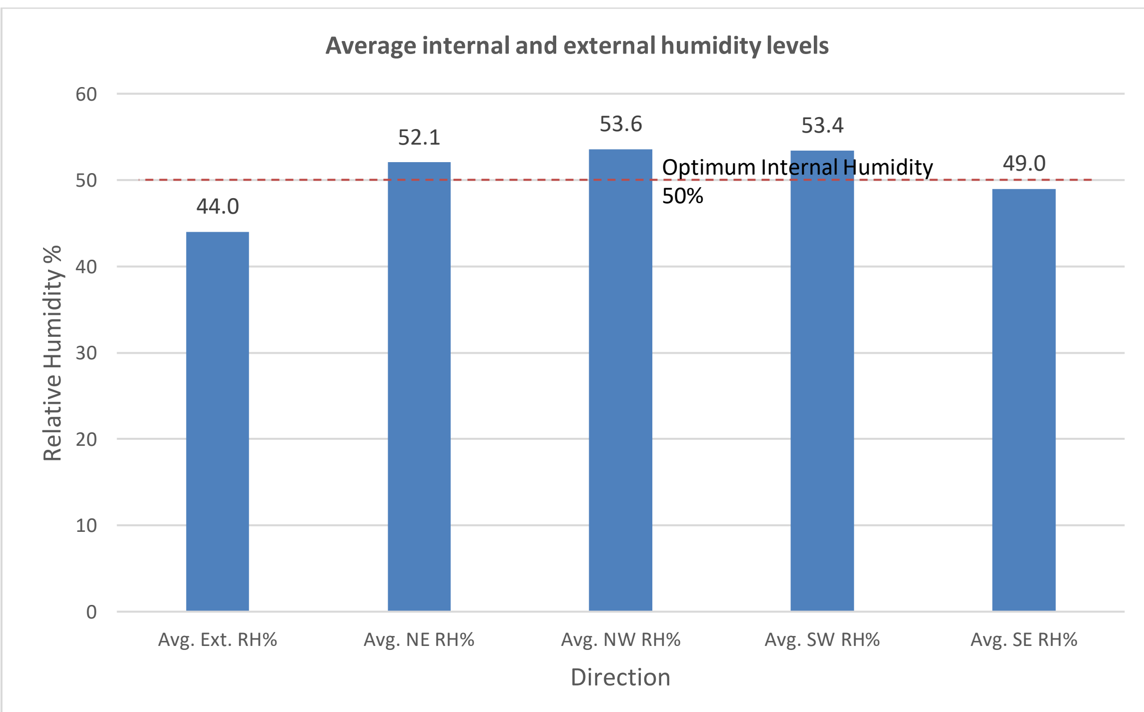

Figure 4.4- Average internal and external humidity levels - Case Study 1

The data collected from the house shows the following –

The temperature inside the house steadily gets warmer as the days progress, since the air-conditioning is switched off and the internal temperature gets progressively warmer through the subsequent days (Fig. 4.1). The maximum internal temperature appears to cap off at 38°C. Internal temperatures recorded does not rise too high and similarly doesn't don't dip lower than 30°C. The principles of the design of the house appear to help to maintain the house within 8°C variation of temperature, even without the use of air-conditioning. Even though these temperatures are higher than the accepted temperature range of 22.5°C and 26°C in the summer when the recorded humidity is 50%, the study shows that the internal temperature can be maintained within a limited range.

External temperature climbs at a much faster rate than the internal temperature gain, the internal heat gain happens at a very gradual rate. Similarly, the external temperature drops at a much faster rate compared to the rate at which heat from the house is lost, this could be caused by the insulated concrete which prevents the internal temperature from increasing or decreasing rapidly and simultaneously with the external climate.

Average temperatures from all four directions reflect that the north side is cooler than the south side, but the northwest is cooler than the northeast by an average temperature of 0.9°C and there isn't too much temperature difference between the southeast and southwest (fig. 4.3). This could reflect the fact that the house is oriented as per the principles of *Vaastushastra*, which is that the length of the house is aligned with east west axis. This could be reflective of the fact that the house isn't perfectly aligned to the cardinal directions but is rotated by 15°. The southwest room is the warmest room, which could be due to the fact that it doesn't follow the rectangular geometry and the angular cut in the room is of significant proportion. Average external temperature recorded was 36.2°C. The northwest side is 2.2°C lower in temperature than the average external temperature which is the coolest side of the house. Similarly, the southwest is the warmest side and is cooler than the outside by 1.6°C.

This theory will be tested in the chapter 8 that investigates this house through simulation software. In chapter 8 this case study house will be modified multiple times to observe the internal temperatures when the house is designed based on all the principles of *Vaastushastra*.

Average difference in temperature between the hottest side (southwest) and the coolest side (northwest) is 0.7°C (Fig.4.3). Average indoor temperature is lower than the average external temperature, but the opposite happens with the average internal humidity. The average external humidity is lower than the average internal humidity with the southeast measuring the least average difference of 5% RH and the northwest recording the highest average difference of 9.6% RH (Fig 4.4). Humidity recorded in the house is higher than that recorded outside with only the southeast side measuring humidity lower than 50%. The northwest has the lowest recorded temperature but the highest recorded humidity level. But the southwest has the highest recorded temperature but isn't the lowest for the humidity.

Date	*16/6*	*17/6*	*18/6*	*19/6*	*20/6*	*21/6*	*22/6*	*Standard Deviation*
Average Temperature Variation	8.1	4.1	1.7	0.6	0.6	1.2	2.8	2.7

Table 4.2- Case study 1 temperature variation for week 1 without air-conditioning

Date	*23/6*	*24/6*	*25/6*	*26/6*	*27/6*	*28/6*	*29/6*	*Standard Deviation*
Average Temperature Variation	2.2	2.3	1.6	1.6	0.7	0.1	2.3	0.8

Table 4.3- Case study 1 temperature variation for week 2 without air-conditioning

Date	*30/6*	*1/7*	*2/7*	*3/7*	*4/7*	*5/7*	*Standard Deviation*
Average Temperature Variation	1.2	-0.1	-1.1	-0.9	0.4	0.4	0.9

Table 4.4- Case study 1 temperature variation for week 3 without air-conditioning

Temperature variations between external and internal temperatures in case study 1 are high at the beginning of the study at 8.1°C, averaging at 2°C through the middle of the study and falling to approximately 0.5°C towards the end (table 4.2- 4.4). Towards the end of this study the internal temperature is warmer than the external temperature by a maximum of approximately 1° but this increase doesn't continue rather the internal temperature starts to drop after it touches the maximum. Even though the exterior temperature continues to be high the internal temperature appears to stabilise within the data collected. The maximum difference in temperature is 8.1°C which is seen at the beginning when the house is relatively cooler because of the use of air-conditioning in the space. The minimum difference in temperature is -1.1°C (Fig. 4.4) when the house is warmer than the outside. The standard deviation of the temperature for each week is mentioned in each table 4.2,4.3 and 4.4 and the standard deviation for all the days is 2.01. The standard deviation is higher during the first week of study at 2.7 and drops to below 1 for the next two weeks. The internal temperature stays at a higher range but doesn't vary too much once the air-conditioning is off for a week.

4.3. Test Data Recorded in 5 Case Study Homes (Summer)

To investigate the impact of principles of *Vaastushastra* further the study was repeated in five houses including the house from the first case study. The difference was that the occupants were using the air-conditioning throughout this study. These case studies were carried out in the summertime (01/08/2016 till 08/08/2016).

The data gathered by placing the loggers in the five houses and the observations from this data is shown below-

4.3.1 Case study 1 with the use of air-condition

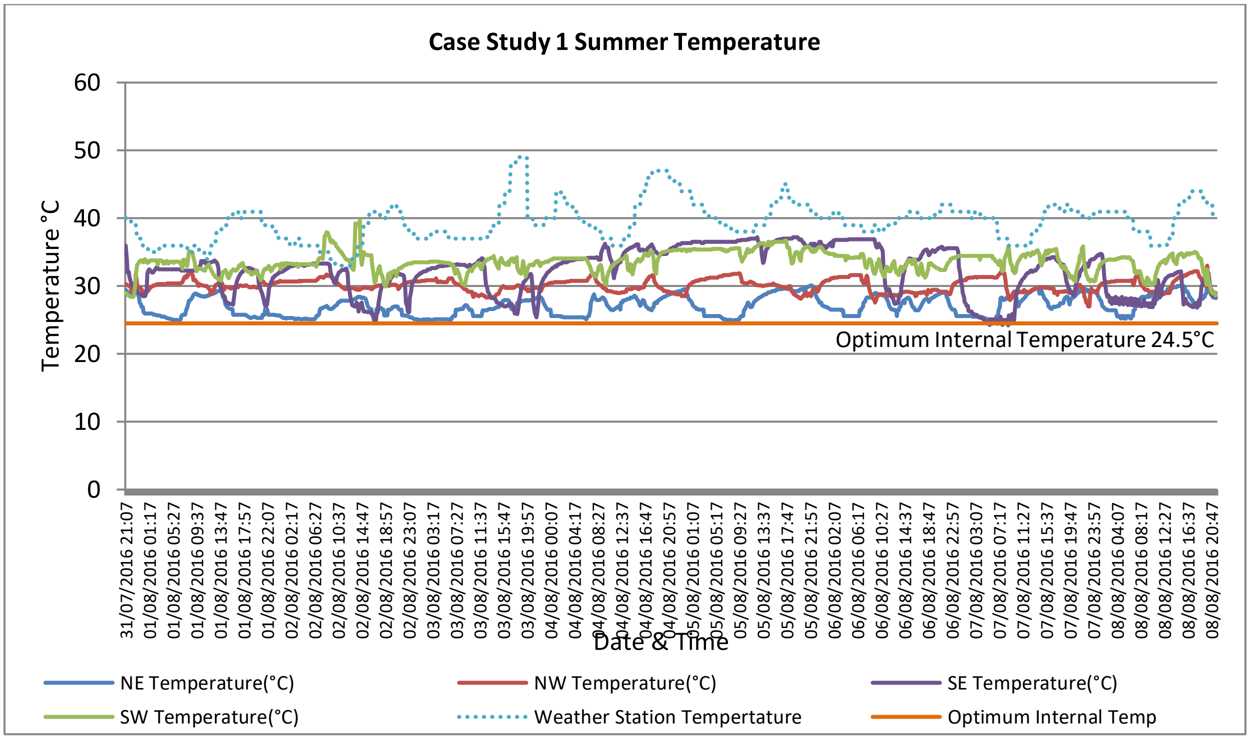

Figure 4.5- Internal temperature compared to external temperature- Case Study 1 with A/C

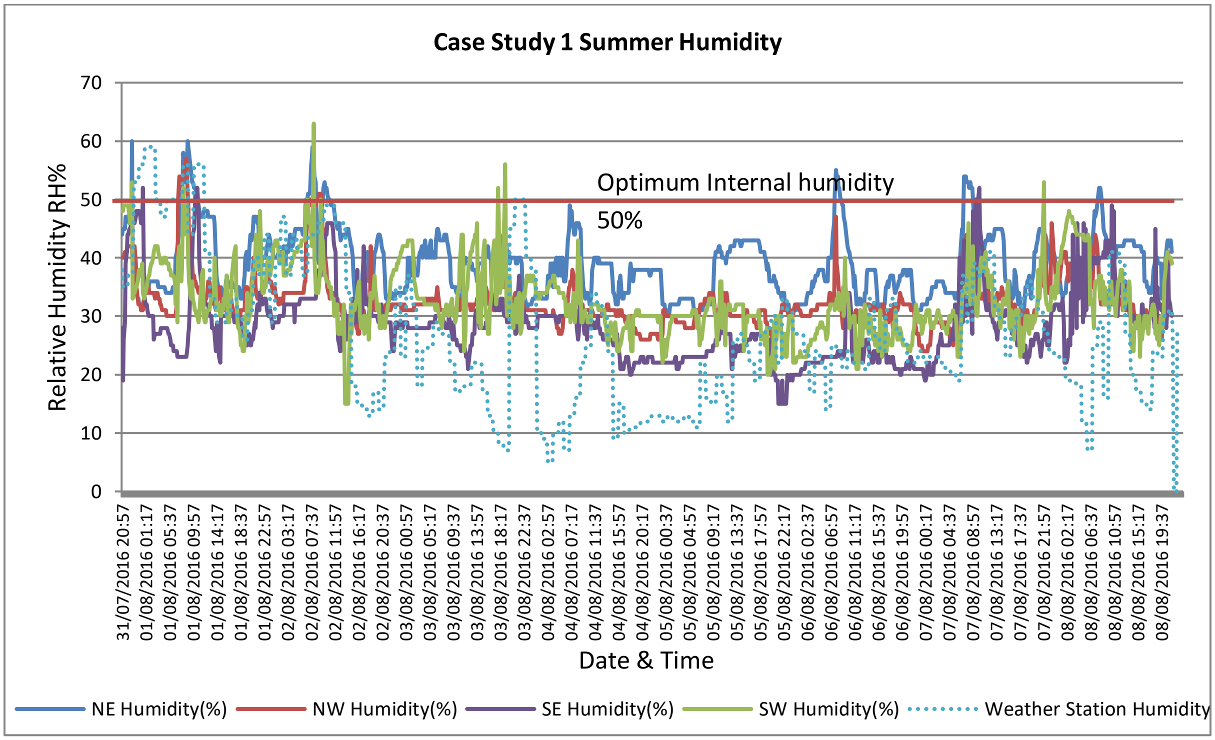

Figure 4.6 - Internal humidity compared to external humidity- Case Study 1 with A/C

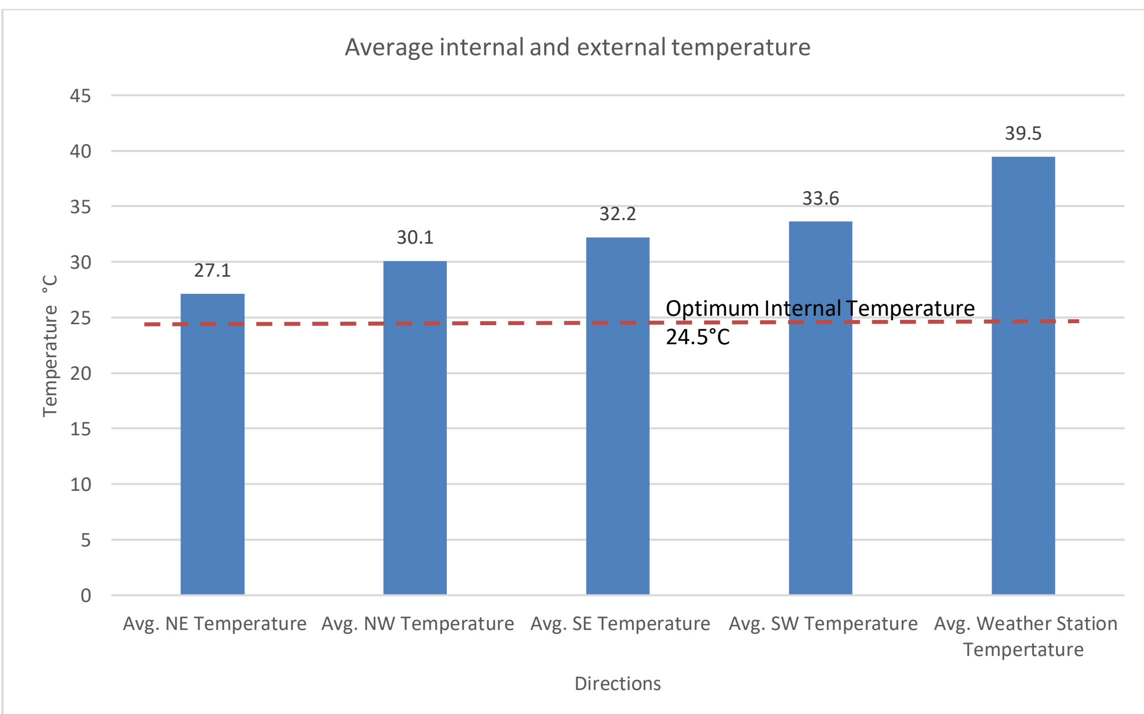

Figure 4.7- Average internal and external temperature - Case Study 1 with A/C

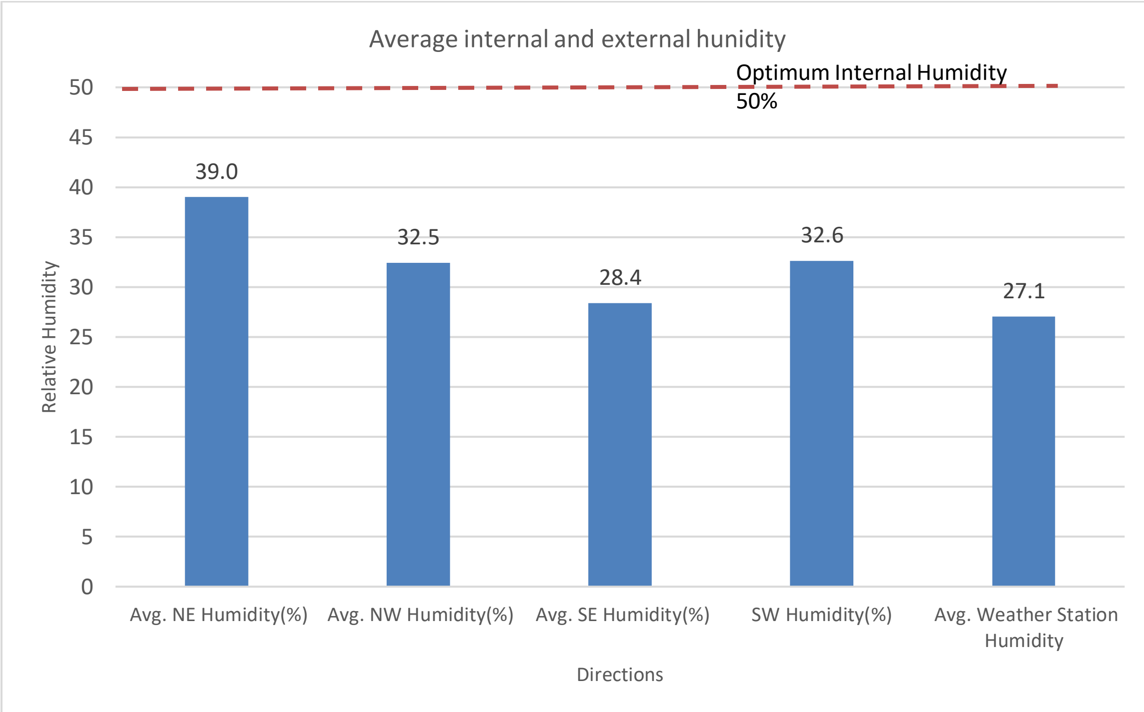

Figure 4.8- Average internal and external humidity - Case Study 1 with A/C

External temperature climbs at a much faster rate than the gain in internal temperature but gain in external temperature doesn't directly reflect on the internal temperatures (fig.4.5). The internal temperature is maintained at a lower temperature since the air-conditioning is operational based on the needs of the occupants. The internal temperature is maintained at an average of 33.4°C with the use of air-conditioning which is similar to the average temperature recorded in the same house without the use of air-conditioning at 34.9°C (fig.4.3). This helps to understand that even with occasional use of air-conditioning the temperature doesn't drop drastically.

Northeast side is the coolest side while the southwest is the warmest side of the four selected intermediate directions (fig.4.7). The southeast is expected to the be the warmest side, but in this house the southwest is recorded as warmest because the geometry of the room is not pure rectangle. Average temperatures from all four directions reflect that the north side is cooler than the south side, but the northeast is cooler than the northwest by an average temperature of 3°C and the southwest is warmer than the southeast by 1.4°C. Average difference in temperature between the hottest side which is the southwest and the coolest side which is the northeast is 6.5°C.

Average external temperature recorded was 39.5°C and the average internal temperature difference ranges from 5.9°C in the southwest to 12.4°C for the northeast sides. The graph shows that the house is higher in humidity, which is probably due to the use of air-conditioning, as the lower internal temperature is a cause for the humidity to rise. Average indoor temperature is lower than the average external temperature, but the internal humidity is higher inside the house. The southeast measures the least average difference of 1.3% RH and the northeast recording the highest average difference of 11.9% RH (fig 4.8). The expected humidity range would reflect the pattern seen in the temperature, but the southwest direction is not the lowest humidity as expected but it was the southeast. This could be because the southwest room doesn't have an air-conditioning unit and is cooled based off the air-conditioning in the rest of the house. Other than that, the northeast is the highest humidity which reflects the fact that northeast is the lowest temperature and the fact that the air-conditioning unit is placed in this room.

Both studies of this house show that the north side has a lower average temperature than the south side which links to the principle of *Vaastushastra* that emphasises on the suitable orientation of the house. It shows that even with the use of air-conditioning the temperatures on the south side are higher which could be due to the windows on this side. Similar to temperature the humidity is higher on the north side than on the south side as the air-conditioning reduces the temperature in the space but increases the humidity levels.

Date	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*	*Standard Deviation*
Average Temperature Variation	7.2	8.9	9.5	10.1	8.2	8.5	9.3	9.9	0.9

Table 4.5- Case study 1 temperature variation in summer with air-conditioning.

The standard deviation in the house is under 1 at both times during the summer, when the air-conditioning is off (table 4.3,4.4) and when the air-conditioning is on (table 4.5) which shows that the principles of design have an impact on the internal temperatures. The variation is seen in table 4.2 where the standard deviation is high, but this is probably linked to the fact that the air-conditioning was on before the temperatures were recorded. The highest internal temperature variation with the air-conditioning on is 10.1 and lowest is 7.2 which is different from the variations noted during the summer when the air-conditioning is off.

4.3.2 Case study 2 with the use of air-condition

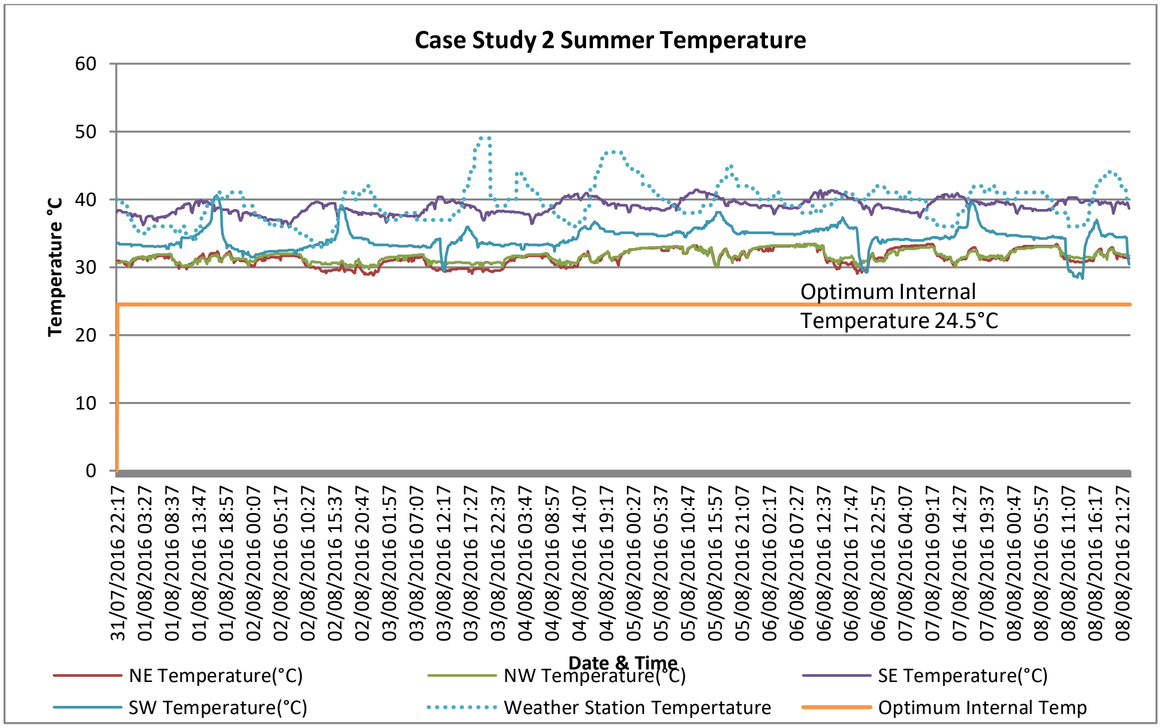

Figure 4.9 - Internal temperature compared to external temperature- Case Study 2 with A/C

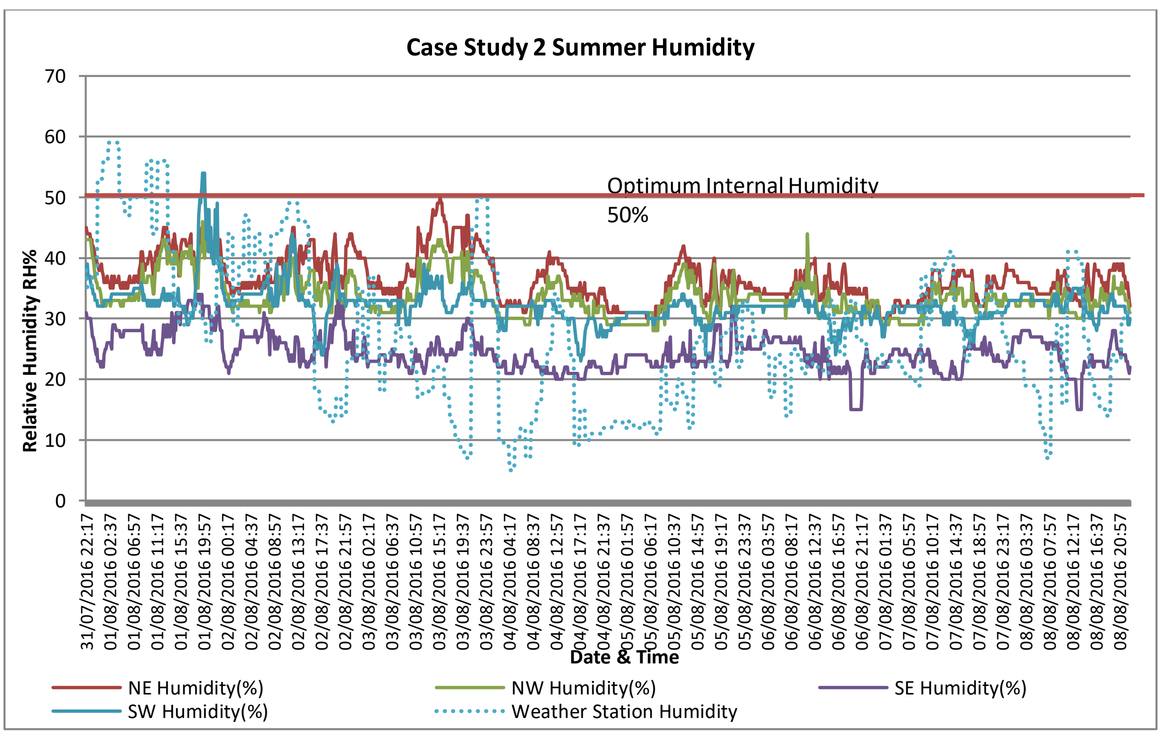

Figure 4.10- Internal humidity compared to external humidity- Case Study 2 with A/C

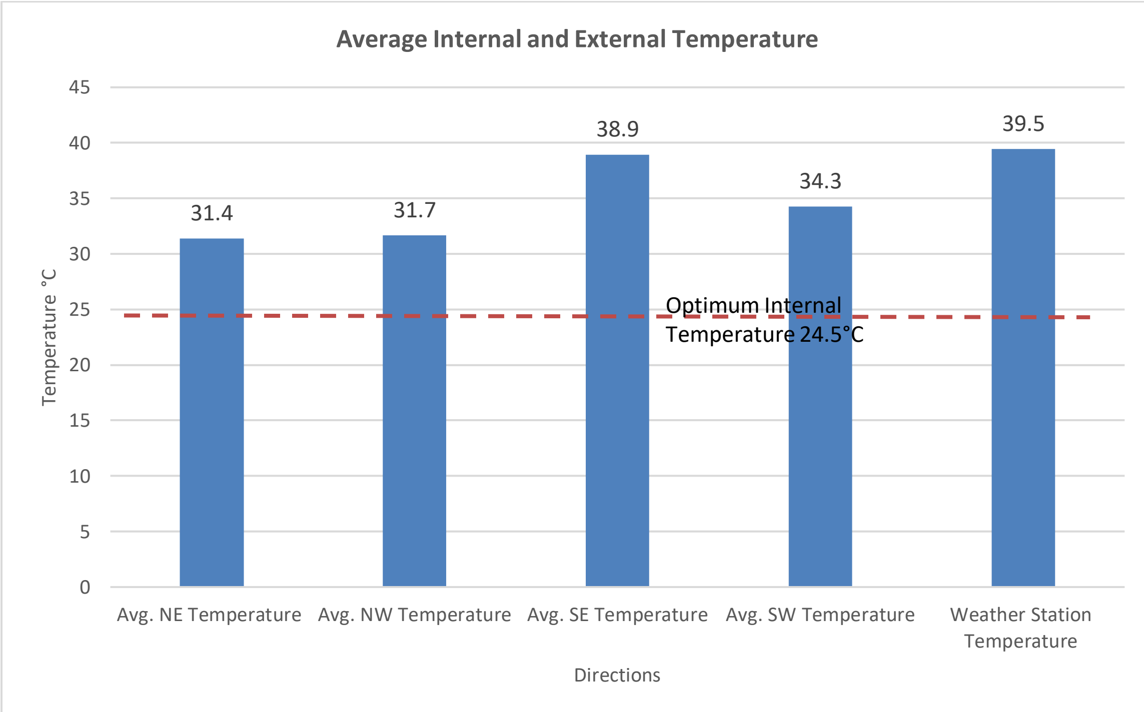

Figure 4.11- Average internal and external temperature - Case Study 2 with A/C

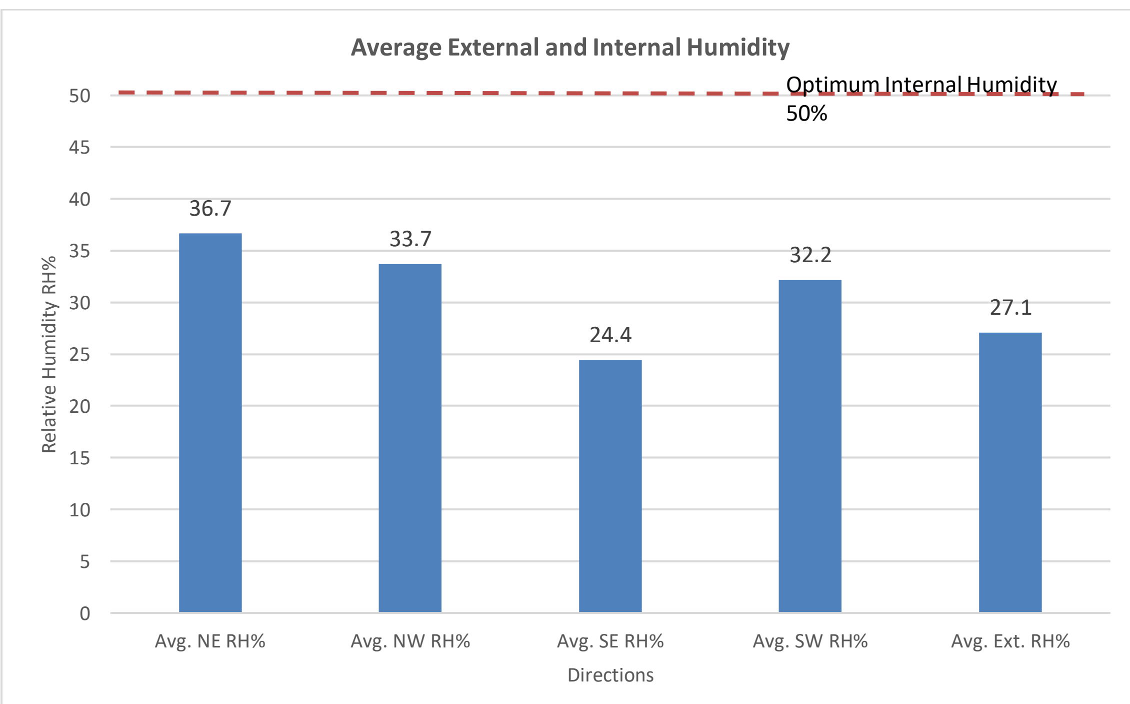

Figure 4.12- Average internal and external humidity - Case Study 2 with A/C

The internal temperature of each room stays within a band of 5°C expect for the southwest room which shows fluctuation in temperature (fig.4.9). The house maintains the temperature lower than 39°C with an average internal temperature of 34°C even with the air-conditioning operational occasionally. Northeast side stays the coolest side and southeast is the warmest of the four selected intermediate directions which is the expected outcome based on *Vaastushastra*. Average temperatures from all four directions reflect that the northeast is cooler than the northwest by an average temperature of 0.3°C and the temperature difference between the southwest and southeast is 4.6°C. Average difference in temperature between the hottest side of the house which is southeast and the coolest side which is the northeast is 7.5°C. Average external temperature recorded was 39.5°C and the average internal temperature difference ranges from 8.1°C to 0.6°C for the northeast and southeast sides respectively.

The average internal humidity is higher than the external humidity with the expectation of southeast side (fig. 4.12). The southeast is lower than average external humidity with a difference of 2.6% RH and the northeast recording the highest average difference of 5.9% RH. The expected humidity range does reflect the pattern seen in the temperature; the southeast direction is the lowest humidity as expected. This could be due to the fact that this room doesn't have an air-conditioning unit and is cooled based off the air-conditioning in the rest of the house. Other than that, the northeast is the highest humidity which reflects the fact that northeast is the lowest temperature and the fact that the air-conditioning unit is placed in this room.

Date	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*	*Standard Deviation*
Average Temperature Variation	3.8	3.9	6.3	7.2	6.0	5.2	5.0	5.8	1.2

Table 4.6- Case study 2 temperature variation in summer with air-conditioning.

The standard deviation of the second case study is higher than the first which shows that the variation in principles has an impact on the internal temperatures. The highest average temperature variation is 7.2°C and the lowest is 3.8°C (table 4.6).

4.3.3 Case Study 3 with the use of air-condition

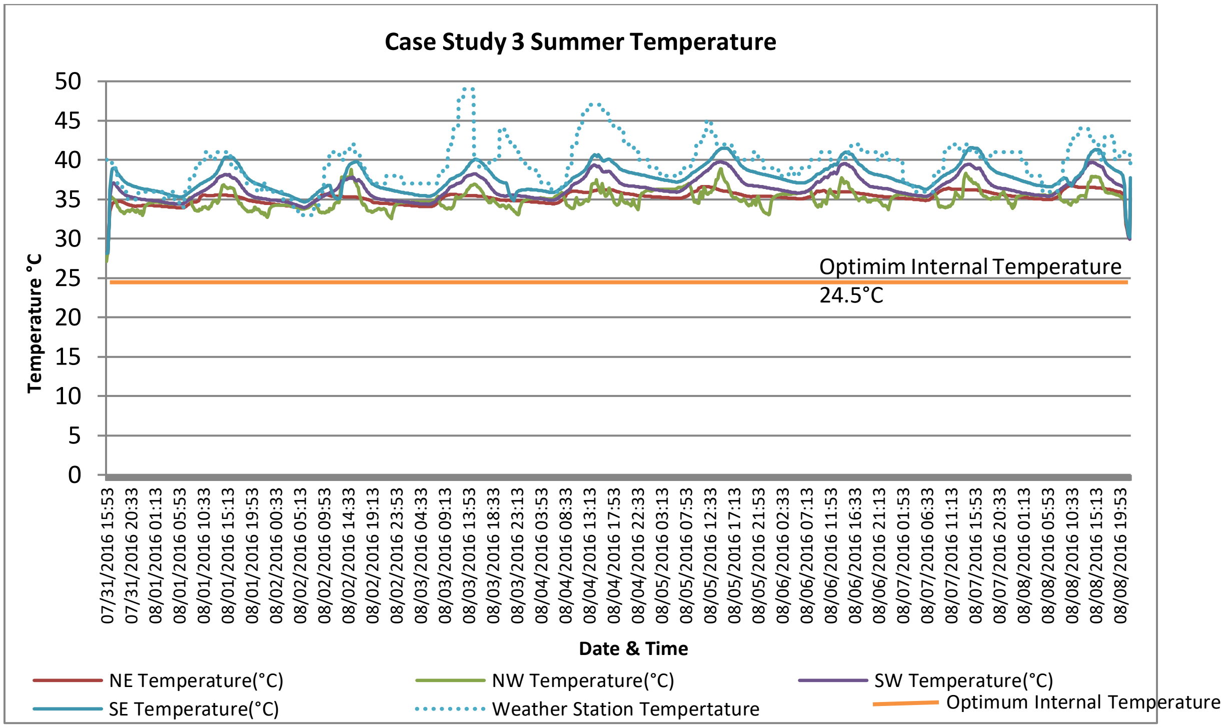

Figure 4.13- Internal temperature compared to external temperature- Case Study 3 with A/C

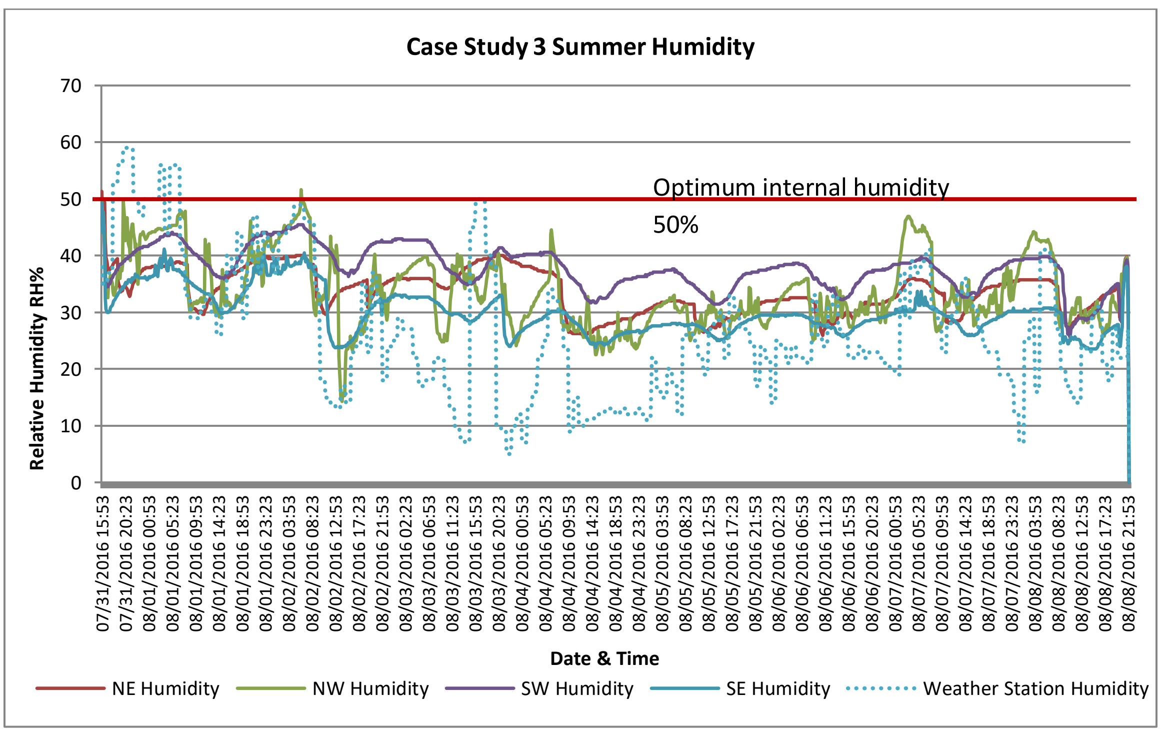

Figure 4.14 - Internal humidity compared to external humidity- Case Study 3 with A/C

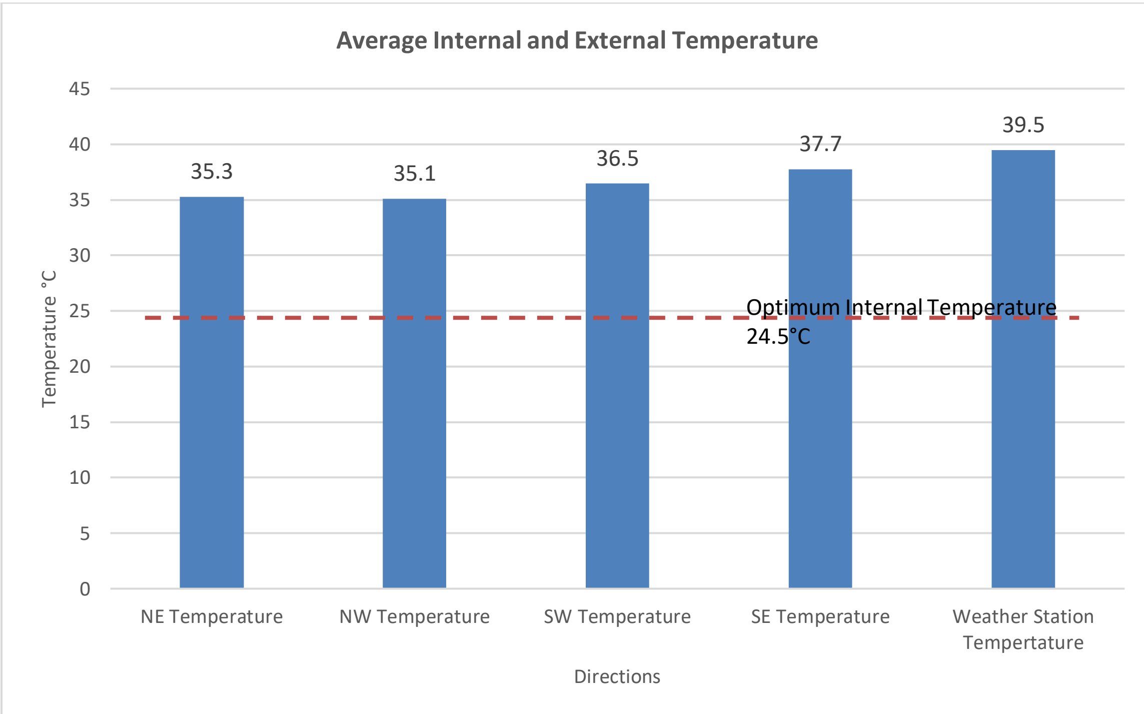

Figure 4.15 - Average internal and external temperature - Case Study 3 with A/C

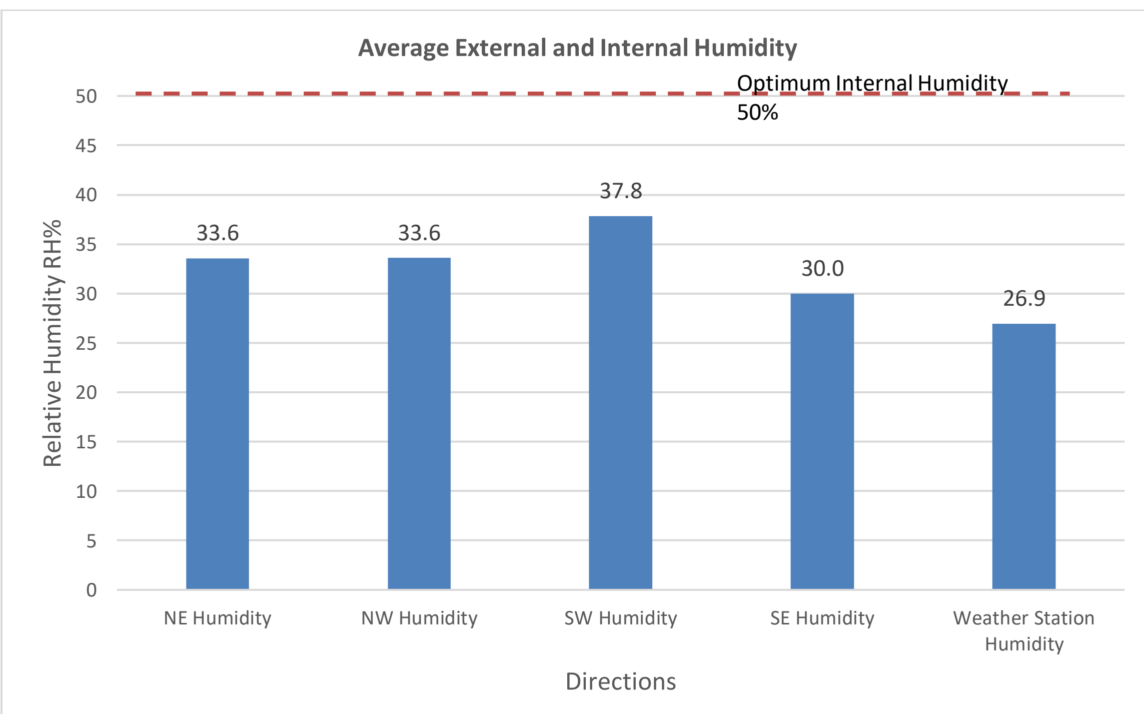

Figure 4.16 - Average internal and external humidity - Case Study 3 with A/C

Internal temperature of the house rises during the day and drops in the evening almost simultaneously with the external temperature, even though the air-conditioning was operational, unlike the other studies the temperatures in case study 3 rise and fall through the day. The recorded temperatures were averagely higher than 35°C (fig. 4.15).

The northeast side staying the coolest side and the southeast the warmest of the four selected intermediate directions (fig.4.13). Average temperatures from all four directions reflect that the northeast and northwest average temperatures are very similar and the temperature difference between the southwest and southeast is 1.2°C. Average difference in temperature between the hottest side which is the southeast and the coolest side which is the northeast side is 2.4°C. Average external temperature recorded was 39.5°C and the average internal temperature difference ranges from 1.8°C to 4.4°C for the southeast and northwest sides respectively. The graph shows that the house is higher in humidity which is due to the use of air-conditioning, which means that in this house the air-conditioning is unable to reduce temperature but keeps the humidity high.

The average external humidity is lower than the average internal humidity with the southeast measuring the least average difference of 3.1% RH and the southwest recording the highest average difference of 10.9% RH (fig. 4.16). The expected humidity range would reflect the pattern seen in the temperature, but the southeast direction is lowest humidity as expected but the northwest didn't record instead the highest humidity it was recorded in the southwest. This could be because the south side is this house don't have any external shading devices or trees which increases the internal temperature and humidity.

Date	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*	*Standard Deviation*
Average Temperature Variation	2.1	1.9	4.9	5.1	3.4	3.3	2.9	3.8	1.1

Table 4.7- Case study 3 temperature variation in summer with air-conditioning.

The standard deviation for case study 3 is higher than 1 with the minimum temperature variation at 2.1°C and the maximum at 5.1°C. variations in temperature reflect that the house has windows on all sides, which causes heat gain at different times of the day.

4.3.4 Case Study 4 with the use of air-conditioning

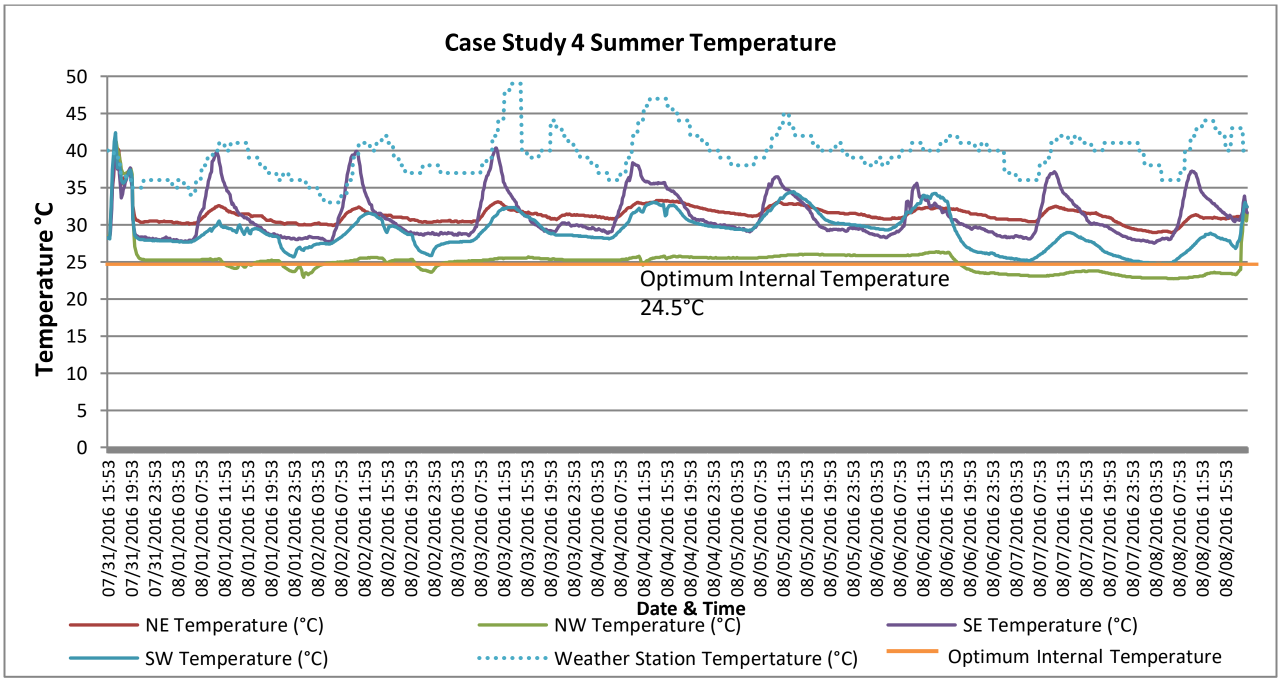

Figure 4.17- Internal temperature compared to external temperature- Case Study 4 with A/C

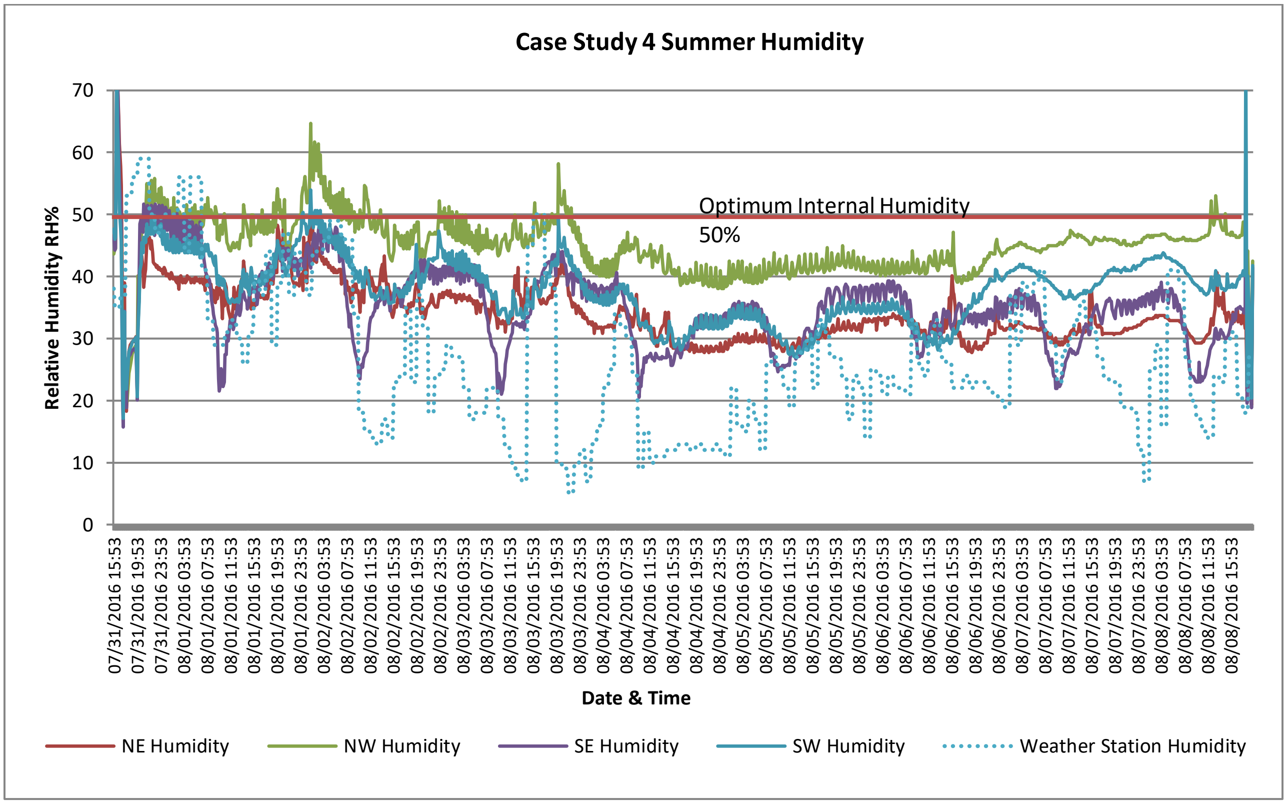

Figure 4.18 - Internal humidity compared to external humidity- Case Study 4 with A/C

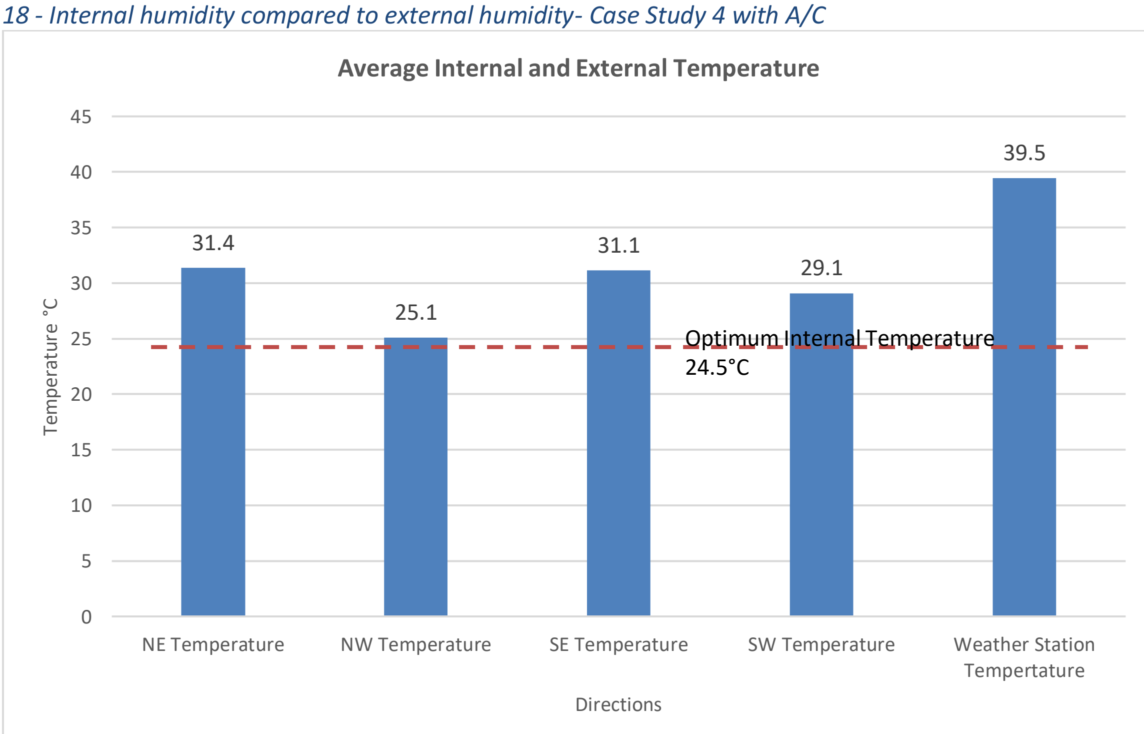

Figure 4.19- Average Internal and External Temperature Case Study 4

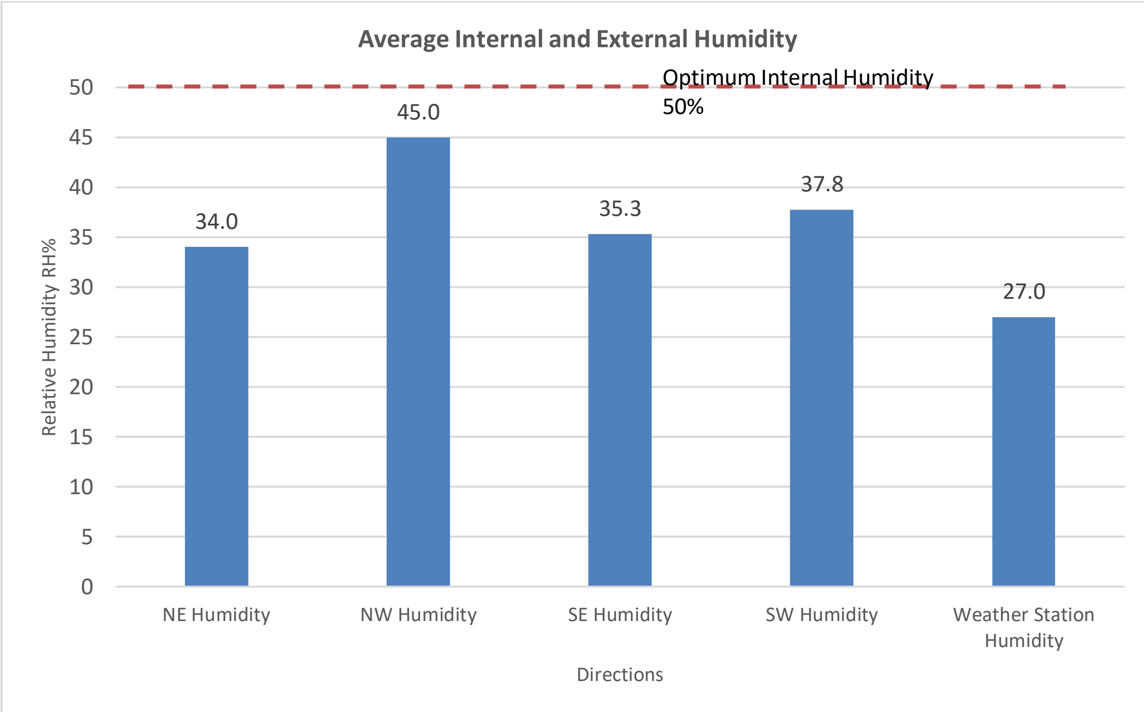

Figure 4.20 - Average Internal and External Humidity Case Study 4

Similar to case study 3, internal temperatures fluctuate through the day. But unlike case study 3 the internal temperature of the house doesn't increase beyond an average temperature of 32°C in any of the four corners, though individual rooms record a higher temperature during some parts of the day (fig.4.17).

Northwest side is the coolest side and northeast is the warmest side which is close to the temperature of the southeast side when understanding the average of the four selected intermediate directions (fig.4.19). Average temperatures from all four directions doesn't reflect that the north side is cooler than the south side. In this house northeast and southeast sides are warmer than the northwest and southwest sides. The reason for this could be that the proportion of the room in the northeast are not matching the recommended proportions (see discussion in chapter 3.7.4)

Average difference in temperature between the hottest side which is the northeast and the coolest side which is the northwest is 6.3°C. The house doesn't have any windows on the northwest side, which is probably the reason why that has the lowest temperature in the house. The average internal temperature difference ranges from 14.4°C to 8.1°C for the northwest and northeast sides respectively (Fig 4.19).

The graph shows that the house is higher in humidity, which is due to the use of air-conditioning, as the lower internal temperature means humidity levels will be higher.

The northeast has the lowest humidity with a difference of 7.0% RH and the northwest records the highest average difference of 18% RH (fig. 4.20). The expected humidity range does reflect the pattern seen in the temperature, the northeast direction is the lowest humidity as expected which reflects the fact that northeast is the highest temperature and the fact that the air-conditioning unit is placed in this room.

Date	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*	*Standard Deviation*
Average Temperature Variation	13.2	12.8	16.1	17.0	15.8	15.5	15.1	15.7	1.4

Table 4.7- Case study 4 temperature variation in summer with air-conditioning.

The standard deviation of this house is the highest at 1.4 with the highest temperature variation at 17°C and the lowest difference is 12.8°C.

4.3.5 Case Study 5 with the use of air-conditioning

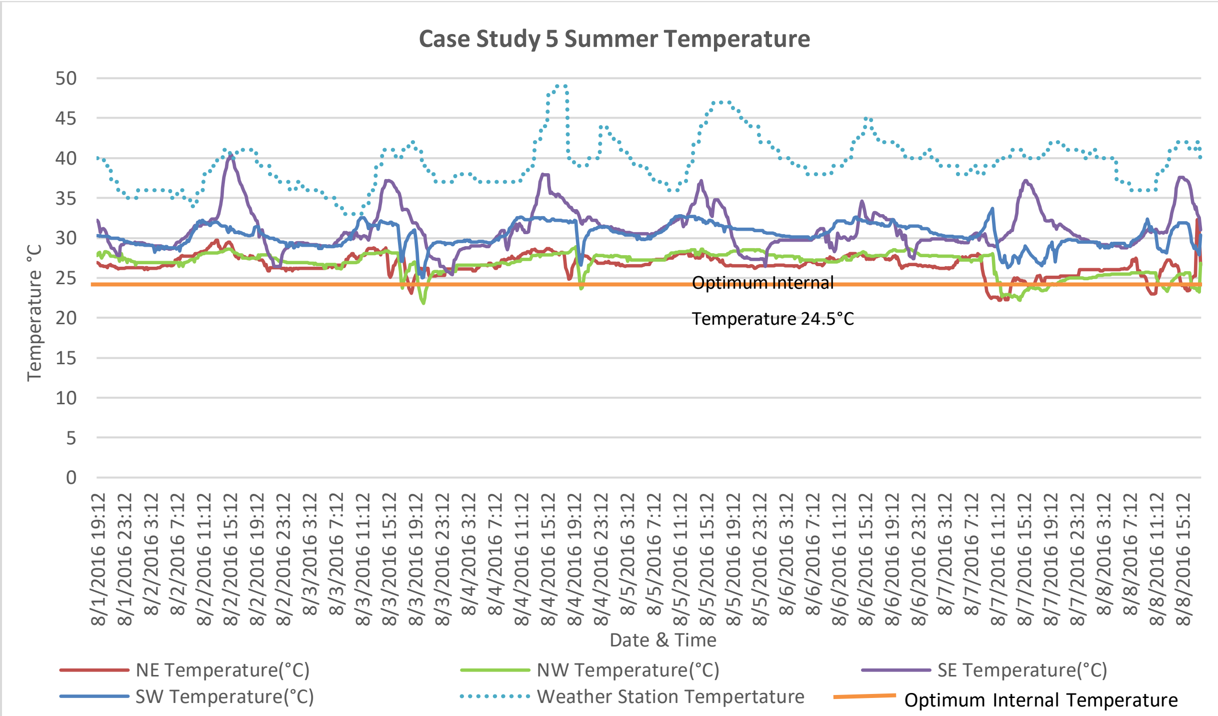

Figure 4.21- Internal temperature compared to external temperature- Case Study 5 with A/C

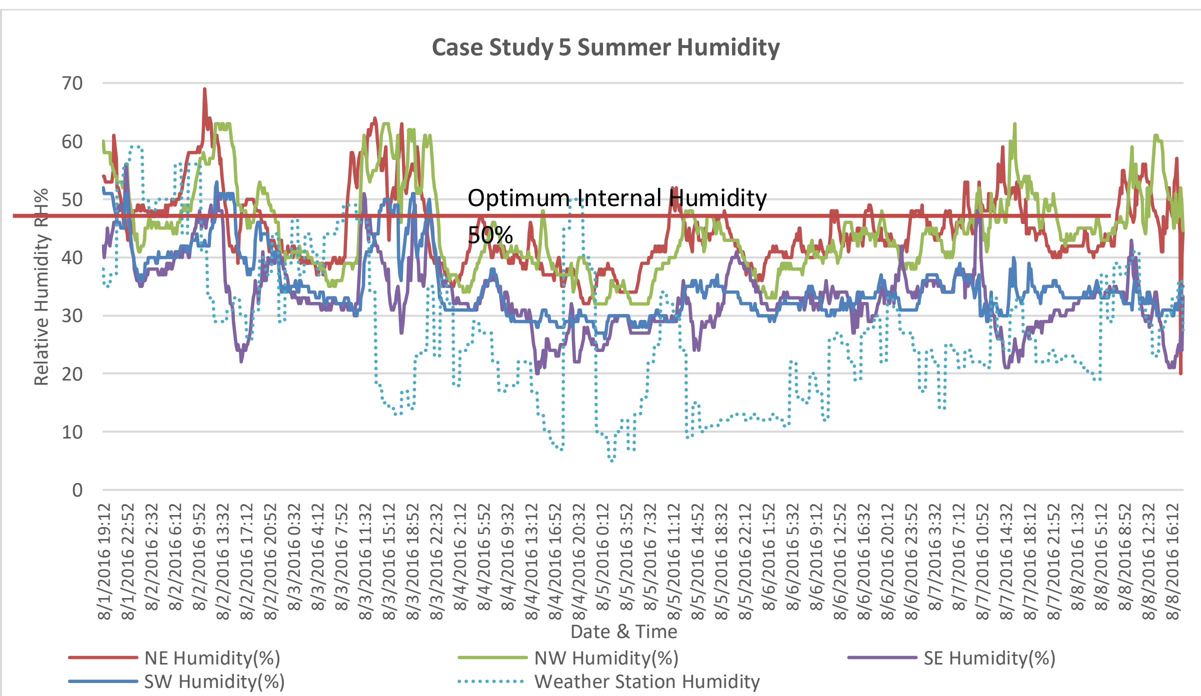

Figure 4.22 - Internal humidity compared to external humidity- Case Study 5 with A/C

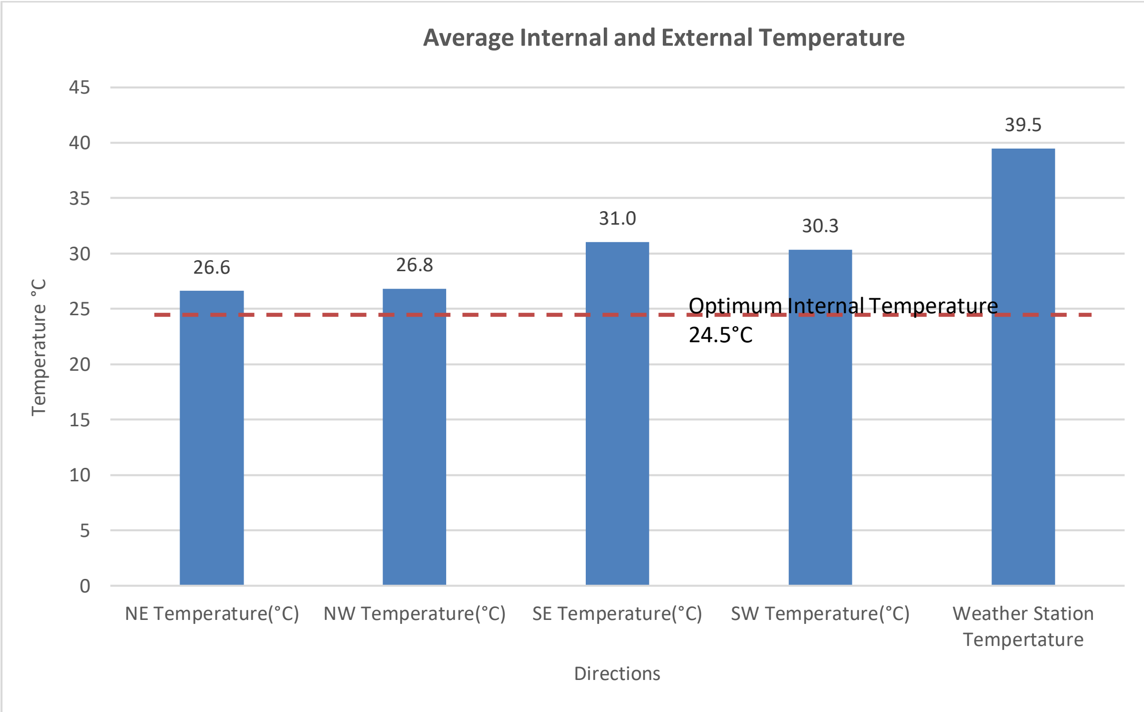

Figure 4.23 - Average Internal and External Temperature - Case Study 5

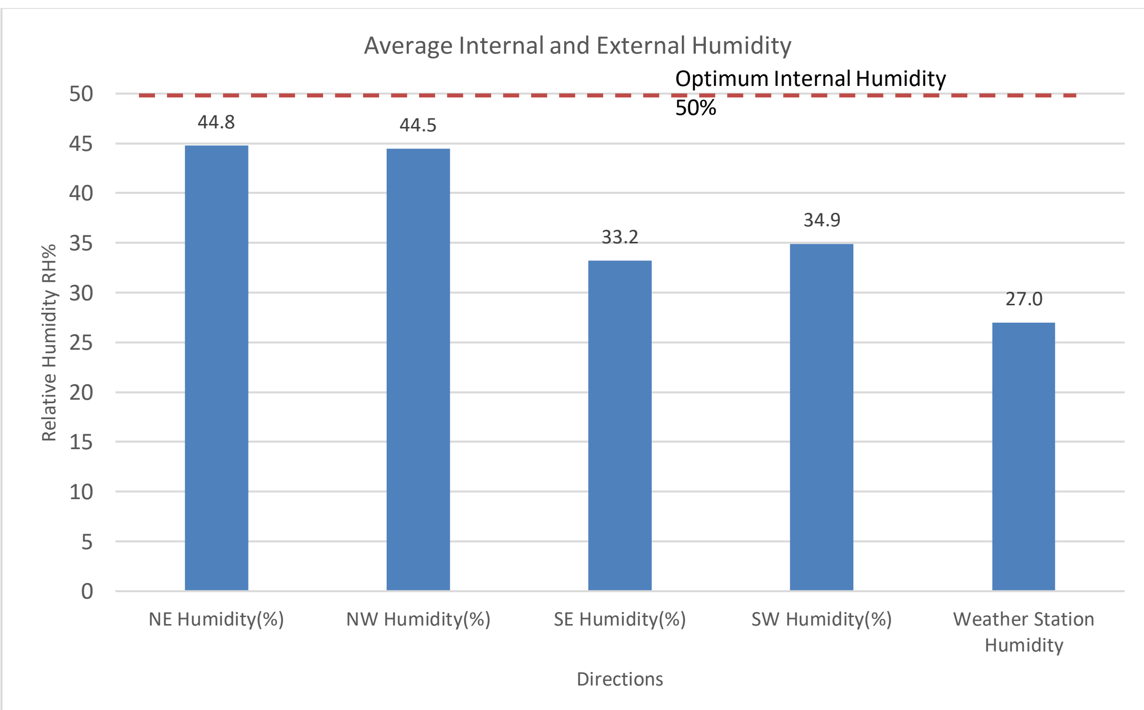

Figure 4.24 - Average Internal and External Humidity – Case Study 5

Individual rooms record different temperatures in this house, but the average temperature in any room doesn't exceed 32°C (fig. 4.23) Average temperatures from all four directions does reflect that the north side is cooler than the south side. In this house the northeast and northwest sides are cooler than the southeast and southwest sides (fig. 4.21).

Average difference in temperature between the hottest side which is the southeast and the coolest side which is the northeast is 4.4°C. The house has windows on the east and west axis which could be the reason it maintains a lower temperature (Chapter 3.7.5). Average external temperature recorded was 39.5°C and the average internal temperature difference ranges from 12.9°C to 8.5°C for the northeast and southeast sides respectively (Fig 4.23).

The graph shows that the house has higher internal humidity which is due to the use of air-conditioning, as the lower internal temperature means humidity levels will be higher (fig.4.22). The southeast measuring as the lowest humidity with a difference of 6.2% RH and the northeast recording the highest average difference of 17.8% RH (fig.4.24). The expected humidity range does reflect the pattern seen in the temperature. The southeast direction is the lowest humidity as expected which reflects the fact that southeast is the highest temperature and the fact that the air-conditioning unit is placed in this room.

Date	*1/8*	*2/8*	*3/8*	*4/8*	*5/8*	*6/8*	*7/8*	*8/8*	*Standard Deviation*
Average Temperature Variation	9.2	10.7	8.7	10.8	12.2	11.4	12.1	11.1	1.3

Table 4.8- Case study 5 temperature variation in summer with air-conditioning.

Standard deviation for case study 5 is 1.3 which is the second highest noted amongst the five houses. The lowest temperature variation in this house is recorded at 8.7°C and the highest temperature variation is at 12.2°C between the internal and external temperatures.

4.4 Test Data Recorded in 5 Case Study Homes (Winter)

The temperature and humidity study for all five houses was carried out during summer months and due to temperature outside the occupants could occasionally use air-conditioning indoors. To verify the trends seen in the summer months temperature and humidity loggers were set up in the five houses in the winter (18/01/2017 till 28/01/2017). The winter months have lower external temperatures than summer, so the occupants kept the air-conditioning off during winter months for the duration of the data collection. Following graphs show the temperatures of five case studies for each intermediate direction during the winter.

4.4.1 Case Study 1 during Winter

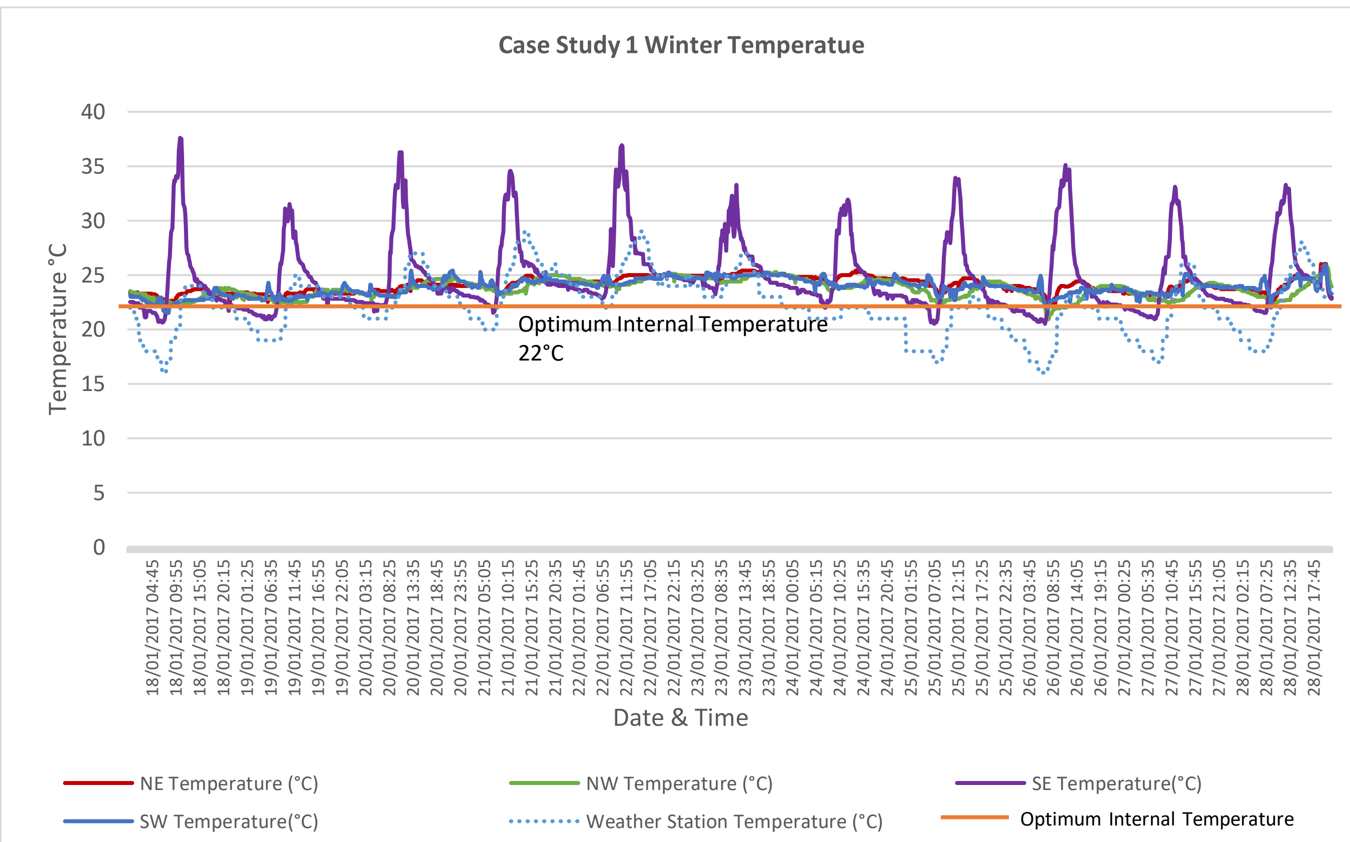

Figure 4.25 - Internal temperature compared to external temperature- Case Study 1 without A/C

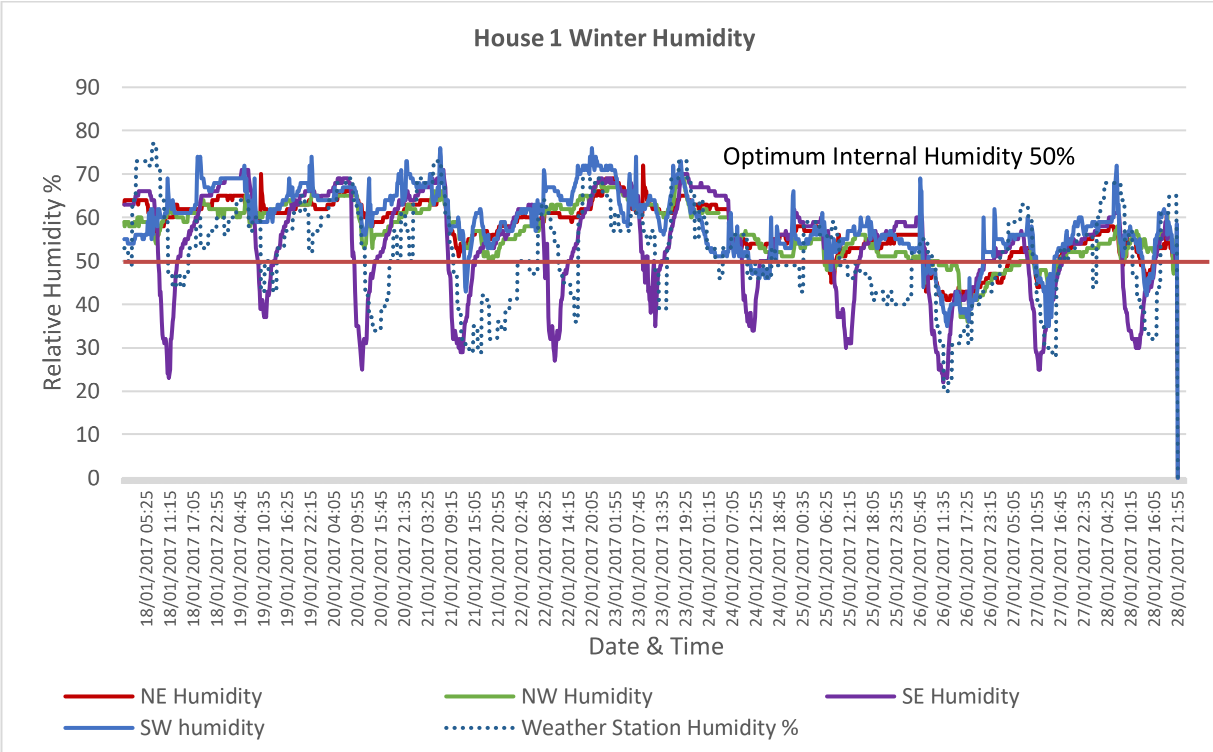

Figure 4.26- Internal humidity compared to external humidity- Case Study 1 without A/C

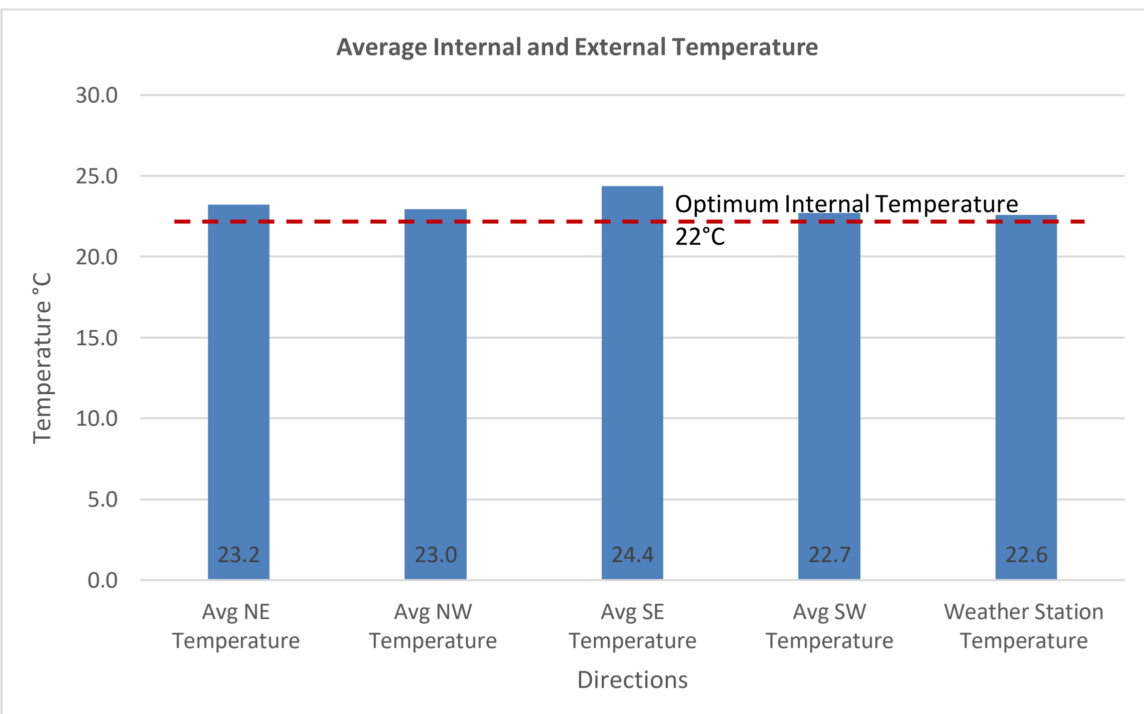

Figure 4.27 - Average Internal and External Temperature - Case Study 1

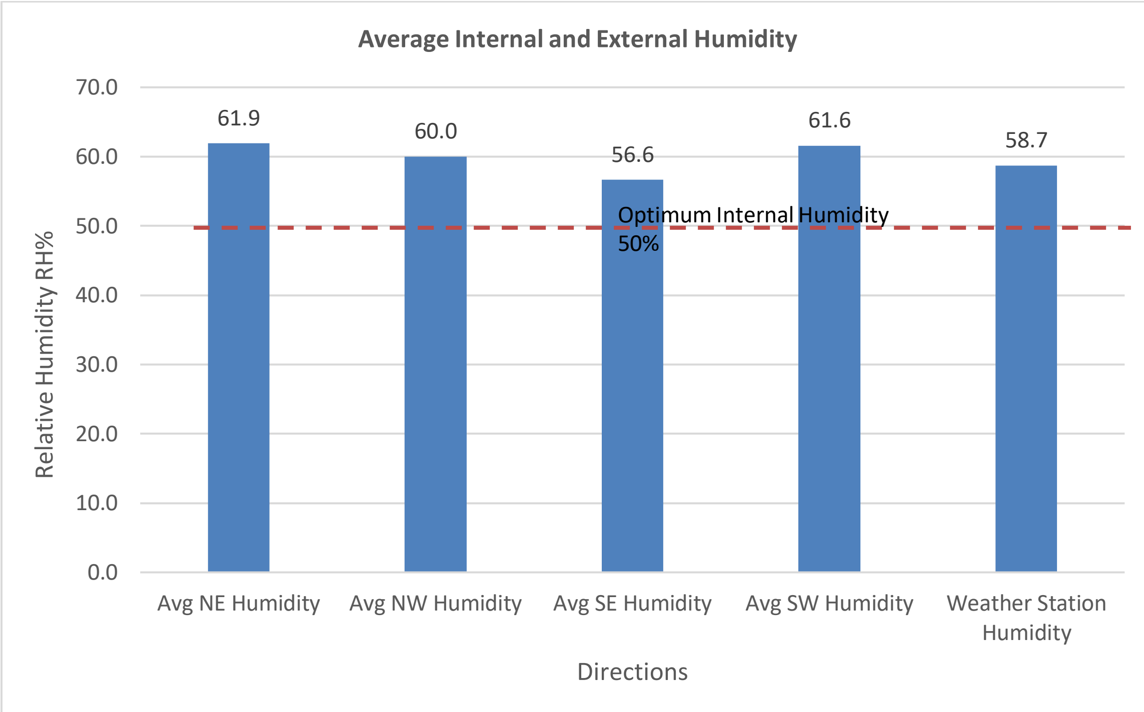

Figure 4.28- Average Internal and External Humidity – Case Study 1

Average internal temperature of the northeast, northwest and southwest corners, stay close to the optimum internal comfort level of 22°C and do not exceed 25°C, without the use of air-conditioning (fig.4.27). The southeast is the only corner that records temperatures higher than 35°C which is possibly because of the large window that doesn't have any overhang or shading device (fig.4.25) See the discussion in chapter 3.7.1. Even though the southeast temperature rises much further than the other temperatures, the average recorded temperature is 24.4°C which isn't too much higher than higher limit of the acceptable comfort range of 23.5°C. The southeast temperature sees a massive spike in temperature around 10am every day which rises above 30°C or more. A couple of factors cause this effect- firstly that the house has a window in the southeast corner. Secondly, there is a large window on the southeast façade which creates heat gain, therefore resulting in a spike in temperature which drops quickly as the sun changes it position.

Due to the lower external temperature the humidity levels both inside the house and outside are high which is expected (fig. 4.26 and fig. 4.28).

Date	*18/1*	*19/1*	*20/1*	*21/1*	*22/1*	*23/1*	*24/1*	*25/1*	*Standard Deviation*
Average Temperature Variation	2.4	1.2	0.8	0.1	0.1	1.4	3.4	3.9	1.5

Table 4.9- Case study 1 temperature variation in winter without air-conditioning

The standard deviation of this case study in the summer months is under 1 and 1.5 (table 4.9) during the winter months which is the highest difference in standard variation for this house. This means that the house is warmer in the winter and cooler in the summer.

4.4.2 Case Study 2 during Winter

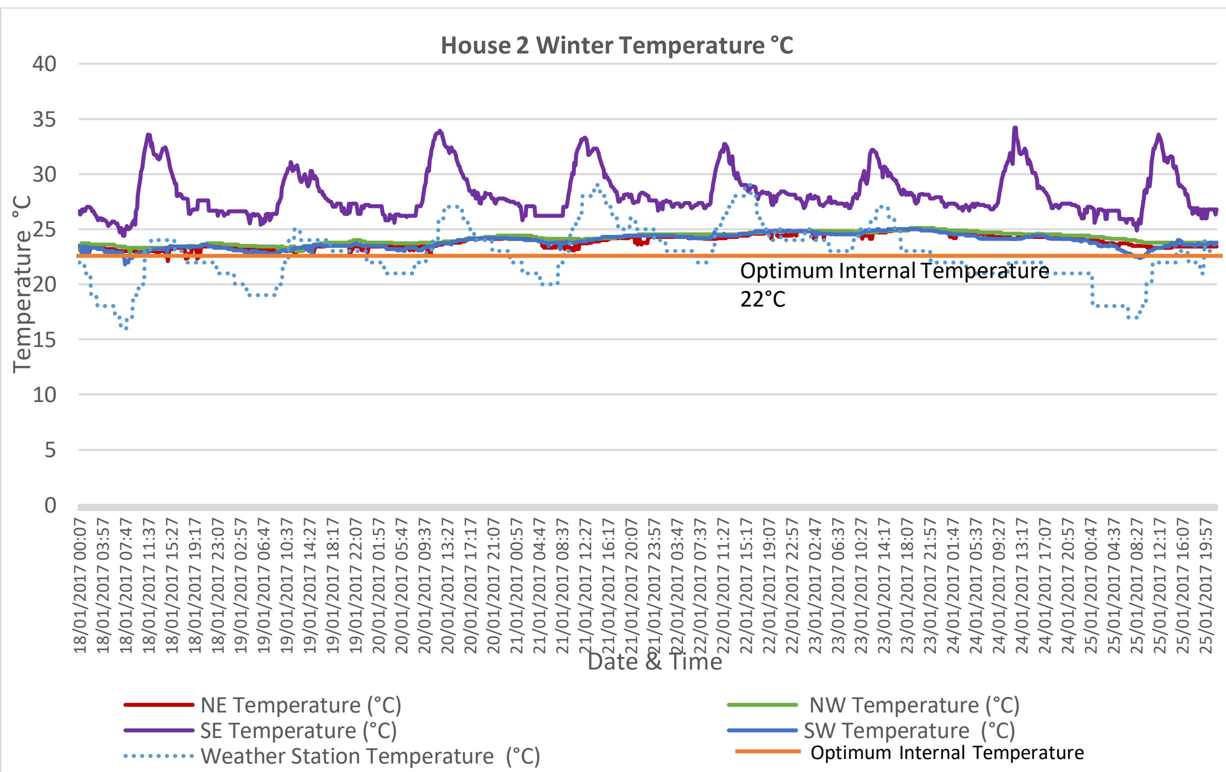

Figure 4.29- Internal temperature compared to external temperature- Case Study 2 without A/C

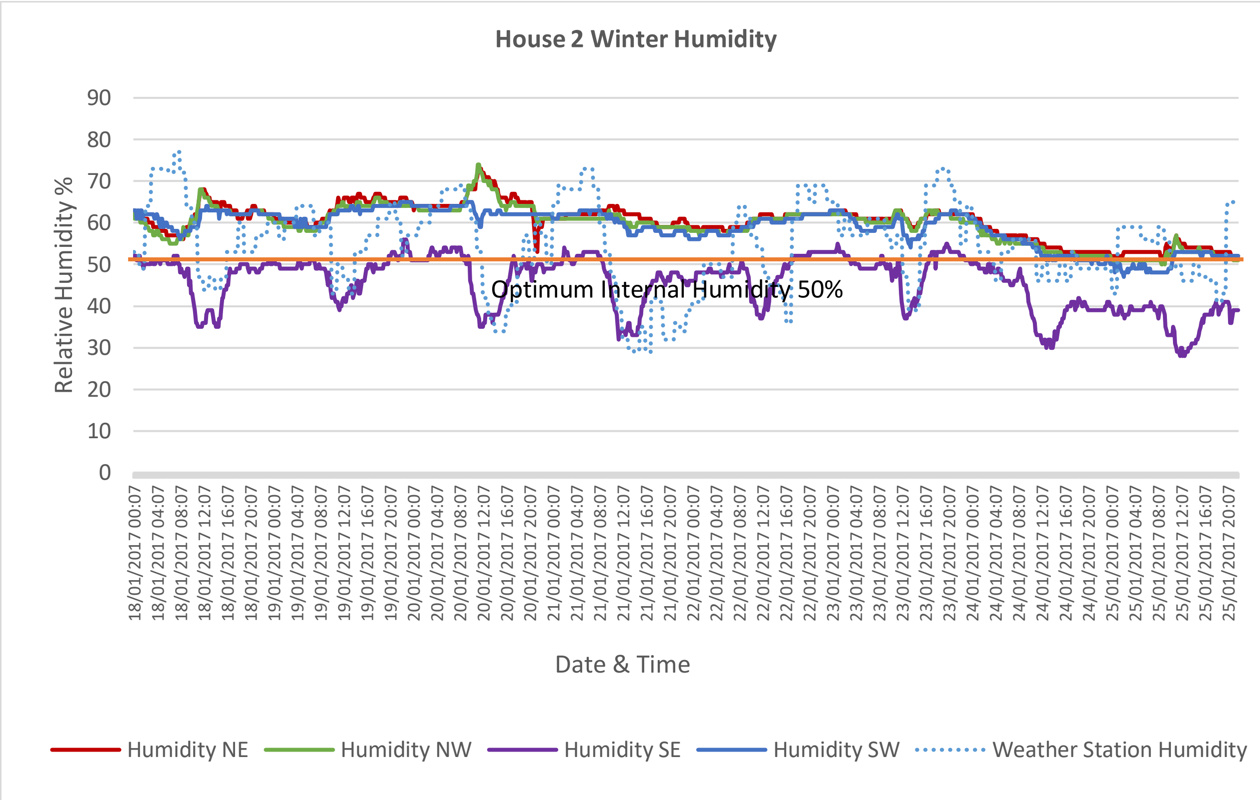

Figure 4.30 - Internal humidity compared to external humidity- Case Study 2 without A/C

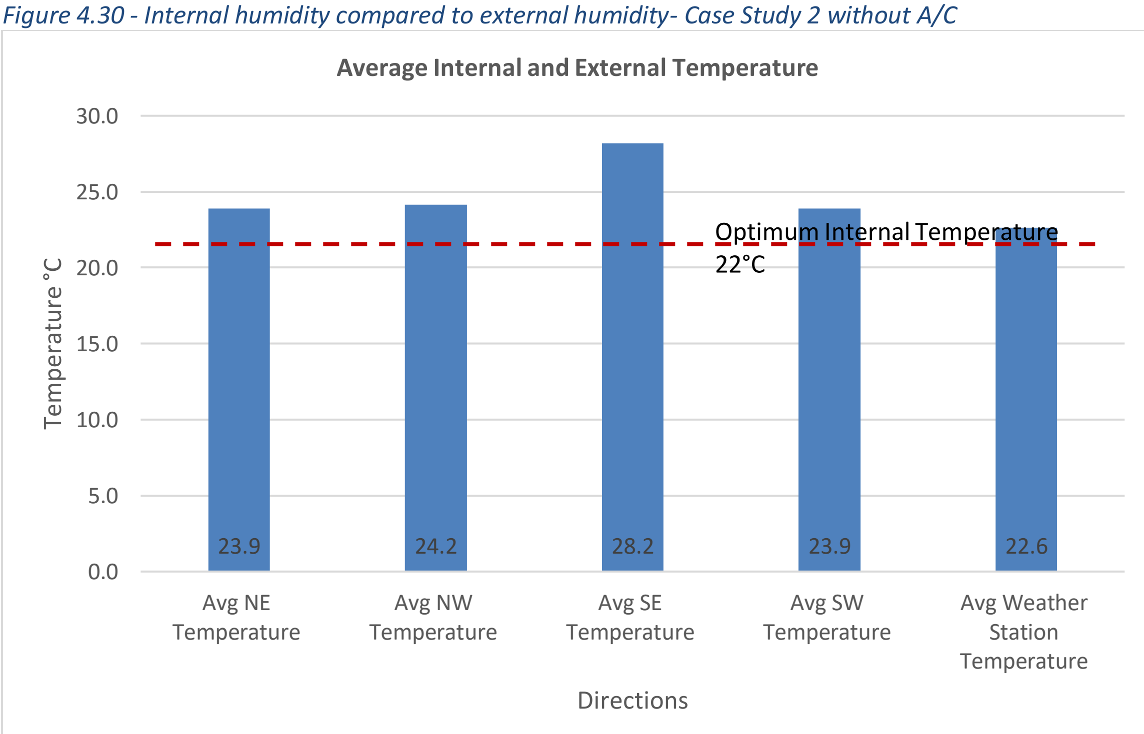

Figure 4.31- Average Internal and External Temperature - Case Study 2

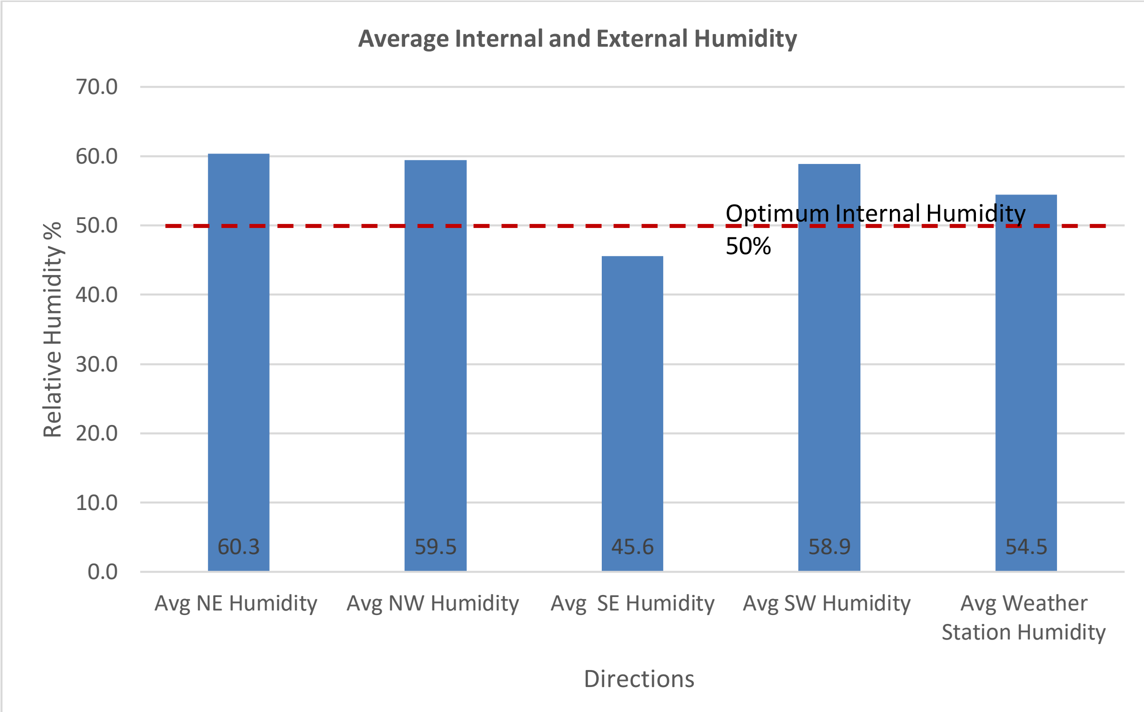

Figure 4.32- Average Internal and External Humidity - Case Study 2

Similar to Case study 1 average internal temperatures of the northeast, northwest and southwest corners stay close to the recommended internal comfort level of 22°C and do not exceed 25°C even without the use of air-conditioning (fig.4.31). Similarly, southeast is the only corner that records high temperatures but in this case the temperature doesn't reach as high 35°C which is possibly because case study 2 has small window on the south side which aren't covered (Chapter 3.7.2).

Even though the temperature doesn't rise above 34°C in the southeast, the average temperature is 28.2°C which is much higher than optimum internal level and the average temperature seen in case study 1 at 24.4°C. The higher recorded average temperature could be caused by the fact that that even though the temperature doesn't raise too much, but it stays high for a longer period. Since the window is smaller the heat gained through isn't lost as quickly as it is lost by the larger window is case study 1.

Date	*18/1*	*19/1*	*20/1*	*21/1*	*22/1*	*23/1*	*24/1*	*25/1*	*Standard Deviation*
Average Temperature Variation	3.5	2.5	1.6	0.9	0.7	1.7	3.9	4.4	1.4

Table 4.10 Case study 2 temperature variation in winter without air-conditioning

The maximum difference in temperature from external temperature during the winter months is 4.4 and the minimum temperature difference is 0.9 with the internal temperature being warmer than the external. The standard deviation during the summer was 1.2 and during winter is 1.4 (table 4.10) which has a difference of 0.2 and is the second highest difference.

4.4.3 Case Study 3 during Winter

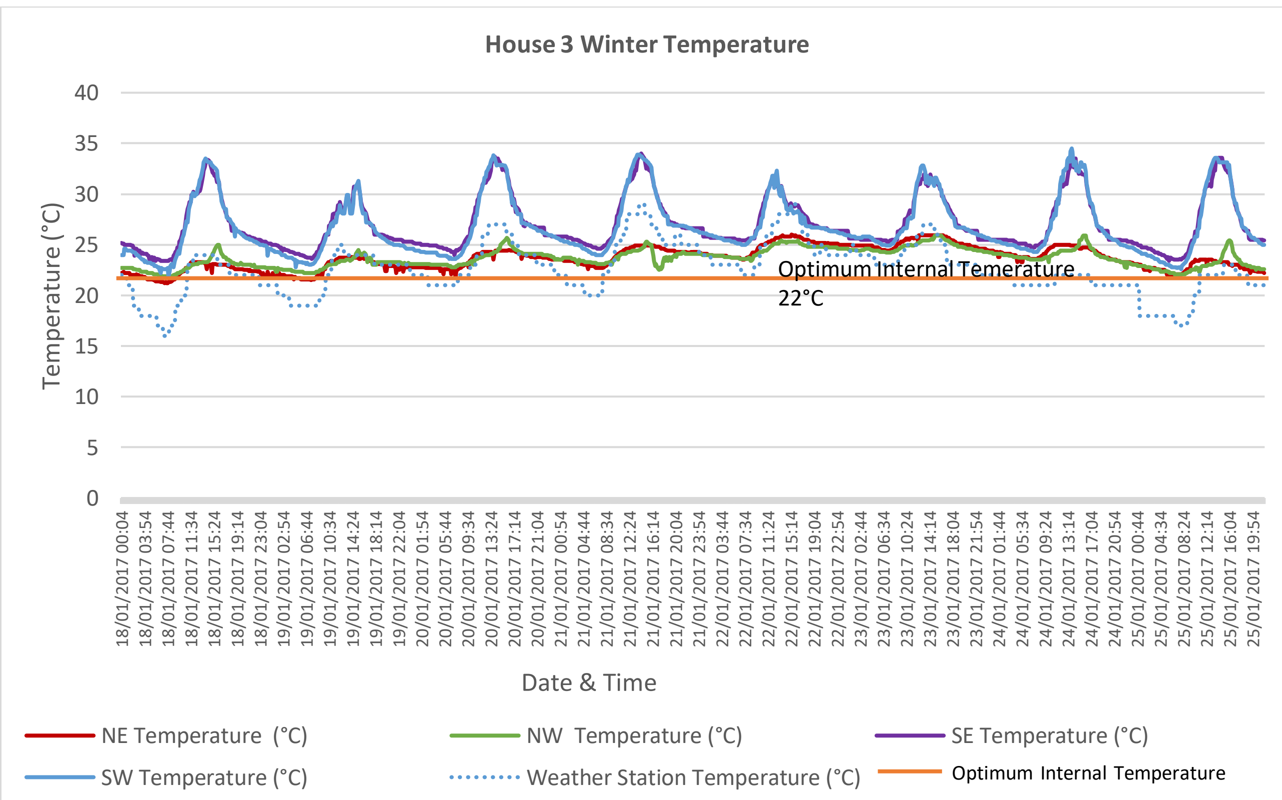

Figure 4.33- Internal temperature compared to external temperature- Case Study 3 without A/C

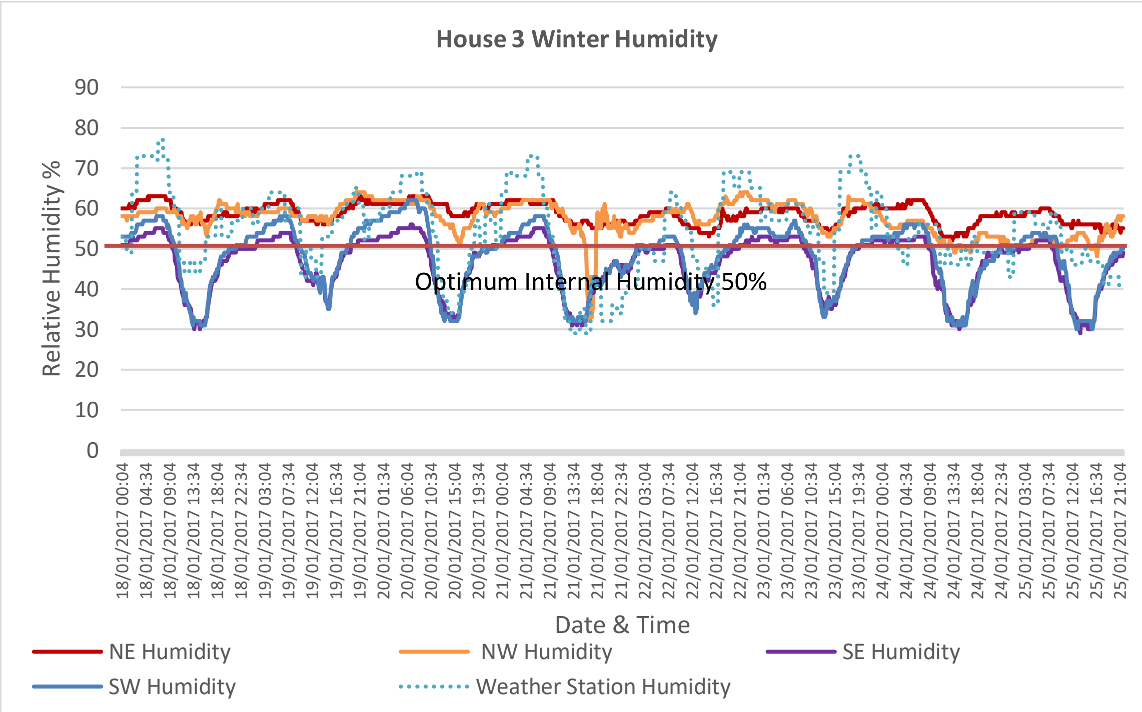

Figure 4.34 - Internal humidity compared to external humidity- Case Study 3 without A/C

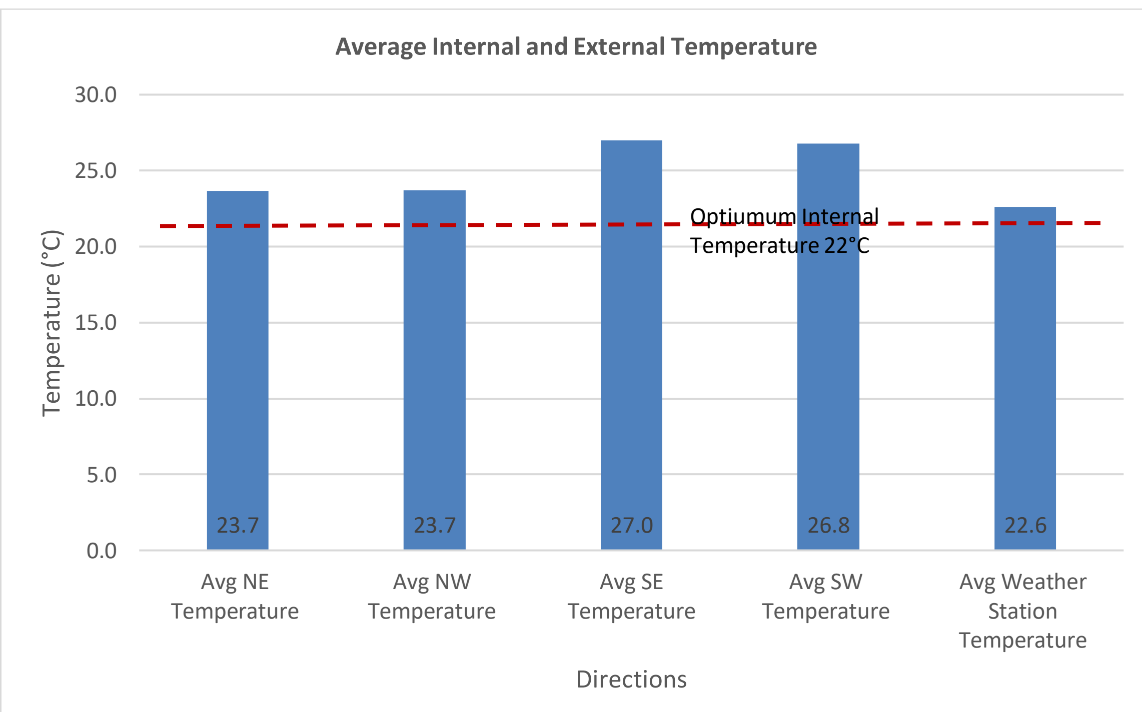

Figure 4.35 - Average Internal and External Temperature - Case Study 3

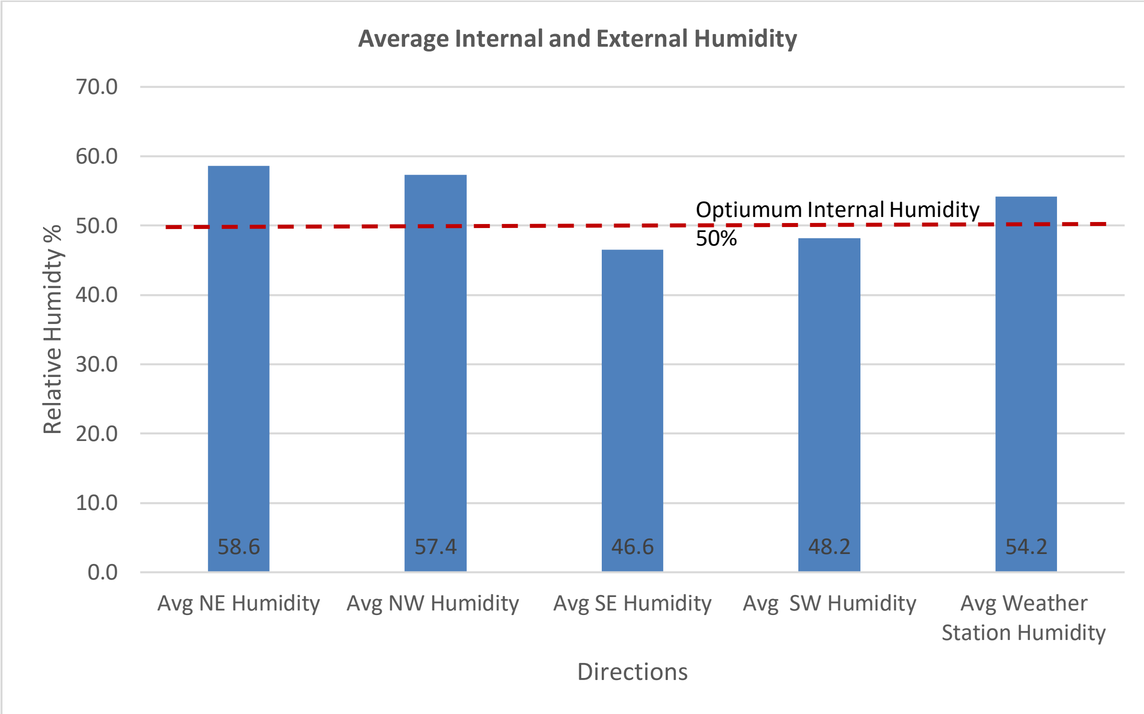

Figure 4.36 - Average Internal and External Humidity - Case Study 3

Average internal temperatures of the northeast and northwest is close to the recommended internal comfort level of 22°C and don't exceed 25°C without the use of air-conditioning (fig. 4.35). In this study the southeast and southwest corners both record temperatures which are higher than 30°C but do not cross 35°C. The cause of this could be that the south and west facades have windows which are not shaded. Similar to case study 2 even though the temperature doesn't rise above 34°C in the southeast, the average temperature of the south sides is 27°C which is much higher than optimum internal level and the average temperature of 22°C. The windows in this study are larger than that seen in study 2 but smaller than those in study 1 which is the reason the recorded temperature of study 3 is between the first two studies.

Date	18/1	19/1	20/1	21/1	22/1	23/1	24/1	25/1	Standard Deviation
Average Temperature Variation	3.6	2.4	2.0	1.5	1.2	2.0	4.2	4.7	1.3

Table 4.11 Case study 3 temperature variation in winter without air-conditioning

The highest temperature difference from external temperature is 4.7°C and the lowest difference is 1.1°C in the winter. The standard deviation in the winter is 1.3, compared to 1.2 in the summer and the difference is standard deviation is very low at 0.1. With windows on all sides of the house there isn't too much variation seen in the temperatures between summer or the winter months. The variation in the summer should be lower which would mean that the house is cooler in the summer. Even though air-conditioning is used in the summer the house remains warmer due to design features that don't follow principles of *Vaastushastra*.

4.4.4 Case Study 4 during Winter

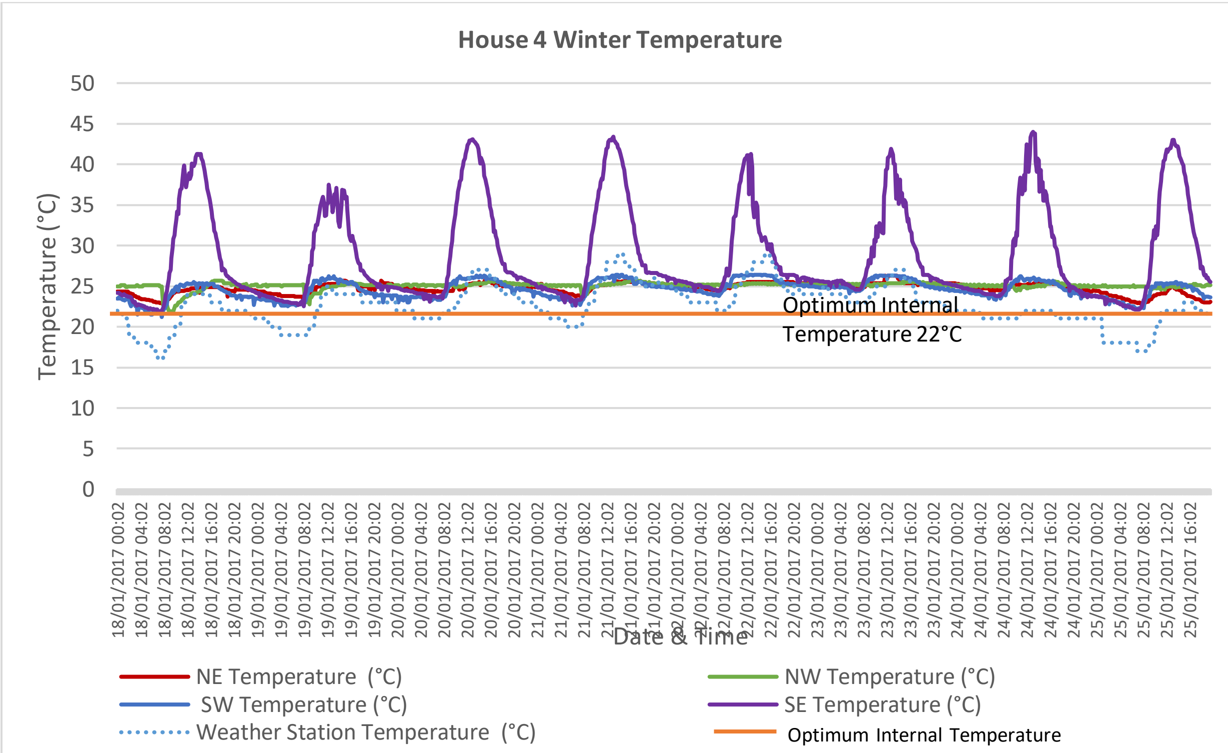

Figure 4.37- Internal temperature compared to external temperature- Case Study 4 without A/C

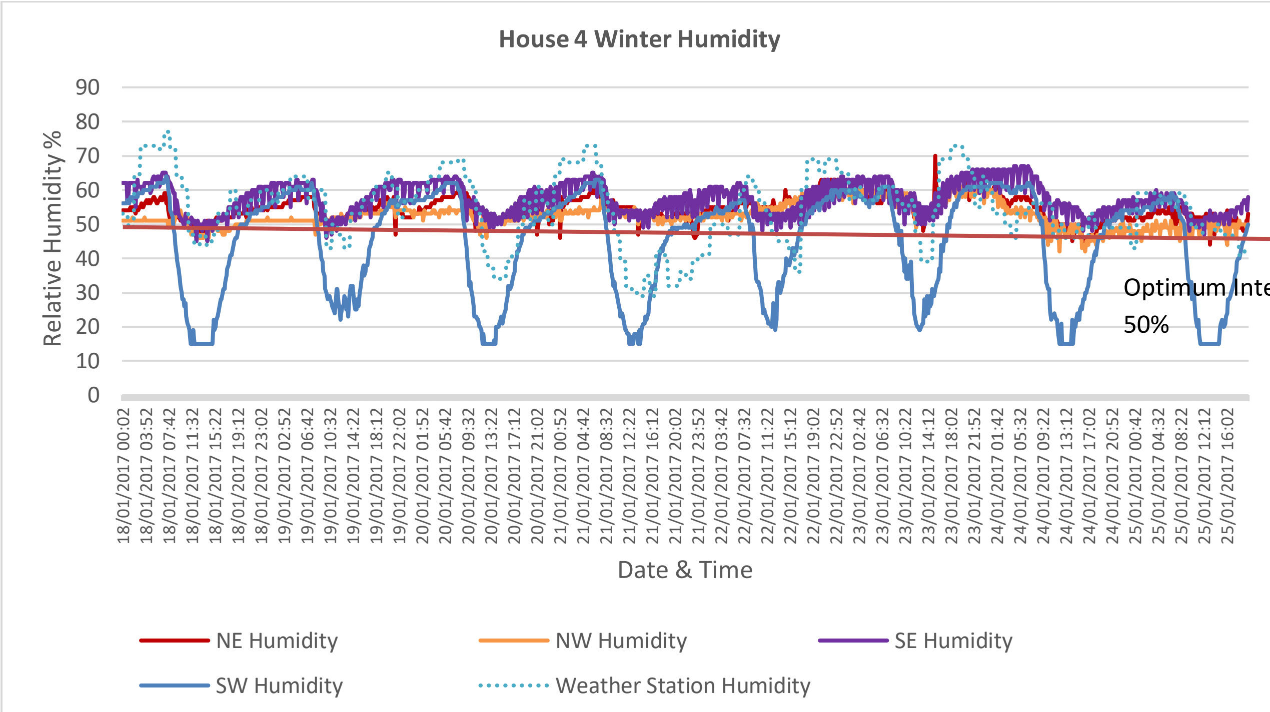

Figure 4.38 - Internal humidity compared to external humidity- Case Study 4 without A/C

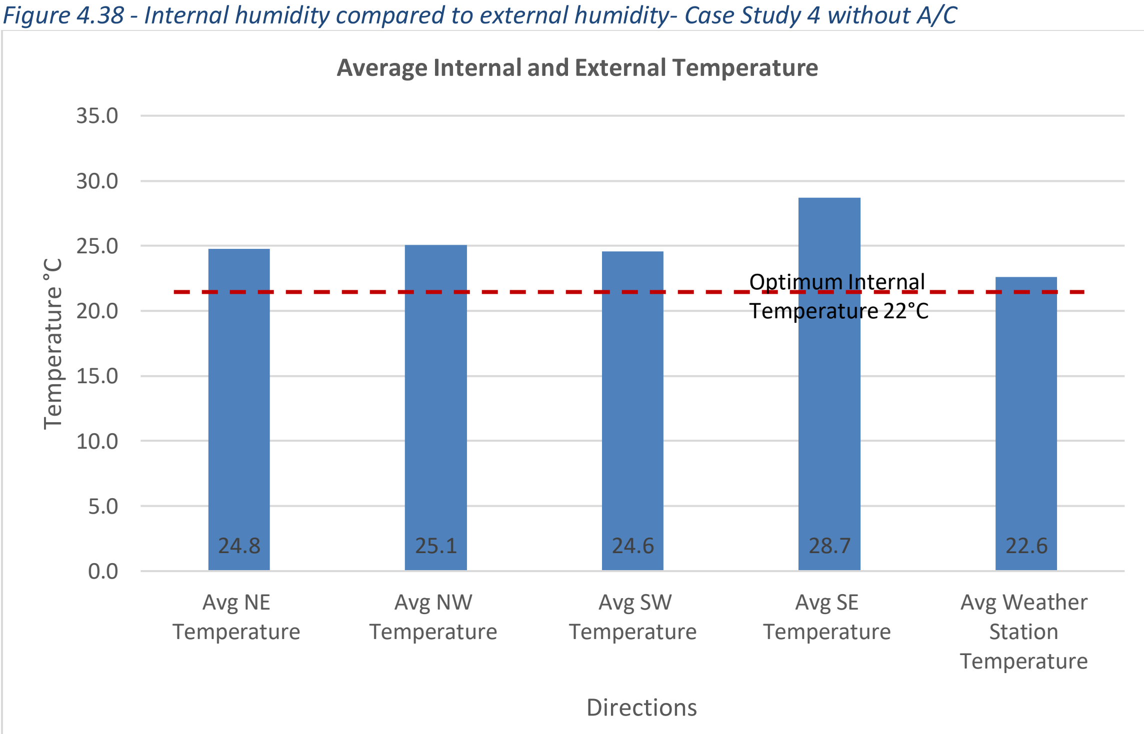

Figure 4.39 - Average Internal and External Temperature - Case Study 4

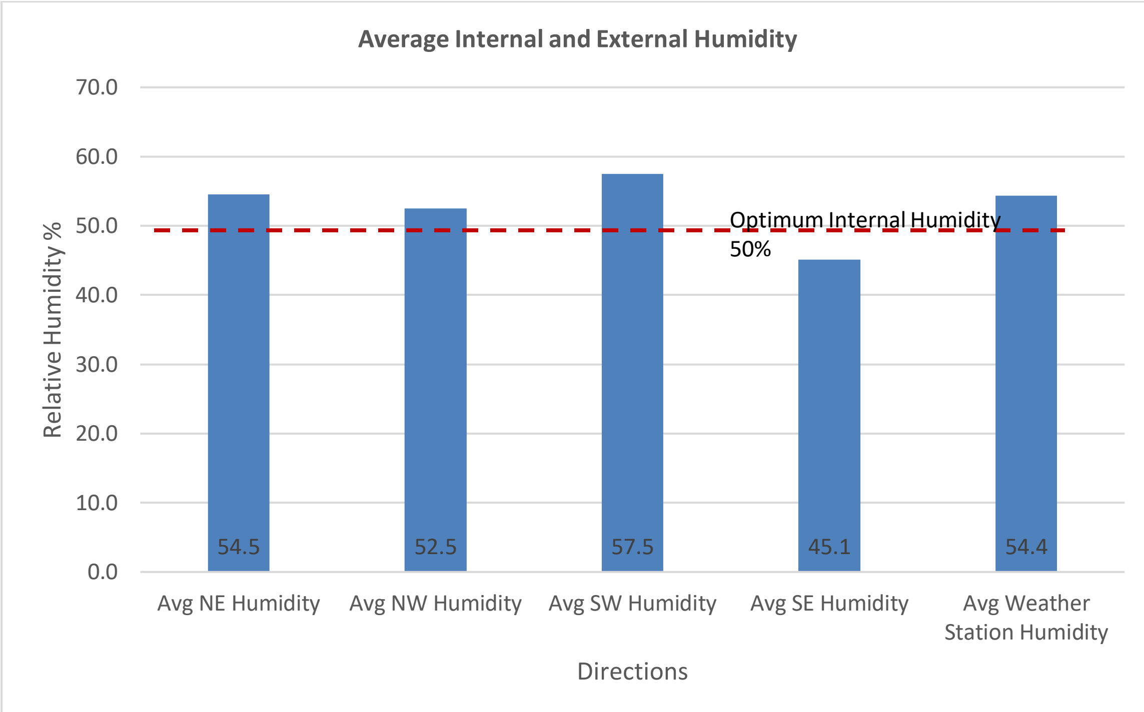

Figure 4.40- Average Internal and External Humidity- Case Study 4

Average internal temperatures of the northeast, northwest and southwest are close to the recommended internal comfort level of 22°C and don't exceed 25°C even without air-conditioning (fig. 4.39)

The southeast corner is the warmest in this case study and the temperature rises above 40°C once in a day. The southeast is expected to be the highest temperature but, in this case, it is too high and the cause of this could be the window placement and irregular proportions of the room (discussed on chapter 3.7.5). The average temperature recorded in the southeast corner in this study is 28.7°C which is similar to the average for the southeast temperature in case study 2 which is 28.2°C. Proportion of the window in this case study are larger than that in case study 2, which is probably a reason why the temperatures are higher and for a longer duration of time.

Date	*18/1*	*19/1*	*20/1*	*21/1*	*22/1*	*23/1*	*24/1*	*25/1*	*Standard Deviation*
Average Temperature Variation	4.4	3.4	2.7	1.9	1.3	2.1	4.4	5.5	1.5

Table 4.12- Case study 4 temperature variation in winter without air-conditioning

Highest temperature variation from external temperature is 5.5°C and lowest temperature difference is 1.9°C (table 4.12). The standard deviation in the house is the same in the summer and in the winter, which is 1.5 and is the highest standard deviation seen in the winter. Case study 1 has the standard deviation of 1.5 in the winter but the summer standard deviation in case study 1 is the lowest which means that case study 1 creates a cooler space in the summer months and that case study 4 is the same warmth in the summer and winter months.

4.4.5 Case Study 5 during Winter

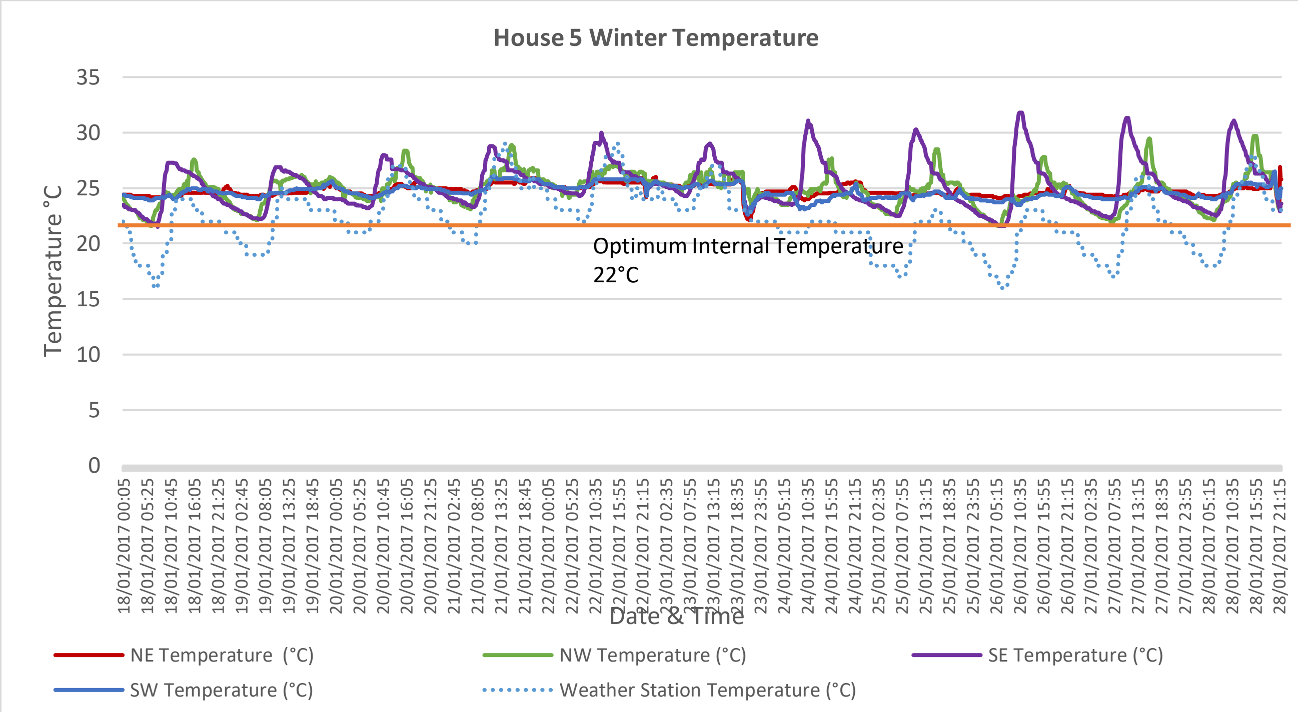

Figure 4.41- Internal temperature compared to external temperature- Case Study 5 without A/C

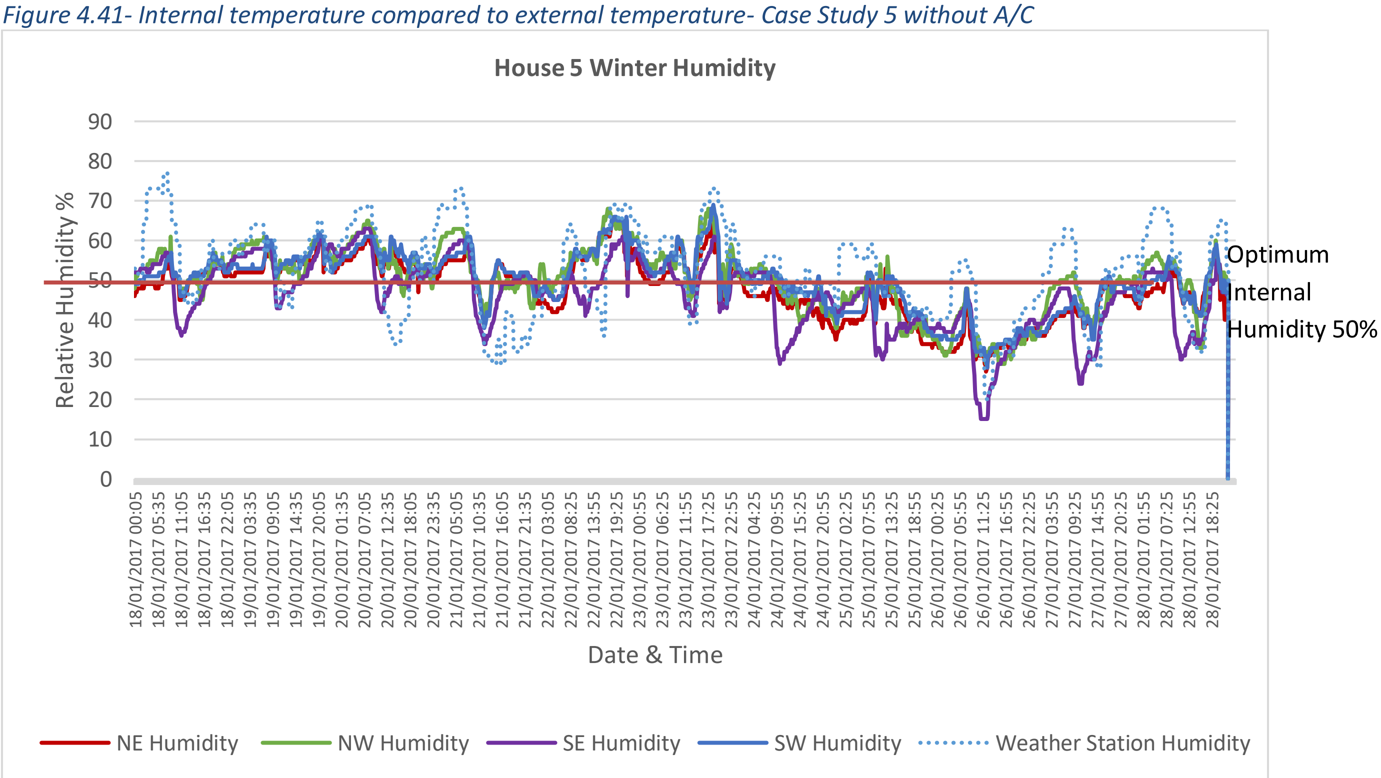

Figure 4.42- Internal humidity compared to external humidity- Case Study 5 without A/C

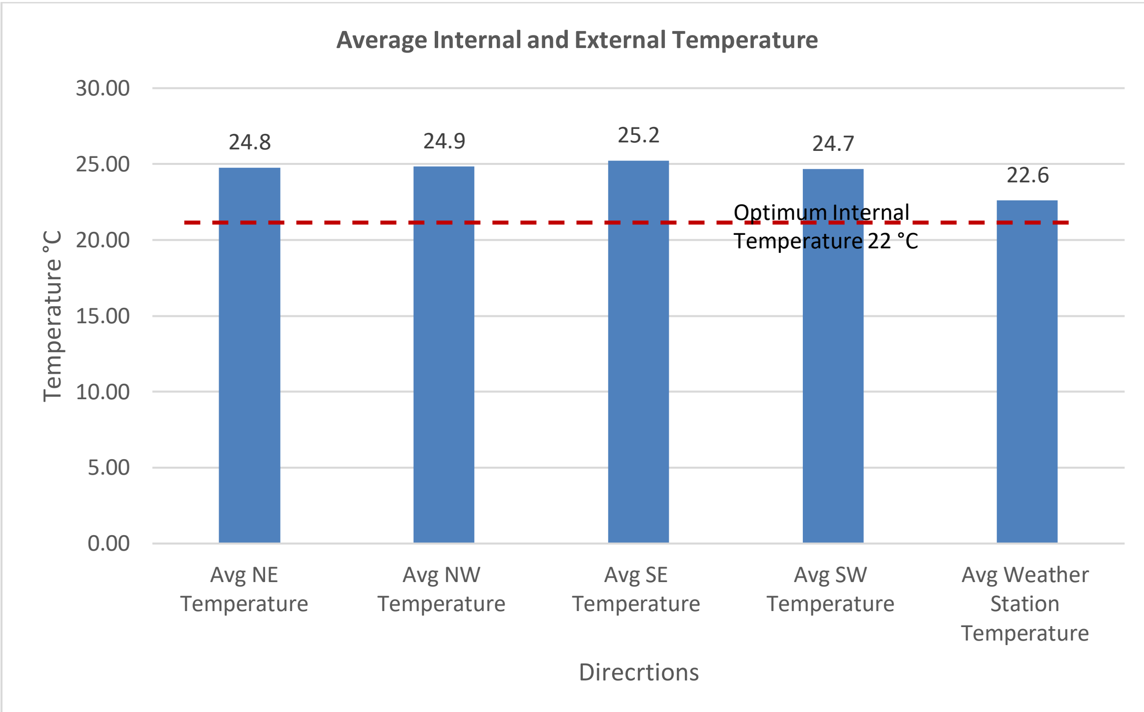

Figure 4.43 - Average Internal and External Temperature - Case Study 5

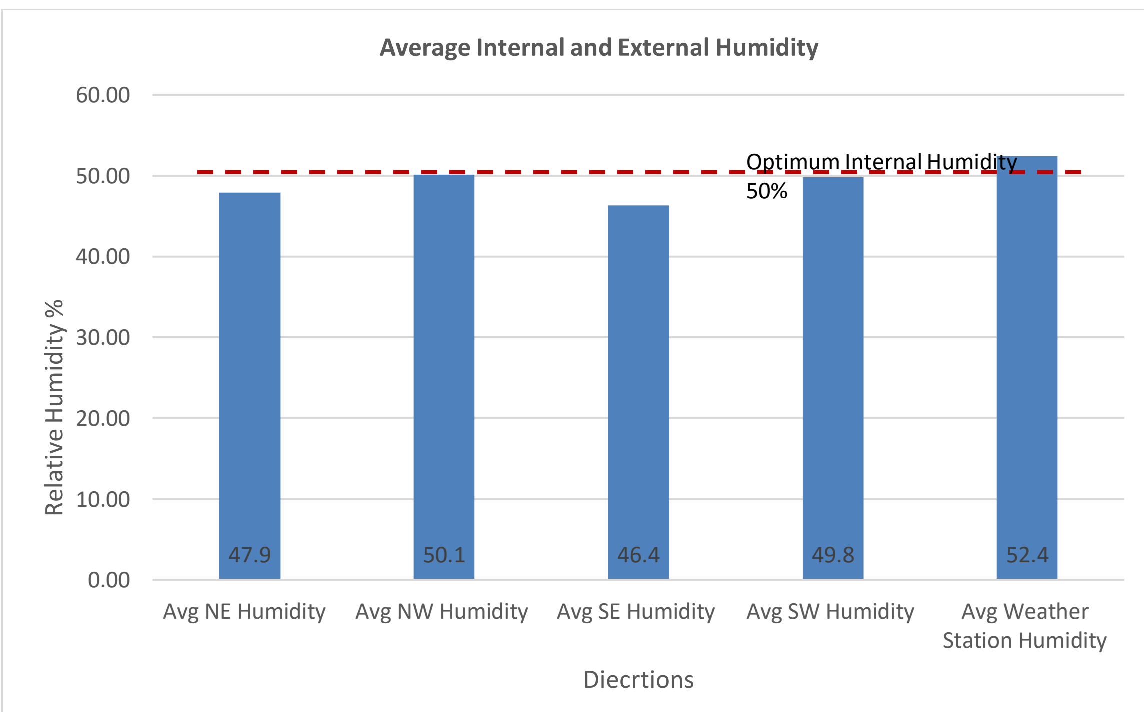

Figure 4.44 - Average Internal and External Temperature - Case Study 5

Unlike the other studies, the northeast and southwest corners that are the coolest but are maintained close to 25°C which is higher than the acceptable 22°C.

The recorded temperature of northwest climbs above 25°C but also dips close to 22°C during the night time which is an example of a large window placed on the west façade without an overhang (fig. 4.41). The southeast is the warmest of the four corners in the house as it climbs up to temperatures higher than 30°C but also reduces in temperature to touch 22°C. The four corners of the house have variations in recorded temperature throughout the day, but the average of all the sides individually is approximately 25°C which is higher than the optimum temperature requirement of 22°C.

Date	*18/1*	*19/1*	*20/1*	*21/1*	*22/1*	*23/1*	*24/1*	*25/1*	*Standard Deviation*
Average Temperature Variation	3.5	2.7	1.6	1.2	0.9	1.3	3.4	4.5	1.3

Table 4.13- Case study 5 temperature variation in winter without air-conditioning

The highest temperature difference is 4.5 and the lowest temperature difference from external temperature is 0.9 during the winter (table 4.13). The standard deviation during the winter is 1.3 which is the same as the summer deviation at 1.3 which reflects the fact that the house is too warm in the summer.

4.5 Conclusion

The loggers were placed in the five case study homes during the summer and winter months. These case studies represent different conditions of *Vaastushastra* in which temperature and humidity was logged. The first is to study homes designed on the principles of *Vaastushastra* and the impact of the summer climate conditions on them when the air-conditions were switched on. Second was to study the houses in the winter without using air-conditioning.

Common finding from all the case studies is that the north side of the house is cooler than the south side of the house. The findings show that in most cases the northeast is the lowest temperature and the southeast is the warmest side with or without the use of air-conditioning and the exceptions reflect variations in the application of the design principles. The temperature difference between the coolest side within each case study and the external temperature during the summer ranges from 14°C to 4°C based on the adherence to the principles of *Vaastushastra*. Similarly, the houses that stay cooler in the summer are close to optimum internal temperatures during the winter months. Findings from the study in the summer without the use of air-conditioning shows that the internal temperature of the house peaks at 38°C. This temperature is much higher than the acceptable temperature for user comfort, but it shows that the design of the house helps to maintain internal temperatures.

The findings from these case studies follow two passive design principles. The form of the building is a key aspect of passive design because it lays the structure of the building which determines how the building interacts with the site. The other important principle is that the building should be oriented along the east to west axis (Discussed in chapter 2). Any natural vegetation on the site helps create shading for outdoor seating in the winter and shading around the windows of the house. Passive design for architecture suggests that the south and west façade of a building should not use too much glass, if glass is used appropriate shading devices should be used. The proportions and shapes of the room help to create comfortable indoor spaces, the case studies show that regular shapes such as square and rectangle which follow a certain proportion create better indoor environments than those that have different shapes or different proportions.

Case studies 1, 4 and 5 are aligned on the east to west axis which is recommended in *Vaastushastra*. Case study 1 is comfortable in the winter months and in the summer months only with the exception of the southwest room which is possibly because of the odd shape of the room. Case study 4 and 5 maintain temperatures of approximately 25°C in the winter which is warmer than it should be but that could be due to the location of the windows on the west in case study 5 and south in case study 4. Case studies 2 and 3 are aligned along the north south axis. the main difference between the two is that case study 3 has many more windows and has a different proportion than case study 2. The difference is that case study 3 has much warmer average temperatures than case study 2.

The temperature on the southeast side for all the houses is high, during both the summer and the winter months. Even with the use of air-conditioning in the summer months, warmer range of temperatures are recorded on the southeast side. The houses have different sizes of windows on the southeast side, which has an impact on the time when the spike in temperature happens and its duration. In case study one, the spike in temperature occurs at 10am and doesn't last for a long time even though there is a large window on the façade. Even with a large window the room doesn't stay warm for a long time because the house has an open plan and the air-conditioning is used throughout the day. In case study 2, there is only one small window on the southeast room where the temperature was recorded , but the temperature stays above 35°C and gradually rises to 40°C, with the peak in temperature occurring at 2pm and the drop-in temperature happening after sunset. The reason for this is that air-conditioning isn't used in this room and therefore the room remains at a high temperature throughout the day. In case study 3, even though air-conditioning is used the southeast room spikes to touch 40°C at midday and falls only to 35°C, which is the average temperature of the house. The reason for the spike in temperature in the southeast is that that are three large windows in this space which cause gain in temperature despite use of air-conditioning. In case study 4, the spike in temperature happens before 10am and touches 40°C and then drops below 30°C after 6pm. Despite the use of air-conditioning the rise in temperature is due to the large window and the proportions of the room because the room is long and narrow rather than being proportionate in length and width. In case study 5, the southeast temperature touches 40°C at 2pm and then drops to temperatures lower than 30°C at 10pm. Even though air-conditioning is used throughout the day the temperature rises to 40°C due to the large window on the southside.

During the winter months the southeast side sees similar patterns for the gain in temperature in the southeast side of the house. The difference is that the highest temperatures aren't as high as they were in the summer with the temperatures rarely crossing 35°C at its peak. The only exception to the rule is that in case study 4, even in the winter the southeast temperature touches 40°C, which could be because the air-conditioning is not operational, but could be due to the proportions of the room. The southeast room in all other houses doesn't go higher than 35°C even though the air-conditioning is off.

Chapter Five: Understanding User Comfort through Questionnaires

5.1 Introduction

This chapter discusses each case study from an architect's point of view by understanding the building and its site conditions. It is based on the author's observations which are different from the discussion in chapter 4, the latter explains whether the case study houses comply with the principles of *Vaastushastra*. In this chapter there is a discussion on the common comfort factors that are found in all the houses. This chapter looks at the architectural features of the house and understands these features in comparison to the data collected from the occupants' questionnaires. Each house is understood based on how the user feels in the space through sensory connections of sight, sound, smell and touch and how they are related to the architecture of house. Touch is understood as a sensory feeling in this chapter which looks how the users feel in the space. In addition to understanding whether the spaces meet the required temperature, the users are asked if the feel comfortable in the space. Data recorded from the temperature analysis was discussed in chapter 4. Since users' comfort is about the way the occupants feel (as discussed in chapter 2) this chapter looks at how comfortable the users feel in the house.

Various authors have written about residential satisfaction and how to assess the quality of indoor residential spaces. The framework of residential satisfaction highlights different urban factors such is "residential safety", "relationships with neighbours" and "overcrowding" and "comfort of house" (Amerigo & Aragones, 1997, p. 50). Of the various aspects of comfort discussed in the paper, acoustics, cleanliness, control of environment, furnishings, humidity, lighting, privacy, smell and temperature were linked to understanding comfort linked with sensory aspects (Ravindu, et al., 2015). Structured questionnaires were set up which asked the residents their level of satisfaction (Mohit, et al., 2010) and the data gathered from the questionnaires was compared to the temperature and humidity data collected. Windows are essential in residences (Kaplan, 2001) but very little attention is given to the view from the window and therefore its size and placement. In this thesis the author looks at the placement and the size of the windows in the case study homes and if these have an impact on comfort.

The questionnaire was designed referring to the template suggested in a paper on how to conduct a study of residential environments (Richardson, et al., 2006). The framework of selecting one of four options was selected from the paper, but some of the criteria such as heating of the house were modified as the climate in Dubai uses cooling, not heating. A selection of factors mentioned in these papers and those that were relevant to understanding users' comfort were used in the questionnaires. Quality of light, existence of smell, level of sound and feel (temperature and humidity) of the space were main issues raised. A sample questionnaire is attached in the appendix. The results from these questionnaires are looked at in connection to the architecture, in this chapter. Each occupant filled in the questionnaire and based on the number of occupants the questions were given a resulting value. For example, if there are 2 occupants and both selected the same answer the result will show 2/2 but if both occupants selected different answers then the value of 1/2 would be shown as a result. Similarly, the value would change when the house had 3 or 4 or 5 occupants. A numerical value is then given to the answers collected from the occupants as follows- often = 4, sometimes = 3, rarely= 2 and never =1. Which means the lower the average score more comfortable the occupants feel. The total number will be divided by 2 in the house that have 4 occupants so that the total of each house is measured from an average feedback of 2 occupants.

5.2 Comfort factors in the case studies

All the case studies share some common features which are mentioned here first (rather than repeating them in each individual case study) and its connection with users' comfort will be discussed. Temperatures in Dubai are high through many months in Dubai and therefore air-conditioning is a necessity in all indoor spaces including residences. Variation in case studies is about the type of air-conditioning used in the space such as central unit, in which a few rooms share the same unit and thermostat or split unit in which each room has an individual air-condition and thermostat. This makes a difference in the comfort levels of the users because if the ground floor has one thermostat then some people might feel cold while other are warm. This makes people lose the ability to switch off the air-condition and therefore feel less comfortable (as discussed in chapter 2). If there are more thermostats in the house the users feel more comfortable. Some homes will avoid using air-conditioning for few months during the winter when the outdoor temperature drops significantly. All the houses have openable windows, which allows the user to adapt his surroundings to be able to feel comfortable (as discussed in chapter 2). When the house is designed based on the principles of *Vaastushastra* the users should feel comfortable in the house. Use of fans is another way in which the users can feel comfortable in the space.

Along with the use of air-conditioning, the use of openable windows also allows for the user to feel comfortable in their space. For this to happen it is important that the house should have openable windows to allow for the occupants to be able to decide if they want to open them or not. Since all the homes selected for case studies are independent homes, they all have openable windows. The weather outside the home has to allow for the windows to be opened. As mentioned above, the weather in Dubai is very hot in the summer months therefore the occupants might not be able to open the windows during the summer. However, during the winter months, the outdoor temperature is low enough for the occupants to open the windows.

Vaastushastra conceptually allows for adaptive use of spaces. This is seen in the literature in chapter 2 which allows for different rooms to be used at different times of the day. Activities are placed around the house based on the time of the day and where the user is likely to feel comfortable. The case studies will be understood in terms of how the internal spaces have been placed based on the placement suggested in *Vaastushastra*. In theory if the spaces that are used the most are located in the right direction the users should feel comfortable in them.

Comfort levels in homes are partially dependant on the materials and finishes used in the spaces. Fixed carpets are not used in any of the case studies and all the homes have tiled finishes which helps in keeping the house cooler as carpeted floors keep the space warm since it is known to retain heat. The furniture in all the houses is covered with textile and therefore helps absorb and sound created and reduces the echo. The floors of all the houses are swept and mopped six days of the week, as this ensures that the house doesn't gather dust.

5.3 Neighbourhoods of the case studies

As mentioned in chapter 2 the case study homes belonged to three neighbourhoods in Dubai. Three of the five case studies were located in a neighbourhood known as Al Mankhool (Fig 5.1). This is a residential neighbourhood and has either single storied or double storied structures. There is one school in this neighbourhood, Ambassador School and there are 4 nurseries around. There is a health clinic and a small communal park next to the health centre. Since the area is predominantly residential there is usually very little traffic and therefore it is a quiet neighbourhood. On the northeast edge the area there is a metro station which is located on a main road. But this is far away from the selected homes and therefore doesn't have an impact on the studies. The homes were selected based weather they followed the principles of *Vaastushastra*. This has resulted in the fact that three of the homes are located very close to each other.

The other two case studies are located in Al Jaffiliya and Jumeriah 1. Case study 4 is located in Al Jaffiliya which is on the south side of Al Mankhool as shown in Fig 5.2. Similar to Al Mankhool this area is also mainly residential with low buildings except for on the east side which has a couple of governmental buildings. There is very little traffic seen on the inner roads of this area, which is where the case study is located. But there is a lot of traffic on the road that is close to the governmental services. There is a small park located within Al Jaffiliya but there is a bigger park, Zabeel park which is across the street from this area.

Unlike the other case studies, case study 4 is located in a residential area, but is facing a major road which get busy during peak hours of traffic and can cause noise of residents of the house (Fig 5.3). There are a few commercial establishments located in this area such as diving centre, veterinary clinic, coffee shops and supermarkets. The structures in this area are also up to two stories high. There are a few clinics and a hospital and located close to the site. There is small community park located across the street from the site which is Al Wasl park.

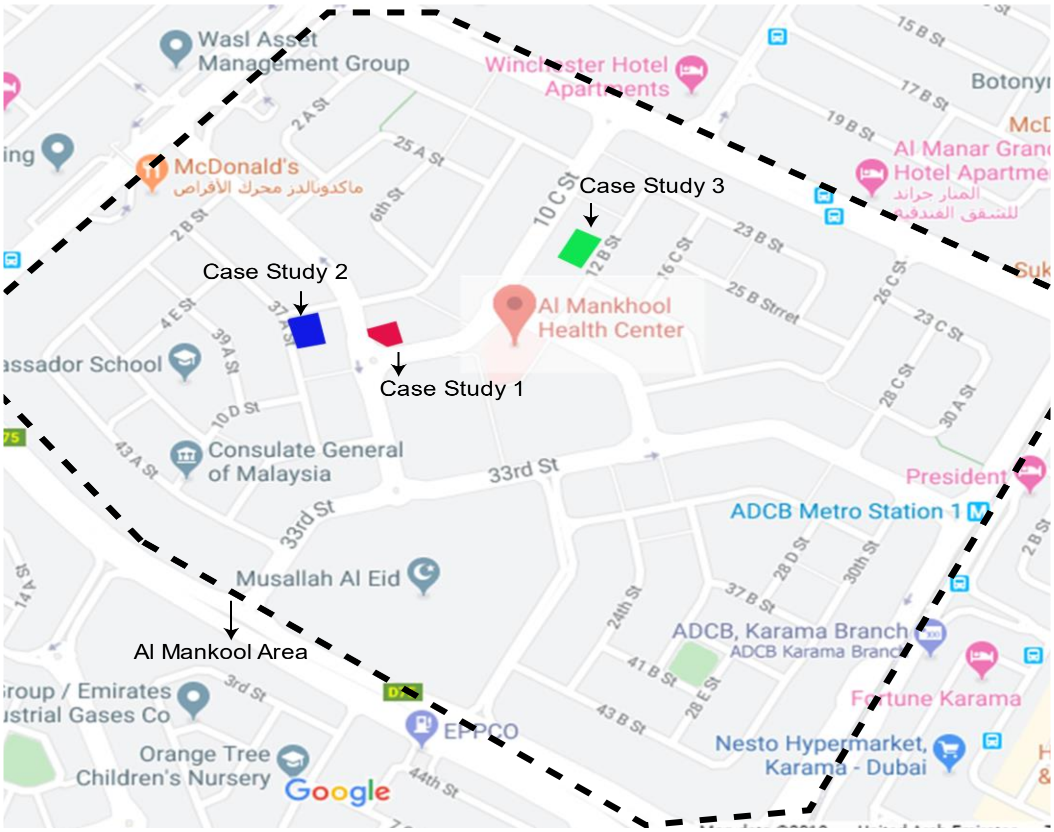

Figure 5.1- Location of 3 case studies

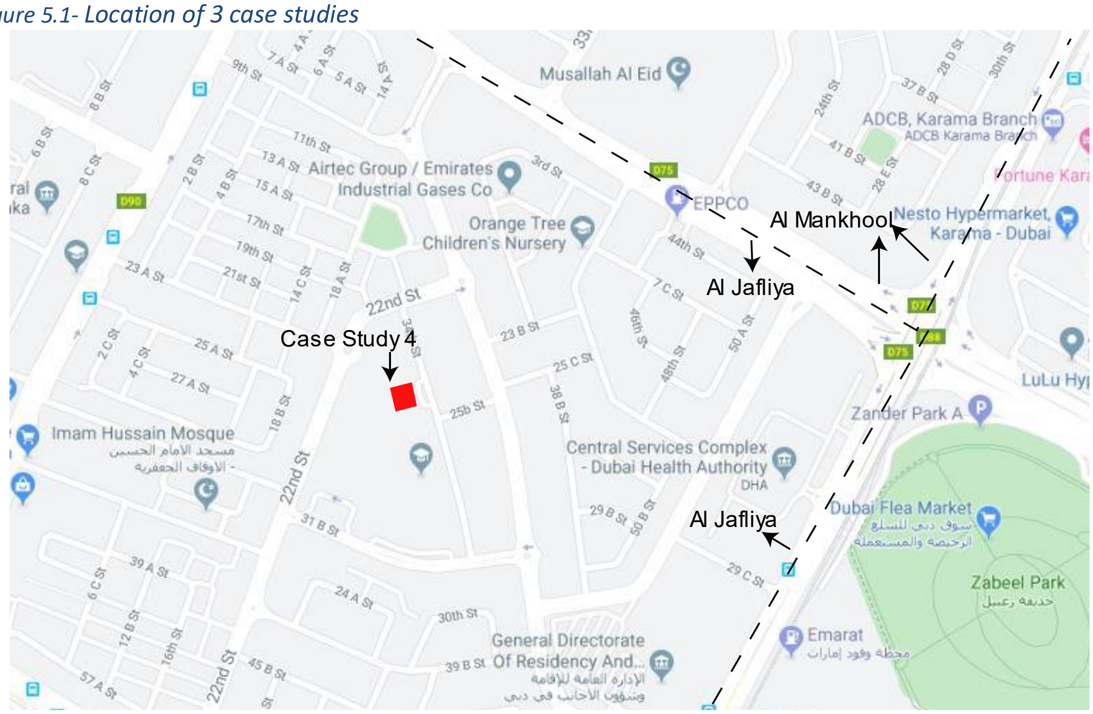

Figure 5.2- Location of Case Study 4

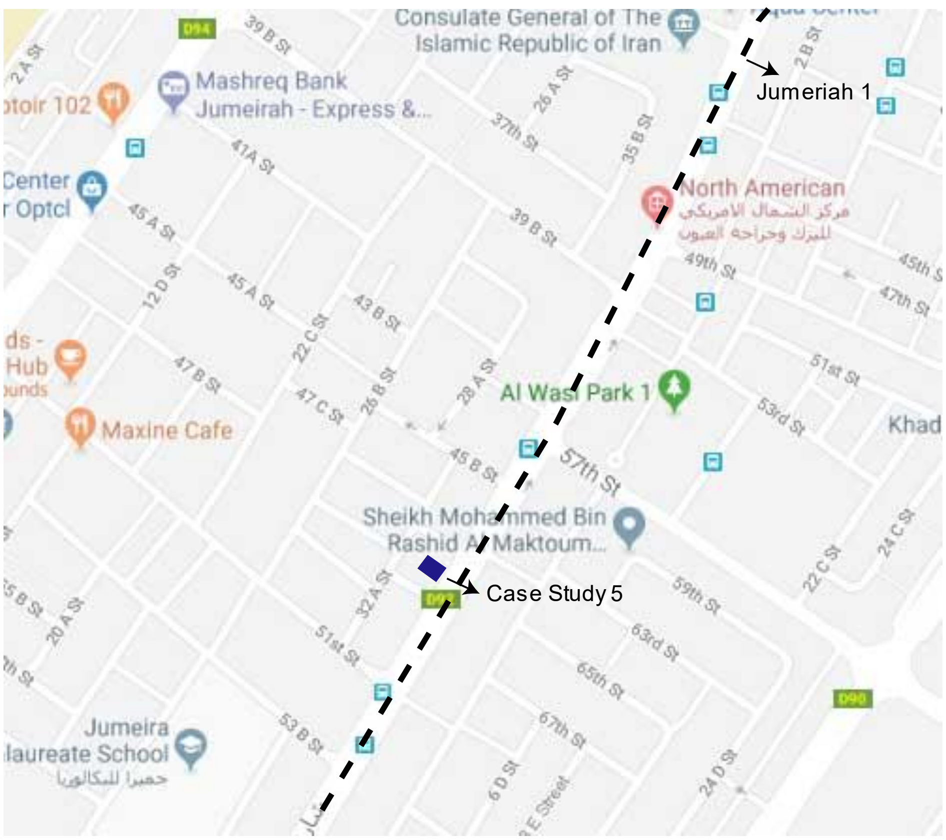

Figure 5.3 Location of Case study 5

5. 4 Case Study 1

5.4.1. Observations from Site

The house is located in a residential area which is approximately 5km away from the commercial area. The house is on a corner plot and therefore has vehicular traffic on two sides, one of which has a few tall trees to try and block the sound (See plan in chapter 3.7.1). These trees are located on the southwest side of the house which has large openings. As a form the house is mainly rectangular is shape which helps to understand the impact the form has on the comfort of the users. It has some parts missing from the southwest corner and therefore will help establish if the cut has an impact on the users' comfort. Occupants use the backyard of the house in the winter months because it is in the southwest/ northwest side of the plot and with the trees it is a pleasant space to use. Boundary walls on the property are high which prevent any traffic sound from being heard in the house or in the backyard. The entrance to the house is shaded since the staircase is placed at the entrance and the second flight of stairs projects outside the entrance lobby.

The house has split units for air-conditioning in each room of the house and in addition to there are ceiling fans and table fans which are used as an alternative source of cooling. In this case study the occupants use the fans (ceiling or table) in the summer months more than in the winter months. Another alternative source of cooling the space is cross ventilation through openable windows. The windows are used as an alternative source of cooling in this house both during the summer and in the winter months, but the windows are opened less frequently in the latter since the house possibly cools in a significant way naturally. Since the house is in a residential neighbourhood the occupants shouldn't hear too much traffic noise. All these methods of cooling give the residents many options through which they can feel comfortable in the space.

5.4.2. Case Study 1 Data from Users' Questionnaires

The house has two residents, and both were asked to fill in the questionnaires. The data collected from the questionnaires is shown in table 5.1 and 5.2 below –

How often the tenants faced problems with	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Natural Light			2/2		4
Noise			2/2		4
High temperature		2/2			5
Low temperature			1/2	½	3
Air/ bad smell			2/2		4

Unpleasant smells		1/2	1/2		5
Static electricity				2/2	2
Humidity		1/2	1/2		5
Total value of 2 users					32

Table 5.1- Sensory reactions of tenants in Case Study 1

How often do tenants	*Often* 4	*Sometimes* 3	*Rarely* 2	*Never* 1	*Value*
Switch on lights (summer)			2/2		4
Switch on lights (winter)	1/2		1/2		6
Use air-conditioning (summer)	2/2				8
Use air-conditioning (winter)		1/2	1/2		5
Experience noise when open the windows				2/2	2
Close the curtains (summer)		2/2			6
Close the curtains (winter)			2/2		4
Close the curtains to reduce noise				2/2	2
Use air fresheners in the house		2/2			6
Total value of 2 users					43

Table 5.2- Tenants interventions to improve indoor quality in Case Study 1

5.4.3. Analysis Case Study 1 in terms of Users' Comfort Levels

Understanding the space through the sensory connections felt by the users (table 5.1 and 5.2)–

Observations of the site - Orientation of the house, location of the windows and courtyard have an impact on this comfort level. As explained in Chapter 4 the house has windows on all sides, is aligned with the east west axis along the length of the house and doesn't have a courtyard space. *Vaastushastra* stipulates that this is the correct orientation of the building, but the building has windows on the west and south which are not recommended and one room in the southwest which has an odd shape.

<u>Touch</u> –A user's comfort in a space is through touch which refers to comfort experienced in the space regardless of actual temperature measured in it. This house has large windows on the south and west façades. The stairwell of the house is placed on the south side and has a full height glazing which causes heat gain because the glazing is exposed. Occupants of the house reduce the use of air-conditioning during the winter months which means that the glazing on the south side has a significant impact on the internal temperature of the entire house. Since the staircase is open to all the spaces on the ground floor, heat gained through the staircase doesn't allow the remaining space to cool down.

The room in the southwest has a corner which is cut off making it a polygon rather than a square. Principles of *Vaastushastra* recommend that rooms should have regular shapes such as square or rectangle. There is no explanation provided to support why polygons should not be used, the temperature studies in the previous chapter can help to understand if the shape has an impact on the temperature recorded. As discussed in chapter 4.2.1the southwest room is the warmest room in the house and that is probably because of the odd shape. Adding windows in the building is a concern for the temperature but allows for sunlight which is very important in habitable spaces.

<u>Sight</u> –The users of the space rarely experience any issues with the natural light levels available in the house. The windows are located on the east west and south walls of the house. During the summertime the users rarely use artificial light which means that the day light supports the activities in the locations where they are carried out. The use of artificial light is needed more during the winter than in the summer which supports the fact that the orientation of the windows helps obtain natural light in the house during summer but falls short during the winter.

Sound – The levels experienced in the house are caused by sounds penetrating from the street and those that are generated inside. Since the house is in a residential area the occupants don't experience traffic noise due to which they can leave their windows open to cool the space and they have mentioned that they don't experience street noise. Sounds that are rarely experienced by the users, therefore seem to be generated by the appliances used in the house, probably the air-conditioning units.

Smell – The finishes used in the house and the air circulation determines the smells that the occupants experience. In this case the occupants are living in the house for quite some time and therefore there no concerns with off gassing materials and finishes. The occupants mention that they experience problems with air and unpleasant smells sometimes which could be a result of use of air circulation as the air-conditions used in this house are individual units which cool the space but do not exchange air which can cause stale air in the house.

5.5. Case Study 2

5.5.1. Observations from Site

The second case study is within the same neighbourhood as the first case study and therefore is also located in a residential area. This house sits in the middle of the road with houses on three sides and has one small road in front of it which has minimal traffic throughout the day. There is a garden between the house and the main road which prevents sound from penetrating into the house. The form of the house is purely rectangular in plan and in section and this case study helps to understand the impact of this form. There are windows on the west façade of the house, but these are covered by overhangs that provide shading and help keep the space cooler. The garden space is used significantly in the winter and also during the early mornings in the summer as there are many trees which help keep the space cool.

There are individual air-conditioning units in each room, and these are operated individually, therefore can be switched on or off based on the users' needs. This house does not use any ceiling or table fans as alternative cooling methods. In this case study the only alternative method is to cool the house through the openable windows located on both floors. In this example the openable windows are not used for cooling in the summer months but are used regularly to cool the house in the winter. Opening the windows in the winter allows for the house to cool naturally.

The house has two residents; both were present during the data collection period and both were asked to fill in the questionnaires. The data collected from the questionnaires is shown in table 3 and 4, followed by a discussion on the findings –

5.5.2. Case Study 2 Data from Users' Questionnaires

How often the tenants faced problems with	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Natural Light		1/2	1/2		5
Noise			2/2		4
High temperature		2/2			6
Low temperature			2/2		4
Air/ bad smell				2/2	2
Unpleasant smells				2/2	2
Static electricity				2/2	2
Humidity		2/2			6
Total value of 2 users					31

Table 5.3 - Sensory reactions of tenants in Case Study 2

How often do tenants	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Switch on lights (summer)		2/2			6
Switch on lights (winter)		2/2			6
Use air-conditioning (summer)	2/2				8
Use air-conditioning (winter)			2/2		4
Experience noise when open the windows				2/2	2
Close the curtains (summer)	1/2	1/2			7
Close the curtains (winter)			2/2		4
Close the curtains to reduce noise				2/2	2
Use air fresheners in the house		2/2			6
Total value of 2 users					45

Table 5.4- Tenants interventions to improve indoor quality in Case Study 2

5.5.3. Analysis Case Study 2 in terms of Users' Comfort Levels

Understanding the space through the sensory connections felt by the users (table 5.3 and 5.4) –

Observations of the site – As explained in Chapter 4 the house has large windows on three sides and only has two small windows on the south side. It is aligned with the length along the north to south axis but doesn't have a courtyard space.

Touch – From the user's experience the house is warmer in the summer and therefore needs constant use of air-conditioning during this time and is cooler in the winter with the use of natural ventilation. This suggests that the orientation of the house helps keep it cooler in the winter months, which means it should be relatively cooler during the summer. The occupants of the house open the windows only in the winter months which cools the house naturally. Even though the house has windows on the west façade these don't gain too much heat as there is a shading structure above the windows to prevent this. Curtains are used more during the summer months which could suggest that they are used to block heat gain from the sun especially for the windows on the west façade. Trees are placed outside the west façade of the building which provide additional shading and prevent heat gain. The house doesn't have any windows on the south façade which is a big factor towards to comfort experienced by the users.

Sight - The users of the space sometimes/ rarely have any issues with the natural light levels in the house. The use of artificial light is the same during the winter and in the summer, which supports the fact that the orientation of the windows doesn't help to obtain adequate natural light in the house and doesn't allow for enough natural light during both seasons. Even though windows are located on east and west sides of the building these do not provide enough natural light because there are no windows on the northeast side of the building which could be a good source of natural light.

Sound – The occupants of the house don't experience traffic noise but have mentioned that they experience noise at home rarely. The experienced noise isn't from outside as the occupants have mentioned that they never close the curtains to overcome the noise levels. The noise levels experienced by the users therefore seems to be generated by the appliances used in the house, probably the air-conditioning units especially since the air-conditioning units are used often in the summer months.

Smell – The occupants mention that they never experience problems with air and unpleasant smells which could be due to the correct orientation of the house, use of openable windows which facilitate in air circulation and exchange which keeps the indoor air fresh. During the months when the windows are closed stale air might be the cause of unpleasant smells.

5.6. Case Study 3

5.6.1. Observations from Site

The third site is located in the same residential neighbourhood as the first two houses. It is an independent house just like the first two homes. This house is located on an internal street and has one road in front of it which has low vehicular traffic. The house is a rectangular cube in volume. This house helps to investigate the impact external windows have on the user's experience because the house has windows on all facades. All the windows in the house are exposed as they are not covered by any awning or roof, even though these elements are present in the design. Sizes of the windows are the same on all facades of house which helps to understand the impact window sizes have on recorded internal temperatures during the summer and winter months. The house is setback from the road and the front yard is completely paved therefore the house lacks any landscape elements which could have an impact on internal conditions in the house. The front yard is rarely used by the family as a living space which is only when there is a large gathering with more than 30 guests.

In this house central air-conditioning units are used with controls either shared between a couple of rooms or some units which are used for a specific room. One of the rooms in the house has a table fan which is used as an alternative method of cooling for that space. An alternative to air-conditioning is natural cooling and this is facilitated through opening the windows on both floors so that cross ventilation is possible. The windows of this house are opened more often during the winter months than in the summer months this allows for the house to cool naturally. Since the house is in a residential neighbourhood the occupants can't hear too much traffic.

5.6.2. Case Study 3 Data from Users' Questionnaires

Even though there are 11 residents in the house the questionnaires were filled by four of the occupants which is the maximum number of questionnaires that were filled by occupants of one house. People of similar age groups as the occupants of the other houses were asked to fill in the forms. The data collected from the questionnaires is shown in table 5 and 6 below –

How often the tenants faced problems with	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Natural Light			4/4		8
Noise	1/4	1/4	2/4		4
High temperature		4/4			12
Low temperature		2/4		2/4	8
Air/ bad smell			1/4	3/4	5
Unpleasant smells			2/4	2/4	6
Static electricity				4/4	4
Humidity		2/4	2/4		10
Total value of 4 users					64
Total value of 2 users					32

Table 5.5- Sensory reactions of tenants in Case Study 3

How often do tenants	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Switch on lights (summer)	2/4	1/4	1/4		13
Switch on lights (winter)	2/4		2/4		12

Use air-conditioning (summer)	4/4				16
Use air-conditioning (winter)		2/4	2/4		10
Experience noise when open the windows			4/4		8
Close the curtains (summer)		3/4	1/4		10
Close the curtains (winter)		3/4	1/4		10
Close the curtains to reduce noise				4/4	4
Use air fresheners in the house	4/4				16
Total for 4 users					99
Total for 2 users					49.5

Table 5.6- Tenants interventions to improve indoor quality in Case Study 3

5.6.3. Analysis Case Study 3 in terms of Users' Comfort Levels

Understanding the space through the sensory connections felt by the users (table 5.5 and 5.6) –

Observations of the site – As explained in Chapter 4 the house has windows on all sides and isn't aligned with in best direction and doesn't have a courtyard space. Windows on the south and west sides don't have overhangs.

Touch – In this house windows of are placed on all four facades, these windows vary in size with the largest windows in common spaces, followed by mid-size windows in bedrooms and small windows in bathrooms. Large windows are placed on the south and west façade which causes significant heat gain the house. The windows have decorative awnings placed on them, but these do not prevent heat gain. If the awnings had been deeper, it would have helped the users feel comfortable in the space. Heat gained through these windows is significant as the occupants typically use air-conditioning even during the winter months. *Vaastushastra* restricts the placement of windows in a house, this house is an example that shows windows on all facades will automatically make the house warmer.

Sight - The users of the space rarely have any issues with the natural light levels in the house because the windows are located all around the building there is sufficient natural light. The use of artificial light is the similar during the winter and in the summer, which explains that the orientation of the windows and their size does not maximize sunlight during the summer season. The amount of light received in a room is also dependant on the orientation of the room within the house, using rooms that are placed away from the natural source of light would mean that the users would need artificial light.

Sound –Occupants of the house rarely experience traffic noise which is due to the fact that there is very little traffic in the area and the house is set back from the road. The occupants have mentioned reasonably high levels of noise within the house which seems to be generated by the appliances that are used in the house, the air-conditioning probably causing the highest noise levels. The occupants open the windows of the house during the winter but have mentioned that they rarely experience noise when due to open windows.

Smell – The occupants mention that they rarely or never experience problems with air and unpleasant smells which could probably be due to adequate air circulation by the air-conditioning systems. This house has a central cooling system which exchanges air and therefore avoids stale air. Similar to the other case studies occupants are living in the house for quite some time and therefore there no concerns with off gassing materials and finishes.

5.7. Case Study 4

5.7.1. Observations from Site

This house is in a community of three and has two other homes within the same site. The houses share the same entrance gate, parking and compound space. The house selected for the study is located on one side of the plot and has another compound adjacent to its fence. The green space for the house is in the front and backyard and the central space of the site is paved with brinks for parking and doesn't have any landscape elements. Residents don't use the shared outdoor space as an occupiable space because there isn't enough shading and there isn't enough space to sit. Each house has its own deck space at the back of the house which is occupied by its residents. The house is almost a square shape because the length and width are almost similar in measurements. The house doesn't have any windows on the northwest side which helps to understand the impact it has on the users' comfort levels. This house is located in a residential neighbourhood but is 2km away from the commercial centre of the city. Even though it is close to the commercial area the house is centrally located in a residential area and therefore the occupants shouldn't experience too much sound.

This house has central air-conditioning units which are used to cool several spaces, the units are controlled by a central system that maintains the temperature at a specified level. There are fans as alternative cooling methods available in the house and the occupants use these more in the winter than in the summer. This house has openable windows that are used as an alternative method for cooling the spaces. The windows of this house are opened more often during the winter months than in the summer months this allows for the house to cool naturally during the winter months.

5.7.2. Case Study 4 Data from Users' Questionnaires

The house has two residents occupying the space while the data was recorded, and both have filled out the questionnaires. The data collected from the questionnaires is shown in table 5.7 and 5.8 below-

How often the tenants faced problems with	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Natural Light				2/2	2
Noise			2/2		4
High temperature				2/2	2
Low temperature				2/2	2
Air/ bad smell				2/2	2
Unpleasant smells				2/2	2
Static electricity				2/2	2
Humidity				2/2	2
Total value for 2 users					18

Table 5.7- Sensory reactions of tenants in Case Study 4

How often do tenants	*Often 4*	*Sometimes 3*	*Rarely 2*	*Never 1*	*Value*
Switch on lights (summer)			2/2		4
Switch on lights (winter)		2/2			6
Use air-conditioning (summer)	2/2				8
Use air-conditioning (winter)		2/2			6

Experience noise when open the windows			2/2		4
Close the curtains (summer)	2/2				8
Close the curtains (winter)	2/2				8
Close the curtains to reduce noise				2/2	2
Use air fresheners in the house		2/2			6
Total value for 2 users					52

Table 5.8- Tenants interventions to improve indoor quality in Case Study 4

5.7.3. Analysis Case Study 4 in terms of Users' Comfort Levels

Understanding the space through the sensory connections felt by the users (table 7 and 8)–

Observations of the site – As explained in Chapter 4 the house has windows on all sides and the house is aligned with the length of the house oriented on the east to west axis but doesn't have a courtyard space.

<u>Touch</u> –Maximum openings in the house are on the east façade, with small openings on the south, a couple of openings on the west and no opening on the north side. The northwest side of the house has no windows and is therefore expected to be the coolest space. This space is designed for the dinning space therefore might not be used as often because there is no natural light available and using artificial light during the day is not preferred by the residents. Occupants use the ground floor during the day and mention that they typically rely significantly on the use of air-conditioning during the winter months as well as the summer. Even though the windows on the west façade have an overhang this is not enough to prevent the house from becoming warmer. There are two windows on the southeast corner of the house which do not have any awning and therefore cause the house to become warmer. Even though the southeast room is closed the gain on both west and south facades prevents the house from maintaining comfortable temperatures.

Sight -. The users of the space never have any issues with the natural light levels in the house, which is even though there aren't too many windows in the house. The occupants use the spaces in the house which have windows which allows adequate light which is the kitchen in the northeast and the office in the east. The use of artificial light is the slightly higher during the winter than in the summer which is related to the difference in light quality during the summer and winter seasons. The occupants probably use the rooms that are oriented towards the natural light during the day and therefore dependency on artificial light is lower in the house.

Sound – The occupants of the house don't experience traffic noise but have mentioned that they rarely experience noise at home. The noise isn't from outside as the occupants have mentioned that they never need to close the curtains to overcome the noise levels. The noise levels experienced by the users therefore seem to be generated by the appliances used in the house, probably the air-conditioning units especially since the air-conditioning units are used often in the summer months.

Smell – The occupants mention that they never experience problems with air and unpleasant smells which could probably be due to the correct orientation of the house, use of openable windows and/ or adequate air circulation by the air-conditioning systems which provides exchange of air as well as cooling.

5.8. Case Study 5

5.8.1. Observations from Site

The fifth house is located in a residential space which is within 2km of the commercial centre of the city. Even though it is located in a residential space there is a lot of vehicular traffic in front of the house because it is close to the city. The house has a small front patch of greenspace which doesn't provide a sound barrier to the residents of the house. It is a rectangular cube in form with windows located on the east and west facades, north and south facades are touching the perimeter walls and therefore don't have any windows. It is a row house which sits in a line of houses that are all identical. One side of the lower west facade is covered with a small overhang and right side of it is left open which will help to investigate the impact this feature has on users' comfort. The backyard is used by the family mainly in the winter because it is too warm during the summer season as there is no pergola or overhead structure that can protect the users from heat gain.

Individual controls are used to maintain the temperatures in each space even though the house has central air-conditioning units. In addition to this the house is cooled by portable table and/ or floor fans in both the summer and winter months. Another alternative for cooling the house is the use of the openable windows on both floors and the occupants use these more often in the winter than the summer. The house is in a suburban area but since it is in close proximity to the city the traffic noise can be heard in the house.

5.8.2. Case Study 5 Data from Users' Questionnaires

The house has seven occupants and all seven were living in the space when the measurements were taken. The questionnaires were filled by four of the occupants which is the limit which was set for the questionnaires. These were given to people of the similar age group as those in the other houses. The data collected from the questionnaires is shown in table 9 and 10 below -

How often the tenants faced problems with	Often 4	Sometimes 3	Rarely 2	Never 1	Value
Natural Light		3/4	1/4		11
Noise	1/4	2/4	1/4		12
High temperature	1/4	2/4		1/4	11
Low temperature	1/4			3/4	7
Air/ bad smell	1/4		1/4	2/4	8
Unpleasant smells			1/4	3/4	5
Static electricity				4/4	4
Humidity		2/4		2/4	8
Total value of 4 users					66
Total value of 2 users					33

Table 5.9- Sensory reactions of tenants in Case Study 5

How often do you	Often 4	Sometimes 3	Rarely 2	Never 1	Value
Switch on lights (summer)		1/4	1/4	2/4	7
Switch on lights (winter)		2/4	2/4		10
Use air-conditioning (summer)	3/4	1/4			15
Use air-conditioning (winter)		2/4	1/4	¼	9
Experience noise when open the windows	3/4		1/4		14

Close the curtains (summer)		3/4		¼	10
Close the curtains (winter)		3/4		¼	10
Close the curtains to reduce noise	1/4		1/4	2/4	7
Use air fresheners in the house	2/4	2/4			14
Total value of 4 users					96
Total value of 2 users					48

Table 5.10- Tenants interventions to improve indoor quality in Case Study 5

5.8.3. Analysis Case Study 5 in terms of Users' Comfort Levels

Understanding the space through the sensory connections felt by users (table 9 and 10)–

Observations of the site – As explained in Chapter 4 the house has windows on east and west sides only and the length is aligned to the east west axis but doesn't have a courtyard space.

Touch – The layout of this house has interesting features which are used to investigate the principles of *Vaastushastra*. Windows are placed only on the east and west façades of the house which are the shorter sides of the geometry of the house. Southeast window on the ground floor has a small overhang above it which is the parking structure, southwest window has a smaller overhang. Windows on the northeast and southwest facades don't have an overhang above them. Ground floor of the house is open plan except for a bedroom on the northeast side and a store on the northwest side. This house has an open plan which has these windows on both sides, it helps to understand the impact these exposed windows have on the comfort levels of the users. Users of the space feel the house is warm during winter and summer seasons which makes them use air-conditioning throughout the year. If the windows had a shading structure that was calculated to prevent heat gain the dependency on air-conditioning might reduce. The use of trees could be used provide shade to the windows and create good views as well as creating relatively comfortable spaces for the users.

Sight - The users of the space (sometime/ rarely) face issues with the natural light levels in the house. Even though the house doesn't have windows on all sides there is adequate natural light in the house because all the rooms in the house have large windows which allows for natural light. The use of artificial light is the slightly higher during the winter than in the summer which is related to the fact that the only natural light sources are from the east and the west side. The orientation of the rooms that are used by the occupants also play a role in the amount of natural light that it receives since there are no windows on the north and south façades.

Sound – All the occupants of this house experience traffic noise and is primarily experienced (75%) when the windows are open. In this case study the house is close to the urban city and therefore residents experience traffic noise when the windows are opened. It is therefore difficult to estimate only from the users answers if the noise is purely from the outside or a combination of internal and external noise. Occupants open the windows for alternative cooling methods more often during winter than the summer months as they also use fans to support cooling in the house during the winter.

Smell – The occupants mention that they rarely/ never experience problems with air and unpleasant smells which could probably be due to the use of openable windows or adequate air circulation by the air-conditioning systems which exchanges air and eliminates bad odour and stale air.

5.9 Conclusion

Touch -One common aspect in the findings of the questionnaires is that most of the occupants feel high temperatures often, except for case study 4 where the occupants never feel warm and case study 5 where occupants feel warm often, sometimes and never. There could be a couple of explanations for this, firstly as external temperatures stay high for up to 8 months of year, most occupants feel that their house is warm. The other reason could be the prolonged use of the warmer spaces within the house. *Vaastushastra* suggests that some spaces in the house such as the southeast followed by the southwest will inherently be warmer spaces, if the occupants use these spaces, then they will feel warmer. In case study1 occupants use the northwest room most frequently, while in case studies 2 the occupants use the northeast room, therefore they feel comfortable. In case study 3 the occupants feel warm majority of the time, even though they use the northeast side of the house which is supposed to be cooler. In case study 4 the occupants use the northeast space most of the time which could be the reason they don’t feel warm. In case study 5 occupants use the southeast room, the most which is suggested to be the warmest space in the house and therefore they feel warm.

Most occupants of the house rarely or never feel cold in the case studies, except for case study 3 and 5. In case study 3 half of the people feel cold sometimes and half of them never feel cold and in case study 5 only one person feels cold often. These exceptions could be because some people use the cooler spaces in the house while the others use the warmer spaces and the house uses central air-conditioning which could make some places cooler than the others making some people cold. It could also be that some people in the house are more comfortable with a slightly warmer temperature.

Sight – both natural and artificial lights are used in the cases studies, frequency of use is dependent on the time of the year but also on the size and placement of the windows. Most of the houses have adequate natural light during the day in the summer months except for house 2 and 4. All the houses have windows on the northeast side except for house 2, where the window is on the north side is not on the east, which results in house 2 requiring more use of artificial light even during the summer. In house 4 the northwest side has no windows and might the reason the occupants use artificial light often during both summer and winter months.

The use of windows allows natural light into the house, but also causes heat gain on some of the sides. The residents of the houses with large windows on the southeast, houses 3 and 5, mention that they feel warm in the house. The other houses have mid to small size windows on the southeast and the residents are more comfortable with the internal temperatures even in the summer months.

Sound- Most of the houses don't experience too much sound from the neighbourhood because the houses are in residential districts, expect for house 5 which is near the city and therefore experiences street noise when the windows are open. Most of the noise in the house is experienced internally and is probably generated from the use of air-conditioning especially in the summer months. All the houses have openable windows, therefore most of them don't have an issue with bad odour. The exception is house 3 which uses air fresheners often probably because of the constant use of air-conditioning which prevents opening of windows and therefore creates stale air in the house.

Chapter Six: Analysis of Case Studies

6.1 Introduction

In this chapter the findings of the previous two chapters will be discussed in relation to the principles of *Vaastushastra*. Both chapters 4 and 5 examined the case studies based on the selected methodology which highlights different aspects of *Vaastushastra*. Data collected from the sites is used to investigate the selected principles of *Vaastushastra* discussed in this thesis. Each case study will be inspected based on the principles that are followed and the principles that are not followed to understand the impact these have on the user's comfort. These principles and how they are applied to the case studies is mentioned in chapter two.

6.2.1 General discussion of case studies based on temperature

Average temperature data collected from the case study homes during the summer (with the use of air-conditioning) and winter (without the use of air-conditioning) is shown in fig.6.1 and fig. 6.2. Average variation from the external temperatures is shown fig.6.3 during summer months and in fig.6.4 during winter months. To understand the significance of the principles that are applied to the house a comparison is made between the average recorded temperatures of the houses during summer fig.6.1 and winter fig.6.2. The summer recordings were taken with use of air-conditioning, since the average external temperature was 39.5°C which was too high to go without. In the winter the temperatures were recorded without the use of air-conditioning as the average external temperature was 22°C which made it possible for the residents to switch off air-conditions.

From the data shown below in fig. 6.1 we can make the following observations. In comparison to the outside temperature the warmest corner in all the houses is the southeast corner, followed by southwest, northwest and northeast, with a couple of exceptions. In case study 1 the southwest corner is the warmer than southeast. A possible cause for this exception could be the shape of the room in case study 1. The southwest room is not a square or rectangle and doesn't follow the proportions of *Vaastushastra* which is the reason for the variation in temperature. In case study 4 the northeast temperature is as warm as the southeast and the temperature of the northwest room is much lower than the northeast. The northeast room has recorded higher temperature probably because of the proportions of the room which don't follow the principles of *Vaastushastra*. The proportions of this room are too long with a small width which probably makes it warmer. The northwest room is the coolest space in case study 4 because this room doesn't have windows and therefore there is no heat gain or heat loss.

Data collected from all five case studies in the winter months is shown in fig.6.2. All five houses maintain temperatures at 25°C or lower in all sides of the house with a few exceptions. The exception noticed is the southeast corner of house 2, 3 and 4. These temperatures are around 27°C even in the winter months. This is an expected outcome because *Vaastushastra* principles predict that the southeast corner of the house is the warmest. Even though the window sizes are different in all three case studies, case study 2 has one small window and case studies 3 and 4 have large windows. Even though case studies 1 and 5 have large windows on the southeast side the temperatures are 25°C. This could be due to the orientation of the houses. Case studies 2 and 3 are oriented with the length along the north south axis, whereas case studies 1 and 5 are oriented with the length along the east to west axis. Even though case study 4 is oriented along the east west axis, because the room isn't of correct proportions it also records average temperature of 28°C.

Through the comparison of the average temperatures of case study, we can understand the impact the principles of *Vaastushastra* have on the actual recorded temperatures. Reviewing the data collected from the occupants' questionnaires supports the principles of *Vaastushastra* which has different finds to the data findings. Users feeling of the space is different to the actual recordings of the space. Analysis of the case studies are presented in the order of user's comfort recorded. Based on the average temperatures recorded during the summer, the houses are analysed in order from lowest to highest, in the following order- case study 5 (28.7°C), 4 (29.2°C), 1 (30.8°C), 2 (34.1°C) and 3 (36.1°C). In the winter months all the houses average at a temperature of 25°C except for case study 1 which has an average temperature of 24.1°C.

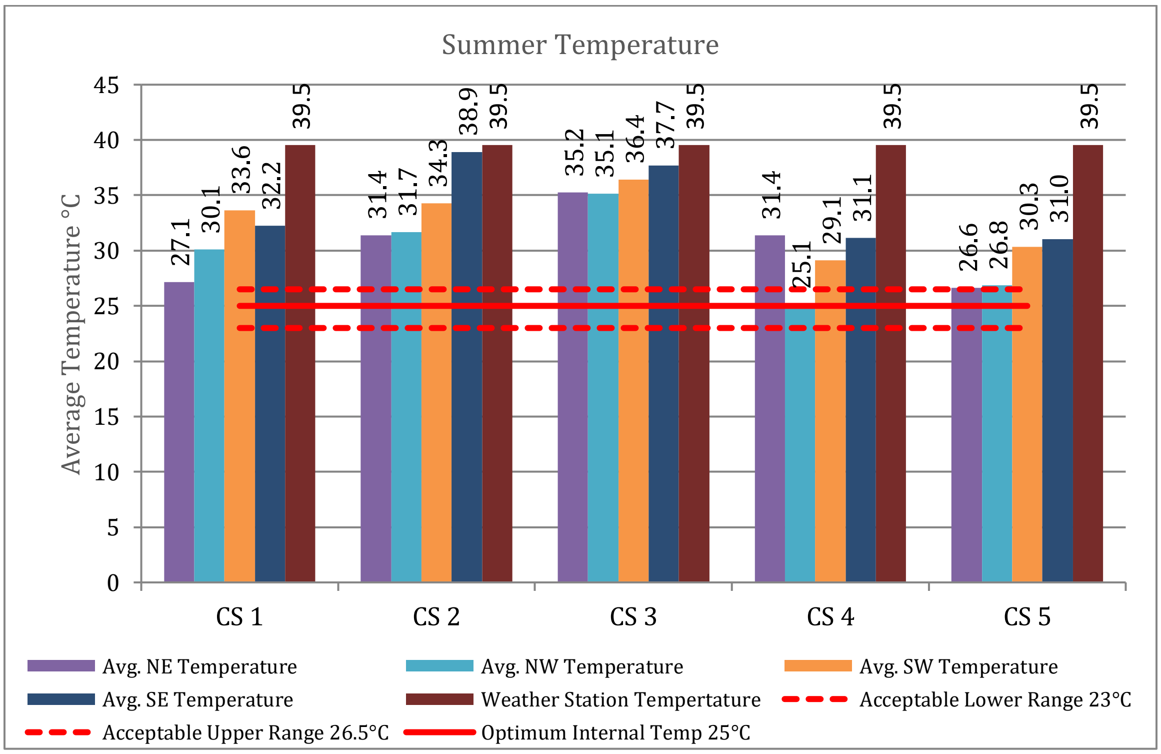

Figure 6.1- Comparison of Average Internal Temperature of Case Studies (CS) in Summer

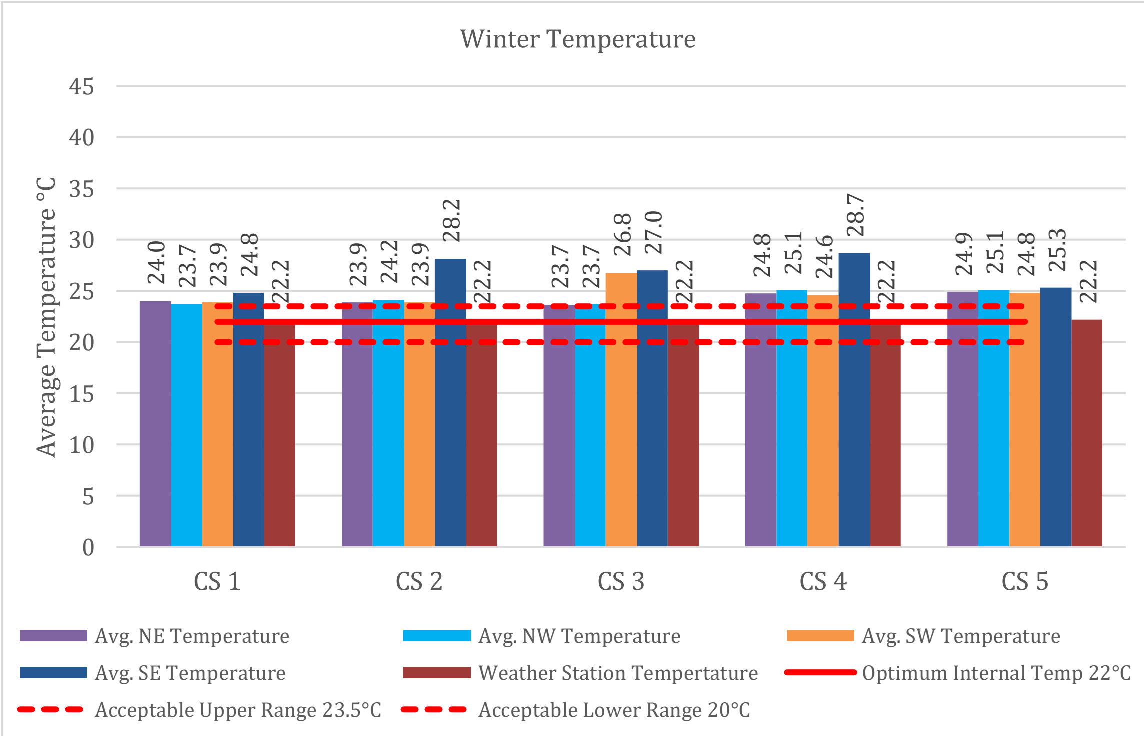

Figure 6.2- Comparison of Average Internal Temperature of Case Studies (CS) in Winter

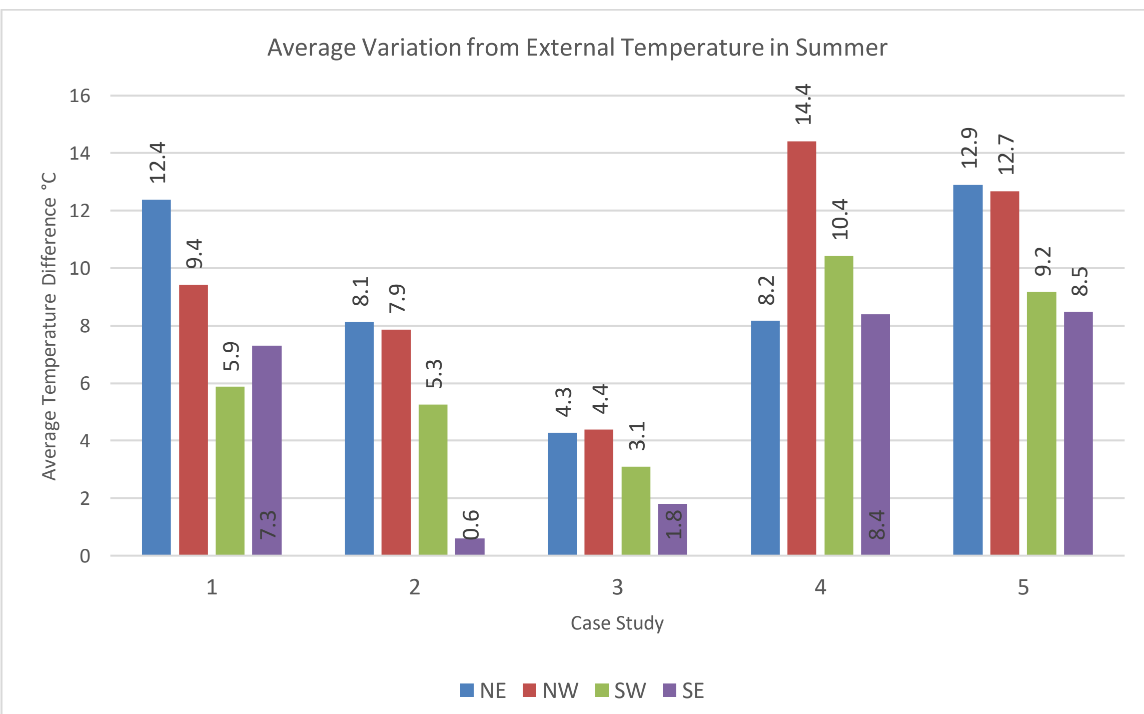

Figure 6.3- Average variation from external temperature in summer

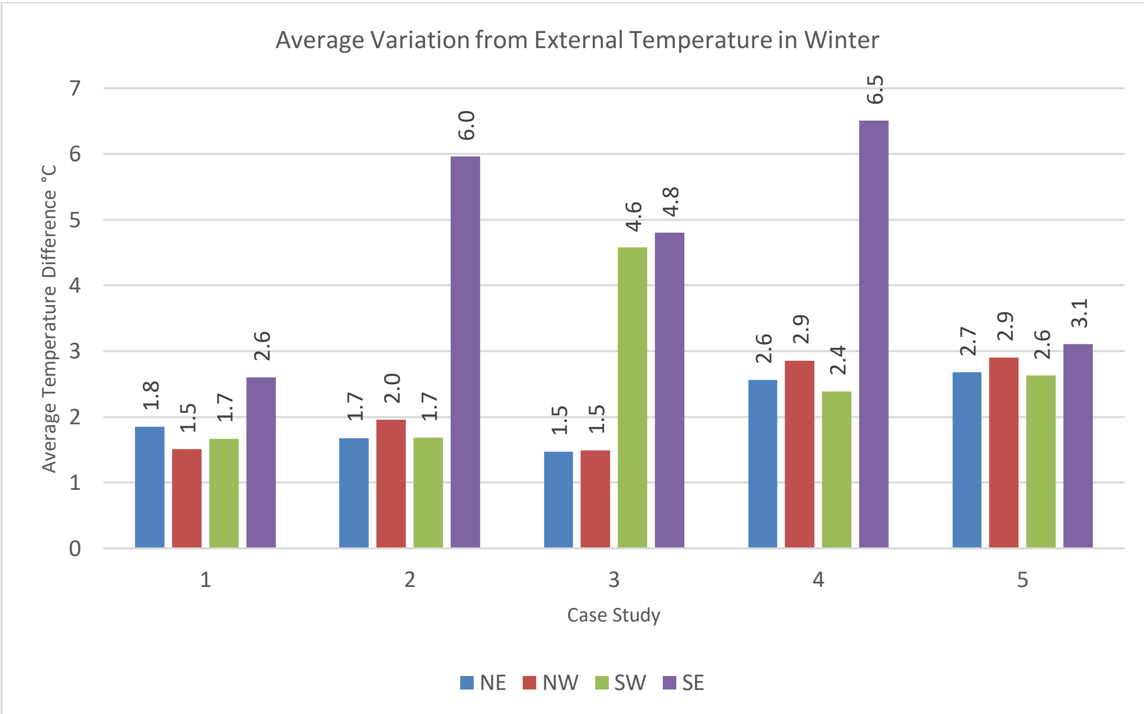

Figure 6.4- Average variation from external temperature in winter

6.2.2 General discussion of case studies based on users' comfort

Occupants of each case study were asked to fill in some questionnaires and the answers have been given a numerical value starting from often = 4, sometimes = 3, rarely= 2 and never =1. The results of these questionnaires are discussed in the previous chapter. Numeric values were given to the answers given by the residents of the homes. If the occupant selected of the option of 'often' that was considered a poor score and 'never' was considered positive. A high score meant that the occupants were not happy with the house and lower score meant that they occupants were happy. The first part of the questionnaire which is labelled 'sensory reactions of tenants' shows how the occupants feel in the space. Whereas 'tenant's interventions to improve indoor quality' shows the actions that the tenants need to take in order to stay comfortable.

The first number is the number of criteria that the questions had, 'sensory reactions of tenants' had 8 questions and the other category had 9. Answers from both are multiplied by 2 because the typical household is 2 occupants. In the homes that have 4 occupants the total is divided by 2, to understand the total for 2 people. The third number is the total of the user's response 1 for 'never', 2 for 'rarely', 3 for 'sometimes' and 4 for 'often'. Banding of the scores for sensory reactions is as follows, the lowest score possible is if in all 8 categories the users chose 'never' which is 8 x2 x1 it gives a total of 16. The next band would be with scores of 'rarely' which is 8 x2 x2 which is 32 and is a good score. If they opted for 'sometimes' it is 8 x2 x3 which is 48. Similarly, the highest score would be 8 x 2 x 4 which gives a total of 64. Scores from each house will show how comfortable the residents feel in their homes.

Tenants' interventions are broken down in the same way. There are 9 sets of questions used here which means the lowest score is 9 x2 x 1 which is 18, 9 x2 x2 which is 36, 9 x2 x3 which is 54 and the highest score is 9 x 2 x 4 which is 72.

CASE STUDY HOMES	*SENSORY REACTIONS*	*OVERALL FEELING OF DISCOMFORT*	*TENANTS' INTERVENTIONS*	*OVERALL USE OF INTERVENTIONS*
1	32	rarely	43	Sometimes
2	31	rarely	45	Sometimes
3	31	rarely	49.5	sometimes
4	18	never	52	Sometimes
5	33	sometimes	48	Sometimes

Table 6.1- Discussion of users' comfort in case study homes

Bigger variation in satisfaction is seen in the outcomes from the sensory reactions of the tenants with three of the four possible outcomes. Case studies 1, 2 and 3 say that the rarely feel uncomfortable in their homes, while case study 4 says the never feel uncomfortable and 5 says they are uncomfortable sometimes. On the other hand, the interventions used by the occupants are all the same with sometimes as the answer. When compared with the interventions used in the house the only the response of case study 5 is the same. Case studies 1, 2 and 3 said rarely for the way they felt in the space but chose sometimes when it came to interventions. In the case of case study 1 outcome of the intervention is closer to rarely, but in case study it is closer to often. This shows that the tenants of house 1 use less interventions followed by the occupants of house 2 and finally house 3.

Based on the sensory reactions the houses are ranked from best to worst as house 4, 3,2,1 and 5. This is a different result from the next set of findings which is about the tenants' interventions, which refer to actions that the tenants need to take in order to feel comfortable. From the tenants' interventions the ranking of the house from best to worst is 1,2 5,3 and 4. In the case of house 4 it is interesting to see that the occupants feel very comfortable in the house, but it is probably due to the interventions that they had undertaken. For example, relying on the use of air-conditioning can make the user comfortable in the space. Similarly opening the windows or using fans can be another intervention that makes the occupants feel comfortable in the space. There is a similar pattern seen is case study 3, where the occupants probably feel comfortable in the house due the use of air-conditioning. The occupants of villa 5 say that they rarely feel uncomfortable and they don't rely on interventions as much as the occupants of 3 and 4. On the other hand tenants of study 1 and 2 also mention that they are very comfortable and they use less interventions then house 3.

6.3.1 Case Study 5

The key reasons this house has the lowest average recorded temperature could be linked to the architectural features that are in line with the principles of *Vaastushastra*. The architectural features of this house could have influenced the temperature and therefore the overall temperatures recorded in the house. These features are- alignment of the house on the cardinal directions, absence of windows on the south wall, overhangs on the windows on the southwest and southeast sides. Three of the houses selected for the study are aligned with the east west directions aligned along the length of the house and this is one of them. In this case study the window is on the east wall of the southeast room, rather than on the south wall. All the other houses have at least one window on the south wall, even if it is very small in size. The impact of these is seen with the increase in temperature noted in the rooms on the south. Massing of the house is such that the first floor is larger than the ground floor which provides overhangs to the windows on the southwest, southeast and northeast walls. On the northwest side however, there is no overhang provided. A spike is seen in the temperature recorded on the south east corner, which is because the overhang on the southeast side is short.

Data collected from the questionnaires however shows that the users feel the most uncomfortable from all the other case studies, but their use of interventions to feel comfortable is moderate. Even though the house is cooler than the other houses during the summer, the occupants mention a constant need for air-conditioning. The reason for this could be that the occupants use the warmer rooms of the house which is the southwest space with an average of 30°C and the southeast space which records an average of 31°C. To improve the users comfort of the space a couple options are recommended, either the layout of the house can be rearranged so that the functions which are used the most are placed on the north side, rather than the functions that are not used as much. Another option is that the southeast and southwest sides have an additional canopy or shading structure above it. Adding pergolas or landscape elements the outdoor spaces could also help to reduce the temperature on that side of the house.

Case study 5 appears to feel warmer than the other houses during the winter months even though average temperatures is similar to studies 2,3 and 4. The difference in this house is that all the four sides have average temperatures of approximately 25°C while the upper range for acceptable temperature is 23.5°C. Since all the sides of the house are slightly warmer than acceptable the tenants of the house feel the need to switch on the air-conditioning during the winter months. As mentioned above, if the house had shading structures or landscape elements on the west side it would have the house stay cooler.

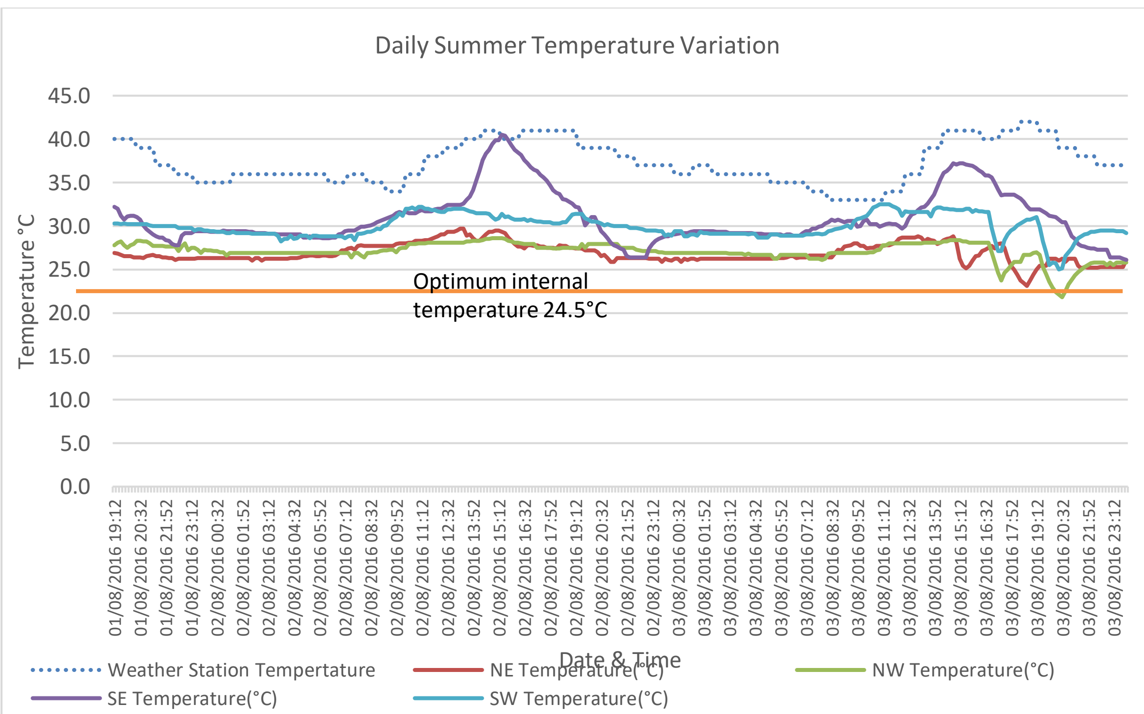

Figure 6.5- Case study 5 temperature variation in Summer

There is an interesting pattern of temperature seen in the house on a daily basis during the summer, which can be observed in the temperature graph in fig.6.5. During the summer, temperatures of the northeast and northwest are similar throughout the day, with rise and fall in temperature either occurring at the same time or happening 30 minutes later in the northwest. The temperature gains and drops seen in the southwest are a similar pattern to the northeast and northwest side except that the temperature in the southwest predominantly stay above 30°C. Gains in temperature on northeast, northwest and southwest are seen from 10am with the peak temperatures happening at 2 pm in the northeast and northwest but at 11pm in the southwest. Even though the northwest doesn't have a shading device it maintains temperatures similar to the northeast. Since the southwest shading isn't too deep, gain of 4°C to 5°C is noticed from 11am till 1pm with a similar drop in temperature from 1pm onwards to stabilise for the evening and night. The southeast is the warmest side of the house, the increase and decrease in temperature is similar to the southwest except that at 2pm temperatures in the southwest start to drop, but the temperatures in the southeast continue to rise to peek at 3pm and then drop significantly till midnight where the temperature is as low the northeast temperature.

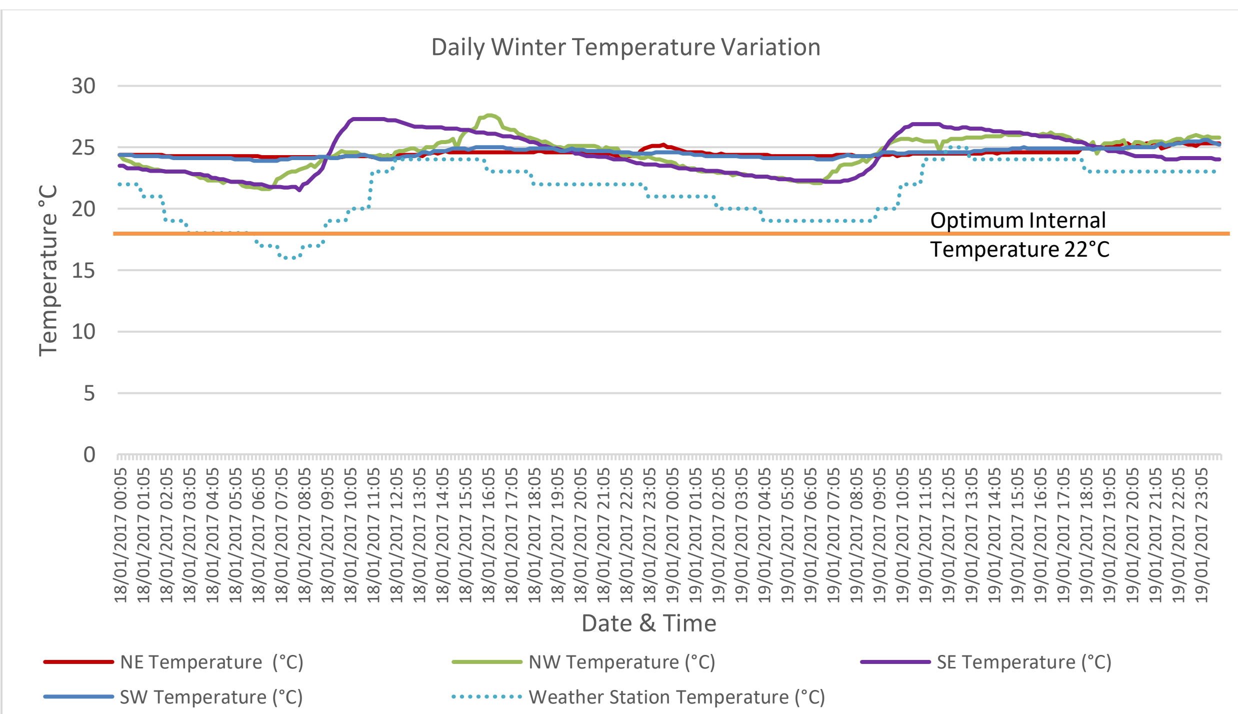

Figure 6.6- Case study 5 winter temperature variation

The trend seen in winter is slightly different with the northeast and southwest maintaining similar temperatures throughout the day and the northwest and southeast showing drastic gains and drops in temperatures seen in Fig. 5.6. Both southeast and northwest sides see a gain in temperature from 7am till 9am when the southeast temperature stabilises but the northwest temperature continues to rise till 4pm when it starts to drop and continues to drop till 7am the next day.

The house is cooler during the summer months as compared to the other studies as seen in fig. 6.1, but this has an impact on the quality of light in the house. As seen in chapter 5, occupants rely on artificial lights equally during the summer and winter months which means the house doesn't receive optimum natural light during the summer. For a space to be comfortable it is important that there is adequate natural light in the space. In this case both north and south walls don't have windows which makes the space dark. If the north wall had windows it might help to create a cool space which has adequate natural light through the winter months.

6.3.2 Case Study 4

The key architectural features of the house, based on the principles of *Vaastushastra* are that, the length of the house is aligned on the east west axis, the northwest corner has no windows and the southeast room has two large windows, one on either side and the proportions of the house are close to being a square. Proportions of the house are an important principle of *Vaastushastra*, there are a variety of proportions that are suitable for residences off which square is a preferred option. When the data from case study 4 is compared with the data from case study 5, a difference in average temperature is noticed. Temperatures recorded in the southeast corner of both homes is similar at 31°C. Both southwest and northwest average temperatures are lower in case study 4 but, because the northeast reading for case study 4 is much higher than in case study 5, the average temperature of the house is lower in case study 5. The southeast temperature reading in case study 4 is high, which is expected because this corner of the house has two full height windows, one on either wall (south and east) and the proportion of this room is too long and narrow. If the width of the room was proportionate to the length, or if the windows had shading devices, the room might not have recorded such high temperatures. Exposing windows on the south façade are known to cause gain in internal temperatures.

The questionnaires show that the occupants feel the most comfortable from all the other studies, but they use the most interventions to feel comfortable. This could be because the occupants feel most comfortable in the space after using all the interventions. Even though the northwest space is maintained at an optimum temperature, it isn't used during the day because of lack of natural light. The occupants rely on use of air-conditioning throughout the house because they use the warmer spaces of the house throughout the day, which are the northeast and southeast rooms which has recorded temperatures of 31°C. Space in the southwest side recorded an average temperature of 29°C, which is considerably higher than the acceptable high range of 26.5°C. This space in the southwest corner has windows on the south and west facades, of which the south side window doesn't have any shading device and the west façade has an overhang created by the extended upper floor. Even though the west façade has a shading structure, the impact of this shading is negated by the window on the south façade which doesn't have any shading.

Average winter temperature of case study 4 is the highest of all the studies at 25.8°C. As mentioned in the questionnaires, occupants rely on air-conditioning more in this house than is study 5 because the southeast room is used frequently which has the highest average temperature in the house. If residents used any of the other rooms during the winter, it might be easier to cool and create a comfortable temperature. Another option is to use shading devices on the windows placed on both south and west wall.

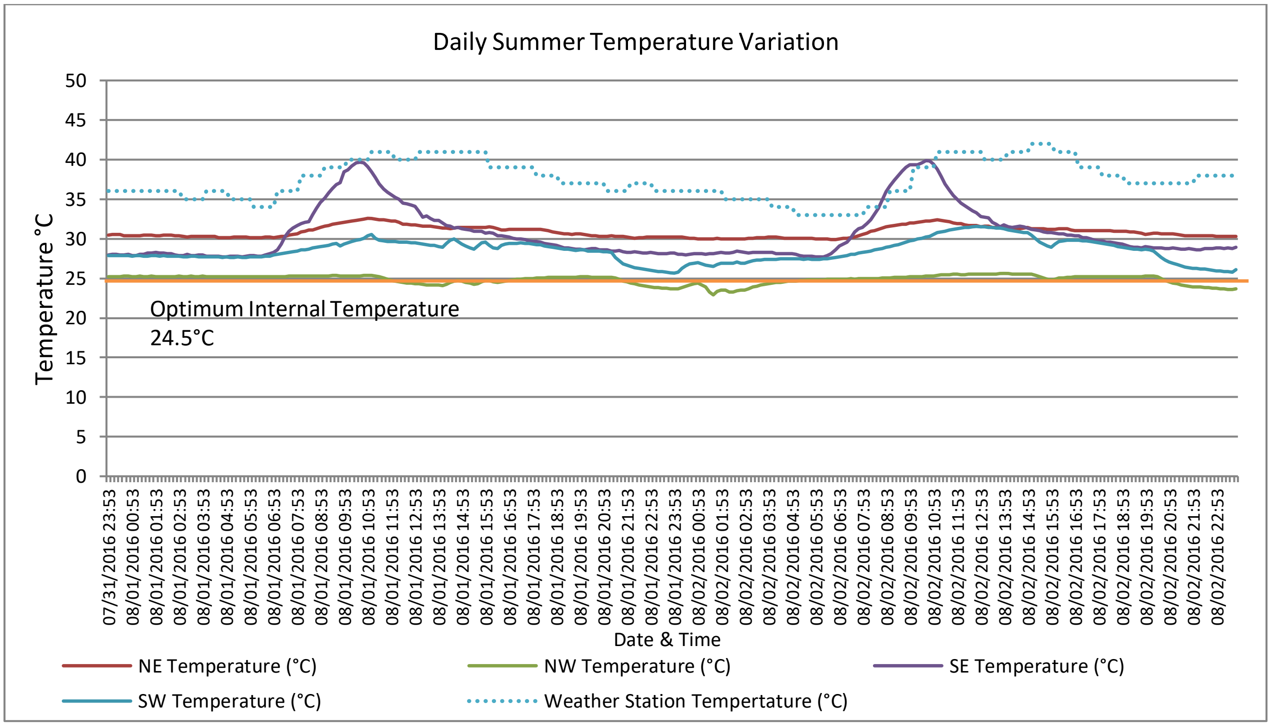

Figure 6.7- Case study 4 temperature variation during summer

In this house the daily temperature variations are similar to case study 5 during the summer because 3 sets of temperature stay within a particular temperature range and one set has a dramatic rise and fall in temperature, seen in fig.6.7. However, it is interesting to note that the northeast temperature in case study 4 is much higher than in case study 5. In case study 4 temperature in the northeast is above 30°C throughout the day, whereas in case study 5 northeast temperature is well below 30°C. Both these houses have large windows on the east wall but in case study 5 the proportion of the northeast room help to maintain the temperature below 30°C.

The northwest room in the house is the coolest space but is used as a formal space which means it isn't used throughout the day or by the entire family. If this space was the living space, or the space where the family would spend most time they would feel more comfortable and possibly not rely on air-conditioning as much as they do. The reason for reduced temperature is that this room has no windows. Gain in temperatures in the southeast, southwest and northeast are seen at the same time at 7am and similarly drops in temperatures start at 11am and by 3pm the temperatures stay level except for the southeast where the gain in temperature is followed by a drop-in temperature that drops below 30°C from 7pm till 7am.

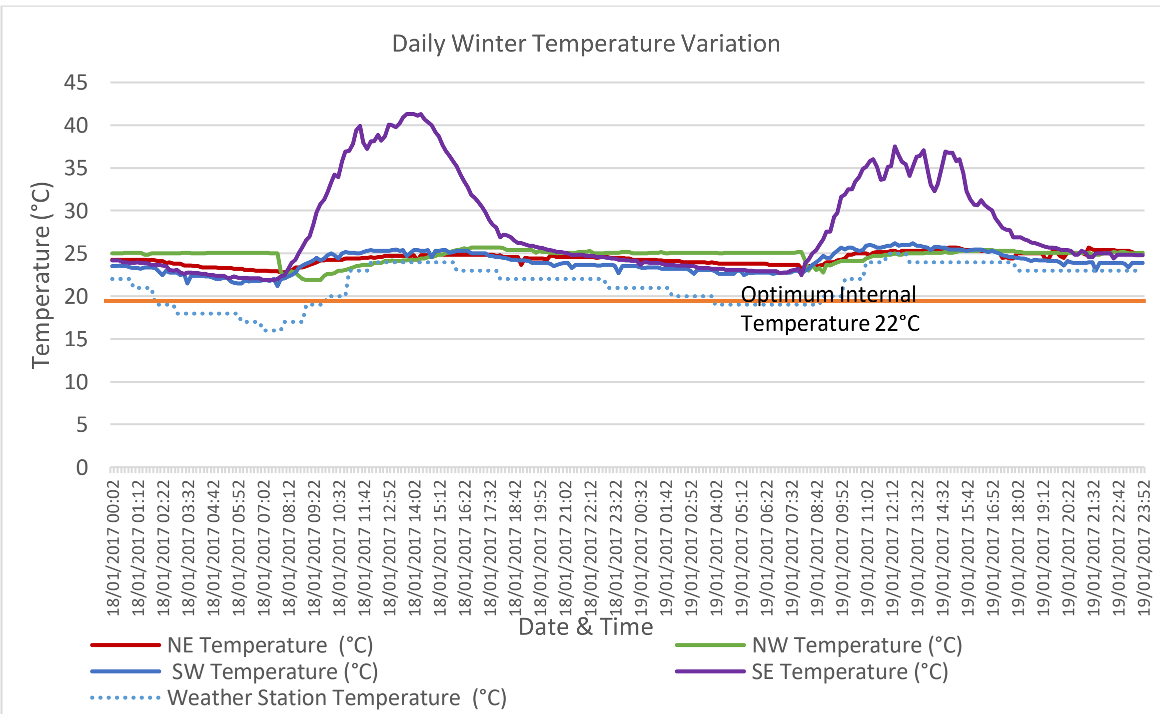

Figure 6.8- Case study 4 winter temperature variation

In case study 4, temperatures in the house stay below 25°C except southeast space because of which the average temperature of the house could be high. The temperature sensor was placed in the same location in all the houses, which is on the windowsill, but the sensor was not exposed to direct sunlight. Temperature in the southeast rises higher than 40°C from 1pm till 4pm, which is the time when this room is used the most. External temperature gain is also seen between 7am and 2pm, but the external temperature doesn't rise higher than 25°C, whereas the temperature in the southeast room increases up to 40°C which is a 60% rise is temperature. The need for air-conditioning in this house is higher because this space is used a lot along with the northeast room. The northwest room is cooler during the winter months and without the use of air-conditioning is maintained at 25°C or lower, which is higher than the acceptable upper temperature of 23.5°C and could be improved with the use of fans or by opening the windows.

The light quality in the house is good as the occupants don't use artificial light too much during the summer and use it moderately during winter. This shows that the orientation of the house allows for adequate natural light in the house. Even though the northwest space is the coolest space in the house it is not used much because of lack of artificial light in the space. Tenants prefer to use the east side of the house more often because of the functions associated with them. The windows on these facades bring in natural light which also causes the space to become warmer. If these windows have shading structures on them it might help to create space which is more comfortable. Alternative methods of bringing light into the house such as sun pipes can be used to bring in the light without gain in temperature.

6.3.3 Case Study 1

This house has proportions that are of a rectangle, with proportions of 1:75. The length of the house is aligned on the east to west axis and its proportions are the main factors that align with the principles of *Vaastushastra*. The south side has one window which is on the staircase, the southwest space has a room which is not a square, but has a cut which makes it a polygon, these are the aspects of the house that help examine the principles prescribed by *Vaastushastra*. Temperatures of the house follow a trend, with the northeast cooler than the northwest, but the southwest is warmer than the southeast side which is not expected. The shape the southwest room is a polygon which could be the reason for the temperature gain, if this would be a square the outcome might have been different. In the chapter 7, case study 1 will be modified through simulation models and one of the simulated situations is to make all the ground floor rooms a square in proportion.

Based in the questionnaires the occupants of this house usually feel comfortable and use the least interventions from all the case studies. This is probably because during the summer months, the northeast room is the coolest space with the lowest recorded average temperature at 27.1°C and is close to the acceptable upper range of 26.5°C. Occupants mention that they use air-conditioning in the space very often in the summer, but sometimes and/or rarely in the winter. Unlike the previous studies, the occupants of this house use the northeast and northwest spaces which are the coolest in the house. Northwest room also has an odd shape and is a polygon similar to the southwest room, which could be the reason why the northwest room temperature is significantly higher than the northeast. Another reason for this could be the lack of an overhang on the west wall.

During the winter months the average temperature of the study 1 is lowest of all the houses. Despite this the occupants mention that they rely on air-conditioning sometimes or rarely in the winter. Though the average temperature is 24.1°C which is close to the maximum acceptable internal temperature of 23.5°C the individual spaces have different average temperatures. In the winter months the odd shape of the southwest room doesn't seem to create an increase in temperature like it did in the summer. Even though occupants use the cooler spaces of northeast and northwest during the day, when they use the rooms which are warmer, they need to switch on the air-conditioning which is probably the reason air-conditioning is still used in the space.

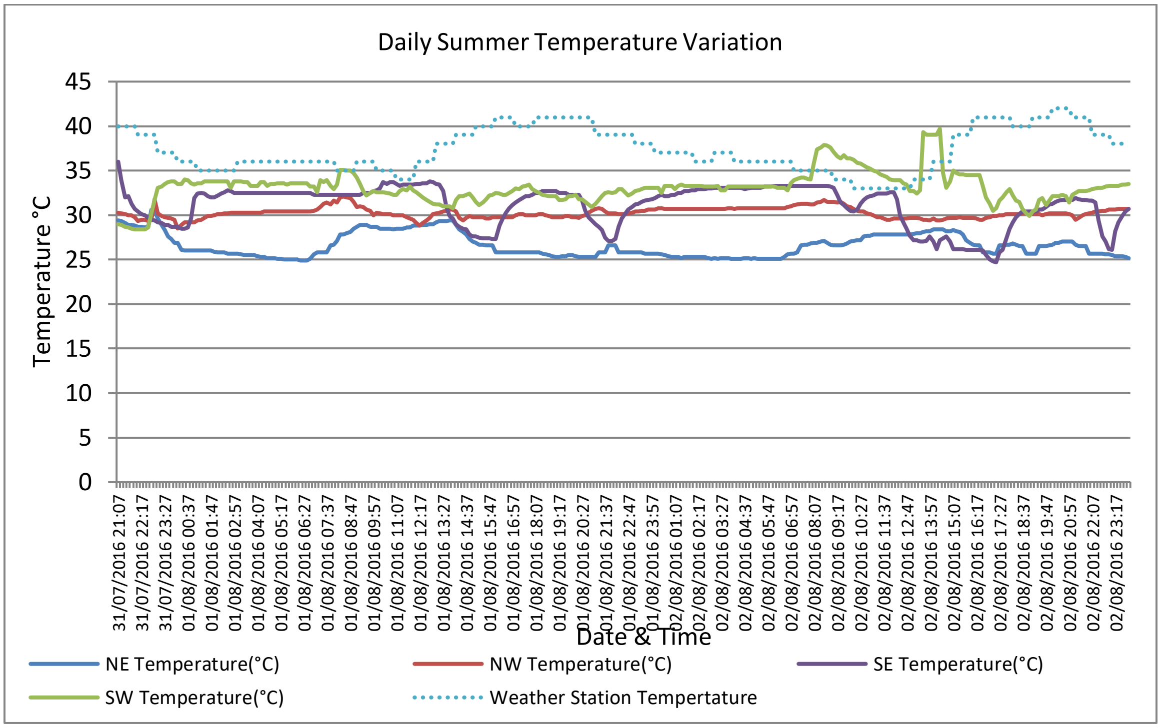

Figure 6.9- Case study 1 temperature variation during summer

Unlike the other two houses, the daily temperatures trends in this study are different in a few aspects but similar in a few aspects compared to the previous two studies, as seen in fig.6.9. Northeast temperature stays below 30°C throughout the day in this case study, with a gain in temperature seen from 9am, even though this gain in temperature is only up to 4°C it lasts for 4 hours which is a reasonable duration of time. As opposed to case studies 5 and 4 where the southeast temperature doesn't fluctuate much during the day, in this case study the temperature in the southeast corner doesn't ever rise above 35°C but stays at this temperature from midnight till 1:30pm and then rises again from 4pm till 8:30pm. The southwest temperature is higher than the southeast temperature which is caused by the shape of the room which is a polygon instead of a square. On an average the temperature of the house remains under 35°C and if the occupants use the cooler spaces during the summer months it might reduce the reliability on air-conditioning.

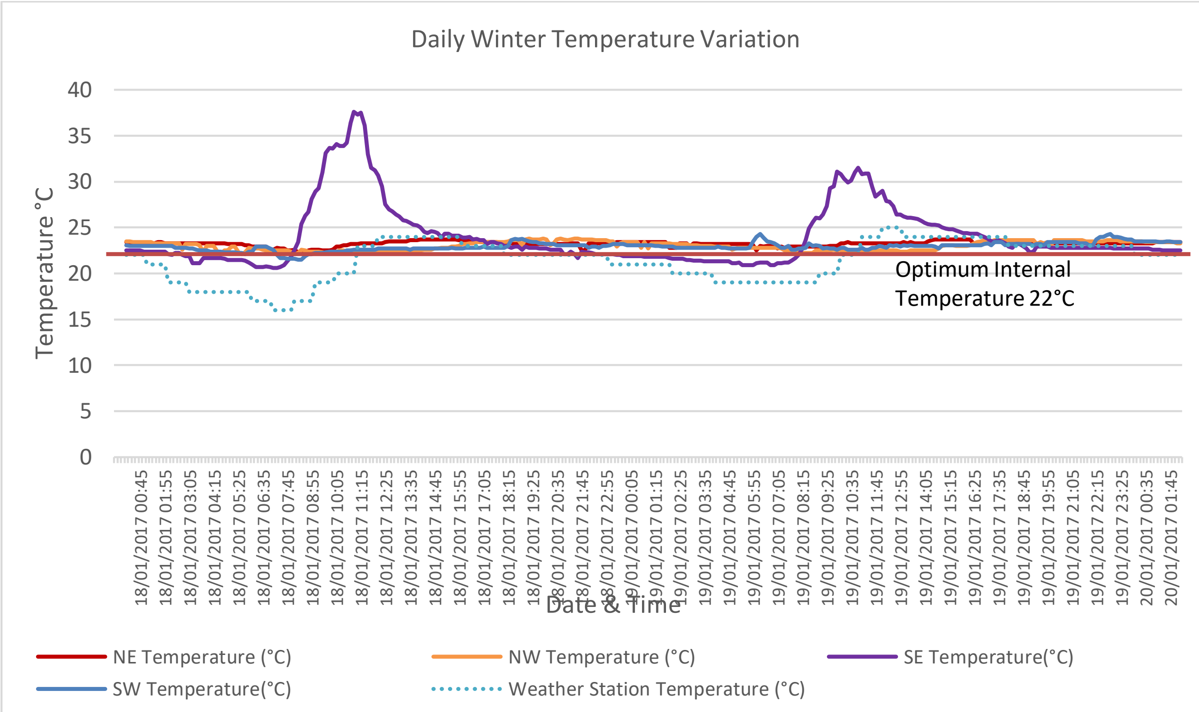

Figure 6.10- Case study 1 winter temperature variation

The winter temperature is the lowest in this case study. As seen in fig. 6.10, all three sides of the house stay below 24°C throughout the day, which is close to acceptable upper temperature of 23.5°C. Temperature of the southeast side rises from 7am, rising sharply till midday and then falls sharply till 2pm. If the southeast window is removed the house might have a lower temperature through the winter months but this would reduce the amount of natural light in the house. If a smaller window placed on the southeast wall that could reduce the heat gain but allow for some natural light and create a balance between heat gain and natural light.

Even though the northeast room is the coldest space in the house, it has a window on the east wall but not on the north wall, which keeps the room cool but might decrease the available natural light which could be the reason the occupants don't use it. Other spaces in the house have adequate natural light, as the occupants mention in the questionnaires that they don't rely on artificial light too much in the summer months. Day light hours are lesser during the winter months and therefore there is a higher need for artificial lights.

6.3.4 Case Study 2

In this case study the house is rectangular in plan and is a cuboid in volume which are both suggested in *Vaastushastra*. The length of the house is aligned with the north and south axis, even though all the walls have windows they aren't all the same size and therefore it conforms to the principles of *Vaastushastra*. Biggest windows are placed on the north and west walls, with mid-size windows on the east wall and very small windows on the south wall. Even though the west side was windows which is not suggested by *Vaastushastra*, these windows have overhangs and therefore this case study is used to understand the difference these shades make to the internal comfort levels. Average temperatures of the house are that the northeast is the coolest and the southeast at the warmest which is expected. Both northeast and northwest temperatures are similar to each other and the southeast temperature is much higher than the southwest temperature.

The questionnaire results show that the occupants are comfortable in the space and rely on interventions a little more than in case study 1. Occupants mentioned in the survey that they often rely on air-conditioning during the summer months this is probably because on an average the temperatures in the house are well above 27°C. Even though the windows on the west have structures to shade the windows these structures are not designed to prevent internal temperatures from rising too much during the summer months. The space on the north side is one common room between both the northeast and northwest spaces and therefore the temperatures on both sides are similar. The southeast room has one small window on the south side and is a small enclosed room and this is the warmest space in the house. In case study 1 the southeast side has a larger window but the average temperature in lower than in case study 2. This could be because in case study 1 even though there is a large window the space is not confined into a small space and therefore the heat dissipates throughout the house. Whereas in study 2, even though the window is small the room is very small which makes the space much warmer.

During the winter the occupants rarely use air-conditioning, because the north spaces have an average temperature which is close to the acceptable upper temperature of 23.5°C and this is the space that they use most of the time. Even though the average winter temperature is similar to the average temperature of case studies 3, 4 and 5, the occupants of case study 2 rely the least on air-conditioning during the winter months. The only room which has a very high average temperature is the southeast room. Windows on the west façade have shading structures which helps to maintain internal temperatures at an acceptable level during winter months.

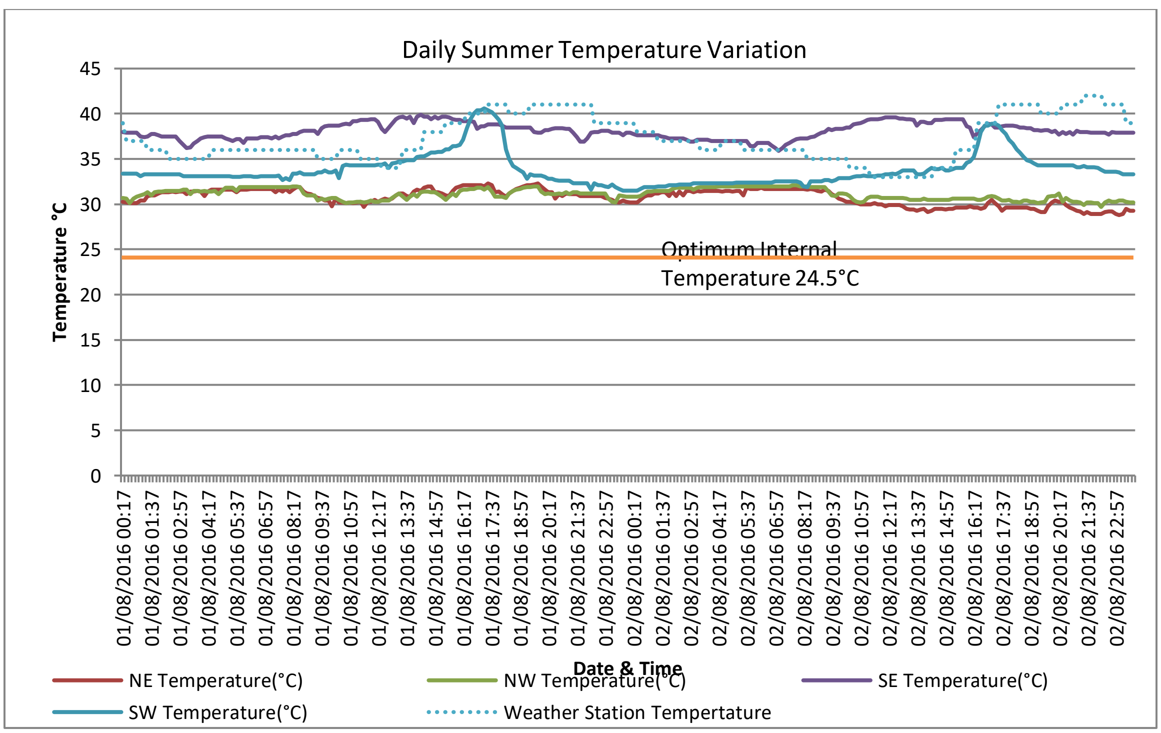

Figure 6.11- Case study 2 temperature variation during summer

The house in case study 2 is significantly warm through the summer months but manages to stay relatively cooler in the winter months. The trend in daily temperature helps to understand the comfort of the spaces as seen in fig.6.11. During the summer the temperatures of this house remain above 30°C throughout the day. The temperature in the northeast and northwest are the lowest in the house but remain above comfort level at 31°C which means the occupants strongly rely on air-conditioning. Temperatures in the northeast and northwest don't fluctuate through the day which could be a reflection of the constant use of air-conditioning. Similarly, even though the windows on the south wall are small the temperature in the southeast corner is high and remains above 35°C through the day. Occupants could use the air-conditioning as they needed but since the space in the southeast corner a small storeroom which doesn't have any air-conditioning and therefore recorded higher temperatures.

The winter temperatures for the same house are much lower and the occupants mention in the questionnaires that air-conditioning is rarely used in the winter. The daily temperature trend in fig.6.12 shows that in the winter months only the southeast corner gains maximum heat. Three sides of the house, northeast, northwest and southwest stay under 25°C throughout the day. Heat gain in the southeast temperature is seen from 9am till 11am and then a sharp drop is seen from 3pm onwards. If this window is removed it might help with the overall temperature of the house both during the summer and winter.

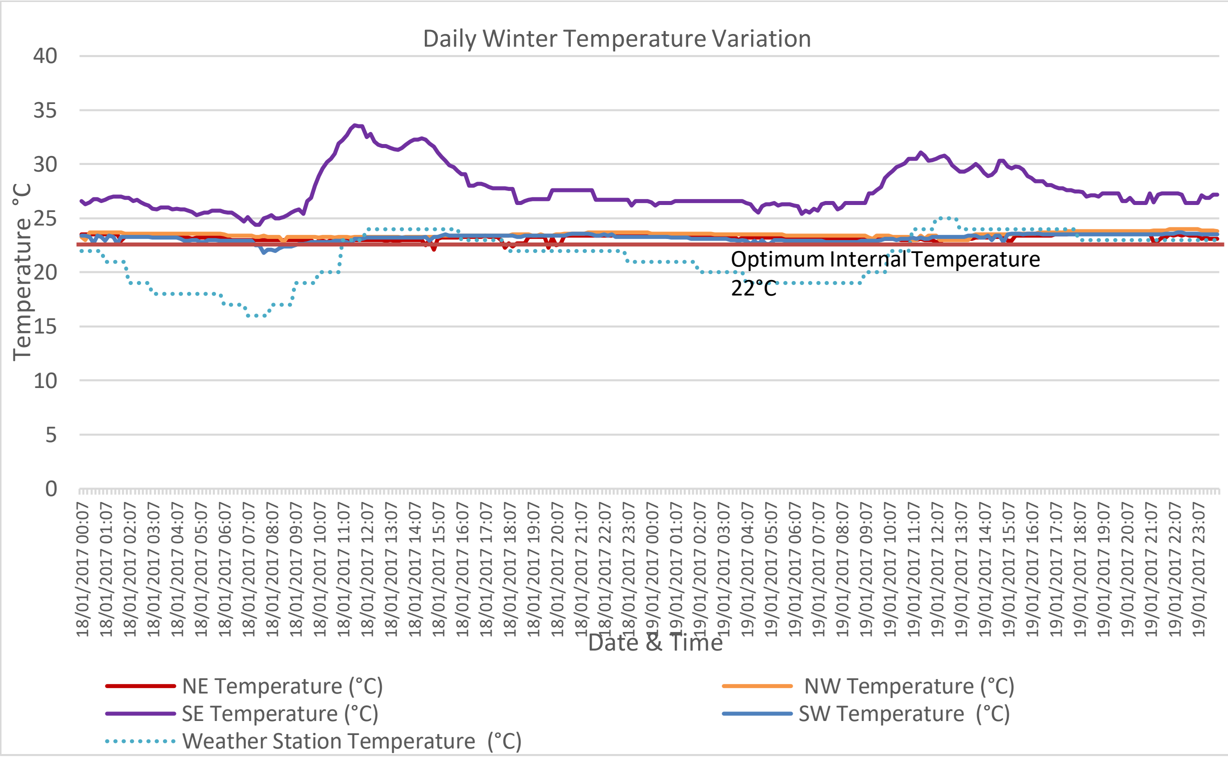

Figure 6.12- Case study 2 winter temperature variation

Natural light is a concern in the house during the summer months as occupants mention that they switch on the lights often. The space used most by the occupants is the northeast and northwest room and there is no window on the east wall of the northeast room which causes lack of natural light during the day.

6.3.5 Case study 3

This is the warmest house from all the five case studies selected. The house follows key principles of orientation, but the length aligns with the north to south direction which is the second-best option. The house has large windows on the north and east sides, which is recommended in *Vaastushastra,* but it has windows in the south and west which does not follow the principles of *Vaastushastra*. The house was selected to understand the difference in temperature that was caused by having large windows on all sides of the house. There are decorative elements on the windows of the house, but these are not designed to create shadows on the windows. These elements are placed on the east façade of the building but should be designed and placed on the south and west facades. There is a balcony on the first floor of the northeast facade which causes reduction in daylight for the northeast room on ground floor. There is a similar balcony on the first floor of the southeast side, but this isn't deep enough to prevent heat gain on the southeast side of the ground floor.

Data collected from the occupants' questionnaires mentions the need for constant air-conditioning through the summer because the average temperature in any room is above 35°C which is much higher than the upper acceptable temperature of 26.5°C. Occupants of the house mention that they aren't comfortable in the space and they use the most interventions from all the case studies. Case study 3 is similar to case study 2 in terms of orientation, the difference is the placement of the windows, overhangs on the windows and landscape features. In case study 3 the house has windows on all sides, were as in case study 2 there is only one small window on the south side. In case study 3 the windows on the west side don't have any shading devices which are available in study 2. Even though the southwest room in study 2 is warmer than the acceptable summer temperature it isn't as warm as the southwest room in study 3. Similarly, the northwest room in study 2 records an average of 31°C which is warmer than acceptable but is approximately 3.5°C lower than study 3.

During the winter months the occupants use alternative methods of cooling, such as fans and opening windows and reduce the use of air-conditioning. Temperatures of both northwest and northeast rooms are close to 23.5°C without the use of air-conditioning. Occupants don't use the northeast room on the ground floor very often because it is a formal living room space and the northwest room is a kitchen and therefore isn't used much by the family. Residents use the southeast and southwest rooms on the ground floor which are warmer due to the placement of windows and lack of both architectural or natural shading.

The temperature variation seen daily in case study 3 in the summer is seen in fig. 6.13. The house is the warmest with temperatures on all sides generally measuring above 35°C. Northeast and northwest are lower in temperature compared to the other sides, with northeast temperature stable throughout the day. Temperature in the northwest gains at 8am and drops again from 1pm till 4pm when it drops below temperature of northeast space. Southwest side steadily becomes warmer from 8am till 1pm and drops till 5pm and remains constant in temperature till 9am the next day. Exposing the southwest window without a canopy causes this increase in temperature, eliminating these windows would see a significant drop in temperature, as seen in the other case study homes. Temperature gain on the southeast side is similar to the temperature increase seen in the external temperature, with the internal space gaining the heat a couple of hours later. Drop in internal temperature is seen within half an hour of drop in external temperature.

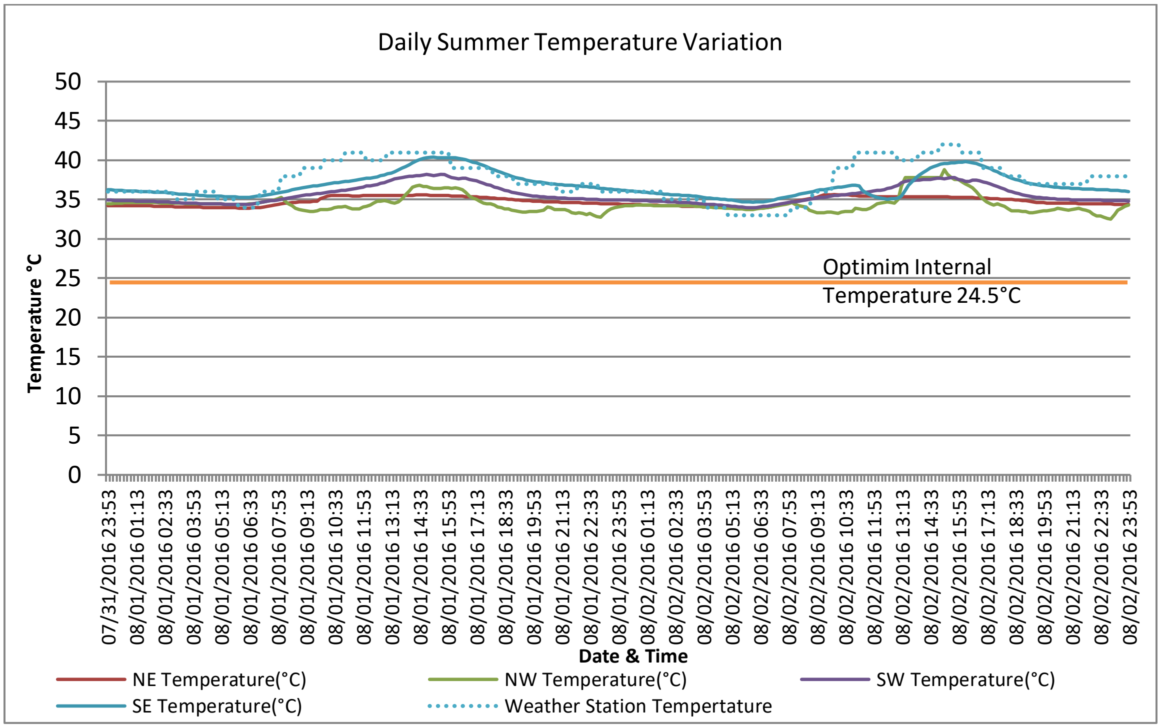

Figure 6.13- Case study 3 temperature variation during summer

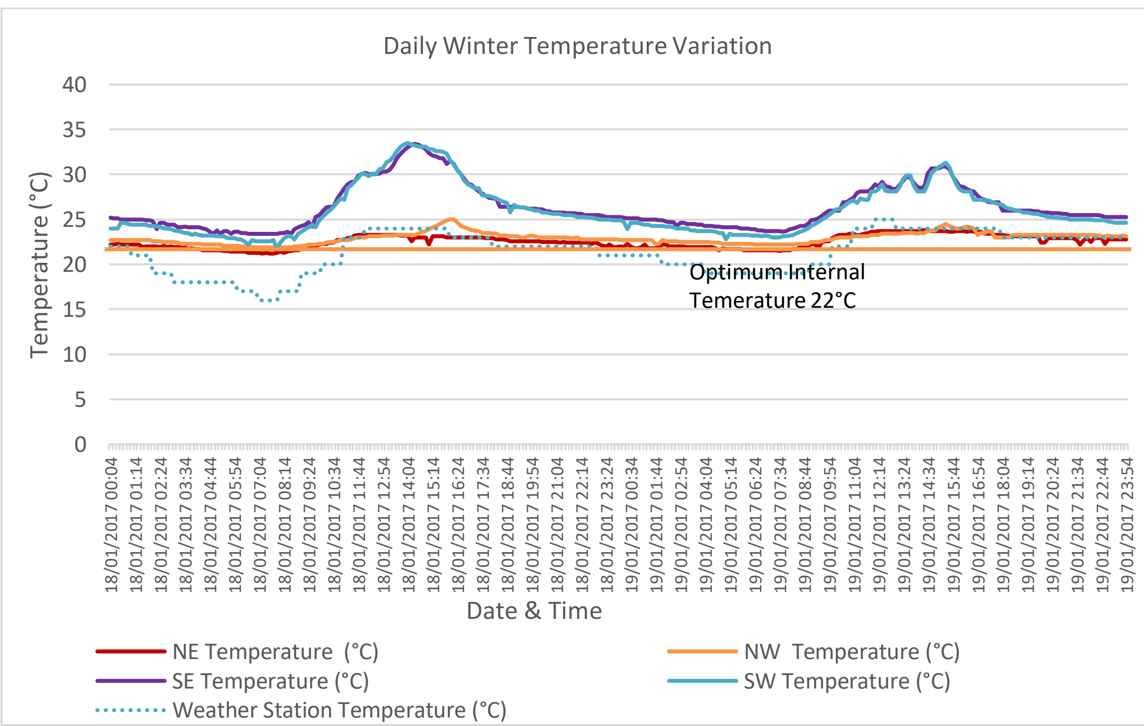

Figure 6.14 - Case study 3 winter temperature variation

In fig. 6.14 shows the daily temperature variation during the winter, which shows that northeast and northwest side are relatively cooler and don't increase in temperature higher than 25°C. The increase in temperature on these sides is minimal as it increases gradually and stays at the temperature till 5pm after which it drops slightly. Southeast and southwest gain temperatures at the same time from 8am to a maximum gain at 2pm and then drops from 3pm till 8pm. Temperatures on the southeast and southwest raise by at least 20°C during the winter due to exposed windows. If these windows were closed or had adequate shading the internal temperature would be lower.

6.4 Conclusion

The results of the data collected from all five houses during the summer are discussed in detail which highlights interesting findings. The spaces typically follow the pattern of northeast being the coolest, followed by northwest, followed by southwest and the southeast is the warmest space with the difference in average temperature as seen in table 6.1. The same patterns are seen during the winter months as well (table 6.2). The lowest temperature difference from external temperature is at 0.5°C and the highest temperature difference is 14.3°C. Maximum and minimum temperature differences between the houses are shown in table 6.3.

	Average North Temperature (NE+NW)/2	*Average South Temperature (SE+SW)/2*	*Difference in Average S Temperature – Average N Temperature*
House 1	28.1	32.9	4.8
House 2	31.5	36.6	5.1
House 3	35.2	37.1	1.9
House 4	28.2	30.1	1.9
House 5	26.7	30.7	4.0

Table 6.2- Average temperature in north and south sides during summer

	Average Highest Temperature	*Average Coolest Temperature*
House 1	SW 33.6°C	NE 27.1°C
House 2	SE 38.9°C	NE 31.4°C
House 3	SE 37.8°C	NW 35.1°C
House 4	NE 31.2°C	NW 25.1°C
House 5	SE 31.0°C	NE 26.6°C

Table 6.3- Warmest and coolest sides of the house during summer

	Average external temperature	*Difference between average highest internal temperature*	*Difference between average coolest internal temperature*
House 1	39.5°C	5.9°C	12.4°C
House 2	39.5°C	0.6°C	8.1°C
House 3	39.5°C	1.7°C	4.4°C
House 4	39.5°C	8.3°C	14.4°C
House 5	39.5°C	8.5°C	12.9°C

Table 6.4- Difference between external and internal temperatures during summer

To verify that the air-conditioning didn't play a major role in the data collected above, data loggers were placed in the houses during the winter. Trends similar to those seen in the summer were noticed in the winter, even when the air-conditioning was switched off in the houses. The north side is cooler than the south side even though the internal temperature is higher than the external temperature (table 6.4). The north side remained the coolest side but in some cases was the south side which had shading structures on the windows. The south and particularly the southeast side remained the warmest in the house (table 6.5). The average external temperature is 22.2°C during the winter and the internal temperatures in the house are warmer (table 6.6).

	Average north Temperature (NE+NW)/2	*Average south Temperature (SE+SW)/2*	*Difference in Average S Temperature – Average N Temperature*
House 1	23.9	24.3	0.50
House 2	24.1	26.0	2.00
House 3	23.7	26.9	3.20
House 4	25.0	26.7	1.70
House 5	25.0	25.1	0.05

Table 6.5- Average temperature in north and south sides during winter

	Average Highest Temperature	*Average Coolest Temperature*
House 1	SE 24.8°C	NW 23.7°C
House 2	SE 28.2°C	NE 23.9°C
House 3	SE 27.0°C	NE 23.7°C
House 4	SE 28.7°C	SW 24.6°C
House 5	SE 25.3°C	SW 24.8°C

Table 6.6- Warmest and coolest sides of the house during winter

	Average external temperature	*Difference between average highest temperature*	*Difference between average coolest temperature*
House 1	22.2°C	+2.6°C	+1.5°C
House 2	22.2°C	+6.0°C	+1.7°C
House 3	22.2°C	+4.8°C	+1.5°C
House 4	22.2°C	+6.5°C	+2.4°C
House 5	22.2°C	+3.1°C	+2.6°C

Table 6.7- Difference between external and internal temperatures during winter

The comfort level of spaces doesn't solely depend on the temperatures recorded in the spaces it also depends on how comfortable the occupants feel in the space. Based on the discussions in this chapter it is understood that the homes in which users are comfort are different from those that recorded the lowest temperatures. Compliance with the principles of *Vaastushastra* can help to understand which homes are comfortable overall.

The above shows the findings of all five case studies examined together to understand an overview of the correlation of the comfort in the home's studies with the principles of *Vaastushastra*. In order to understand the connection between the data collected from all the houses and principles *Vaastushastra* a summary of the finding of each house will be presented in chapter 8. Before that, case study 1 will be modified to make it comply with all the principles of Vaastushastra in chapter 7. Finally, comparison with the simulation data will be done in chapter 8 which will help understand which principles of *Vaastushastra* help create comfort in residences.

Chapter Seven: Software modeling

7.1 Introduction

This chapter will investigate the principles of *Vaastushastra* further using IESVE which is an integrated environmental solution software to test the potential impact these changes make to case study 1. There are many simulation software that could have been used in the thesis. The discussion about the selection of the software is in chapter 3.6. The first part of the chapter is about verification of the simulation software used and ensuring that the results generated from the simulation are close to the data gathered form the case studies. There is a discussion about the changes that were tested using the software.

In the second part the simulation software was used to simulate various conditions that were missing in the various case studies and were recommended to be tested in chapter 6. Using a simulation software allowed modifications in the existing building which would test if the internal spaces would be more comfortable if they were designed based on all the principles of *Vaastushastra*. Data collected from the simulation studies would show if the modifications made to comply with *Vaastushastra* made the spaces comfortable by collecting temperature and humidity data.

7.2 Discussion about the selection of changes made using IES software

Since the house is physically built it would be difficult to test the suggested modifications in the actual house. All the houses selected for the case studies were complaint with most of the rules of *Vaastushastra* but they all the houses had some principles missing. Table 7.1 below shows the key principles mapped against the case study houses as a guide to highlight the few missing design principles.

	Case Study 1	*Case Study 2*	*Case Study 3*	*Case Study 4*	*Case Study 5*
Orientation of the house	✓	✓	✓	✓	✓
Proportion of the house	✓	✓	✓	✓	✓
Ideal location of windows in the house	✓	✓	✓	✓	✓
Proportion of the rooms in the house	✓	✓	×	×	✓
Use of a courtyard the house	×	×	×	×	×
Placement of windows on South and West side with the use of solar shading	✓	✓	×	×	✓

Table 7.1- Application of key principles of *Vaastushastra*

Key elements of *Vaastushastra* were identified in chapter 2.3.8. Each of these factors were then discussed with reference to each of the case studies in chapter 3.7.1- 3.7.5. Table above lists these key principles and roughly identifies the key principles that were followed by each of the case studies. Principles of *Vaastushastra* can be interpreted in different ways. These principles need to be understood and then applied based on the location of the site and its conditions. Following is a discussion on the principles and why the author feels that these need to be modified in the case study house.

The orientation of the house is an important factor in both *Vaastushastra* and in comfort studies. Three of the five case studies, 1, 4 and 5 are oriented with the length along the east west axis and the other two case studies, 2 and 3 are oriented along the north south axis. It is important to investigate if east west orientation is the best orientation, therefore the first change to the model is to change the orientation of case study 1.

Proportions of the house is another principle; each case study had a different proportion, and these are mentioned in chapter 3.71- 3.7.5. These proportions vary from the proportions of case study 4 with 1:98 (almost square), to case studies 1 and 5 which have proportions of 1:75, case study 2 which has a proportion of 1:67 and case study 3 which has the proportions of 1:6. Since this house had a good proportion the overall proportion of the house wasn't changed.

Vaastushastra stipulates that the house should have windows on the north and east side but should have minimum windows on the south and west sides. Windows on the north and east sides can be large and without any shading devices and windows on the south and west should have appropriate shading techniques. The next thing that is modified in the simulation model is the orientation of the windows in the house. Window sizes were also changed to see if these had an impact in the house.

Proportions of the rooms also have an impact on the way the users feel in the space. Some of the rooms in the house have good proportions which are square or close to square. This is was the only house which had rooms that were polygon in shape which was caused by a cut in the shape of the plan. In order to investigate this further the northeast and northwest rooms that had the cut were changed in shape to have pure square geometry.

The principles of *Vaastushastra* that are not followed in any of the houses were the design of courtyard in the house and the use of indigenous building materials. The key criteria for selection of the house to find mid-size houses in Dubai which comply with most of the principles of *Vaastushastra*. The next change through the simulation was to add various sizes of courtyards to the house.

The materials suggested in *Vaastushastra* are indigenous materials which are few and have limited availability in Dubai. Concrete is produced locally and is the material commonly used in all the houses. Local regulations stipulate that concrete should conform to the sustainability rules that are set up the by concerned authority and therefore even though it is not a material that was used traditionally it can be considered as a local resource in this specific study.

7.2 Simulation testing

Simulation software provides the opportunity to test changes in the house without altering the physical house. The first step was to ensure that the house modelled using the virtual software was accurately replicating the conditions of the physical house. Case study 1 was selected as the house that would be modeled using IESVE software as the temperature and humidity readings of this house were taken without any air-conditioning or alternative methods of cooling. Therefore, the first simulation for case study 1 was done for summer months. Dates of the simulation were set to match the original dates of when the data loggers were placed in the physical house. The software was used to generate temperature and humidity readings for the rooms of the house which are located on the four corners Data recorded by the model was mapped to the readings gathered in the real situation which showed a margin of error of up to % (fig.7.1-7.4). The simulation can replicate real circumstances with limited accuracy and therefore a small margin of difference was acceptable.

To verify that the data collected from the simulation was accurate temperature loggers were placed in all five houses during winter. The data gathered from the loggers placed in the house during winter was mapped against the temperatures generated from the simulation software (Fig 7.5- 7.24). Data collected from the remaining houses during the summer were with the use of air-conditioning and since these timing were not regular it was difficult to replicate in the simulation. There is a variation between the weather station data and the data used by the simulation software. The difference that was noticed in the external temperature variation is similar to the difference seen in the temperatures gathered from the internal spaces. The results of comparing data collected with the simulation confirms that the later was within close range to the real data collected which establishes simulation modeling as a way through which design modifications can be tested.

Once the model was replicating the conditions of the real house to a level of satisfaction, modifications were made to the house to test the various principles of *Vaastushastra* and understand if these had an impact on the internal spaces. each principle was tested individually against the original house to see how the temperatures varied with the changes made. Case study 1 was modified through the simulation software to test various principles of *Vaastushastra*. Each modification had an impact on the temperatures of the internal spaces, some of which were successful while others didn't have the desired outcome.

Case Study 1 (Summer)

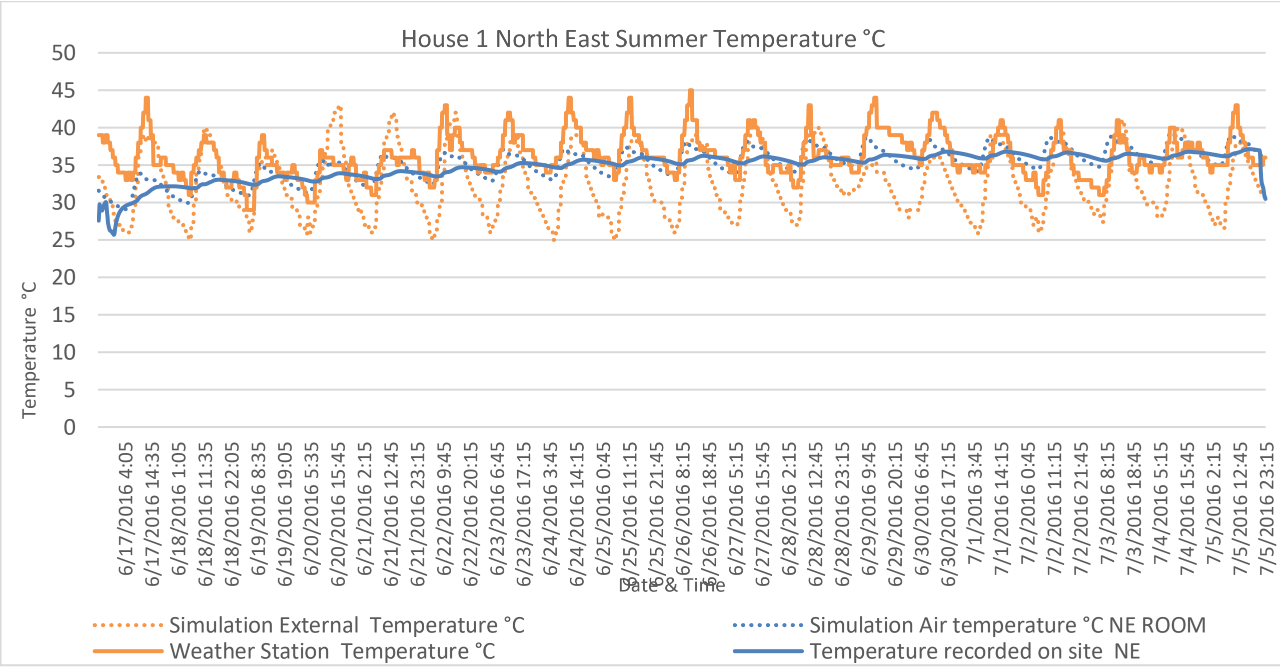

Figure 7.1 – House 1 Simulation Temperature Comparison Summer – NE

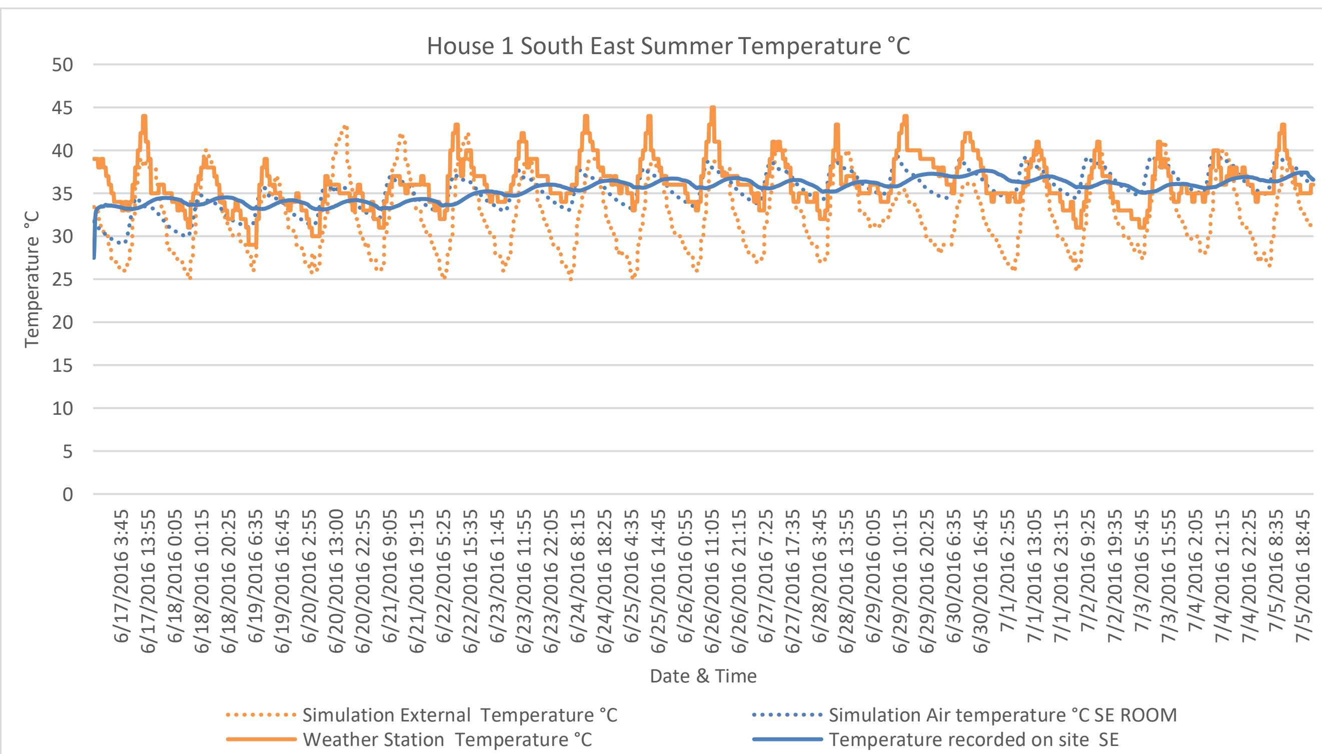

Figure 7.2 - House 1 Simulation Temperature Comparison Summer – SE

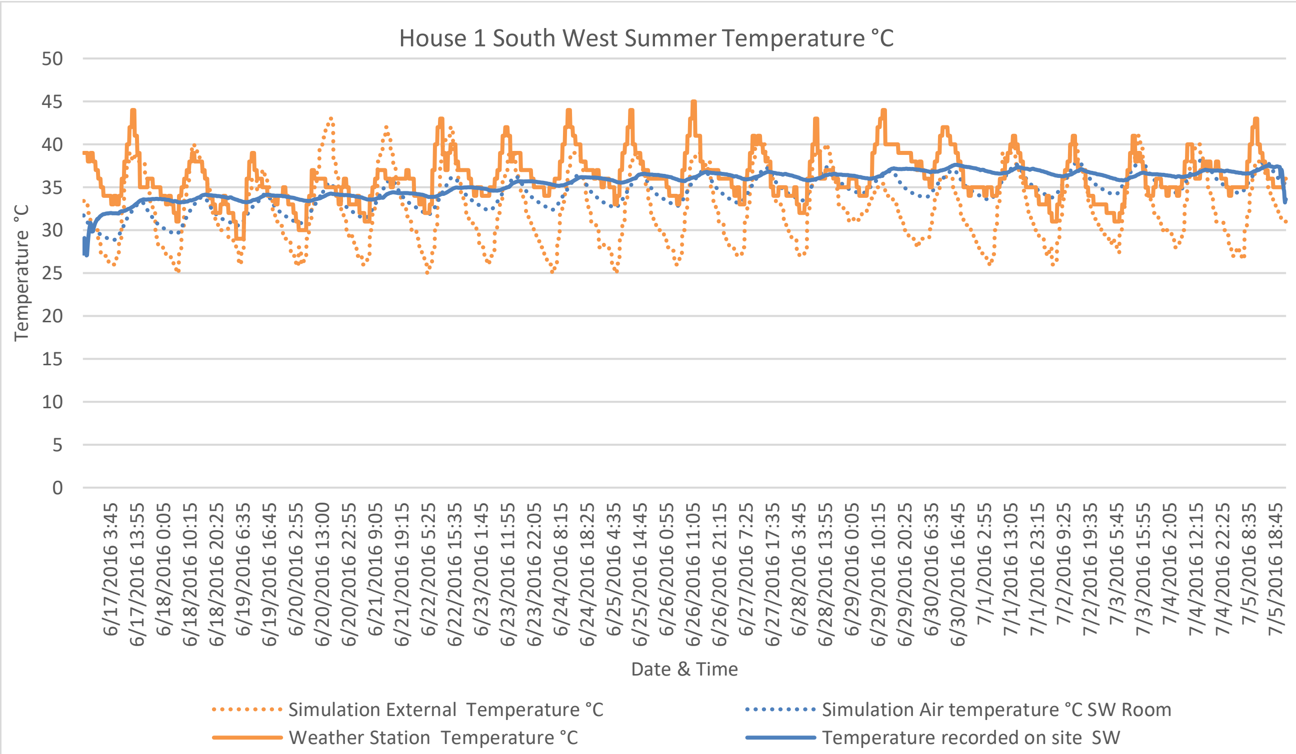

Figure 7.3 -House 1 Simulation Temperature Comparison – SW

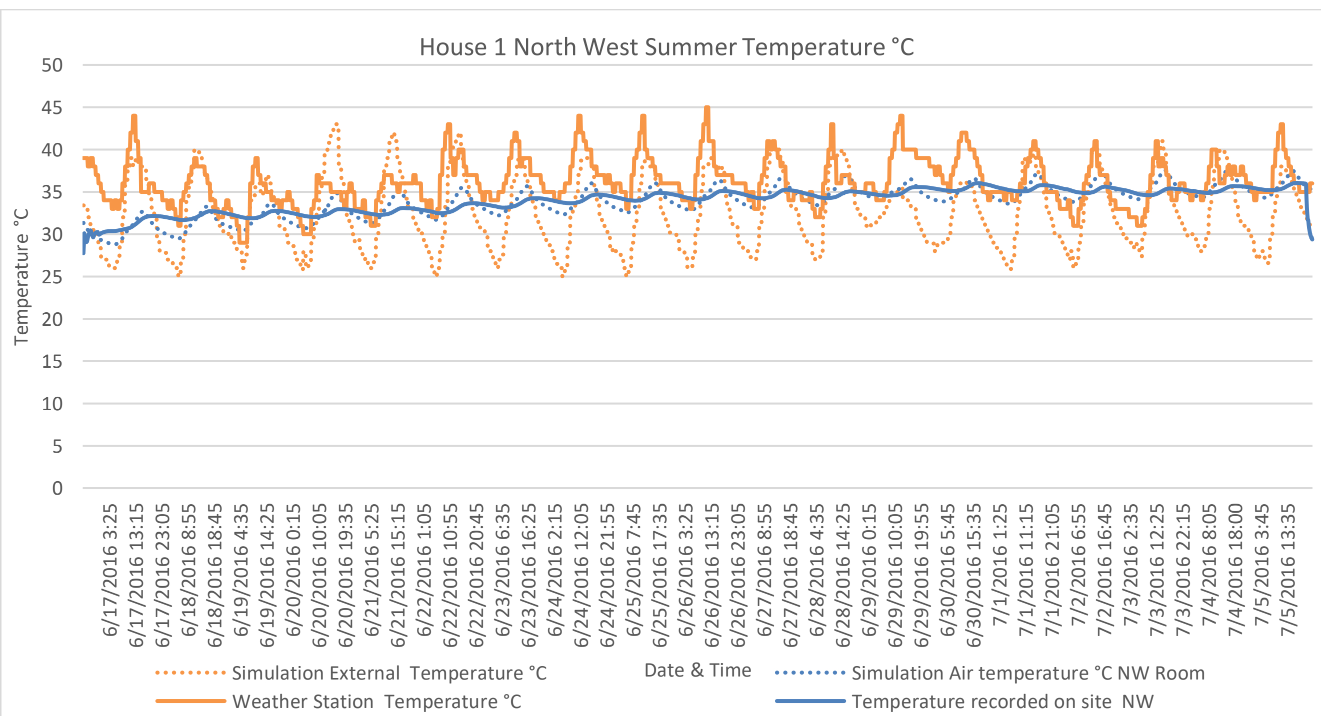

Figure 7.4 - House 1 Simulation Temperature Comparison Summer – NW

Case Study 1 (Winter)

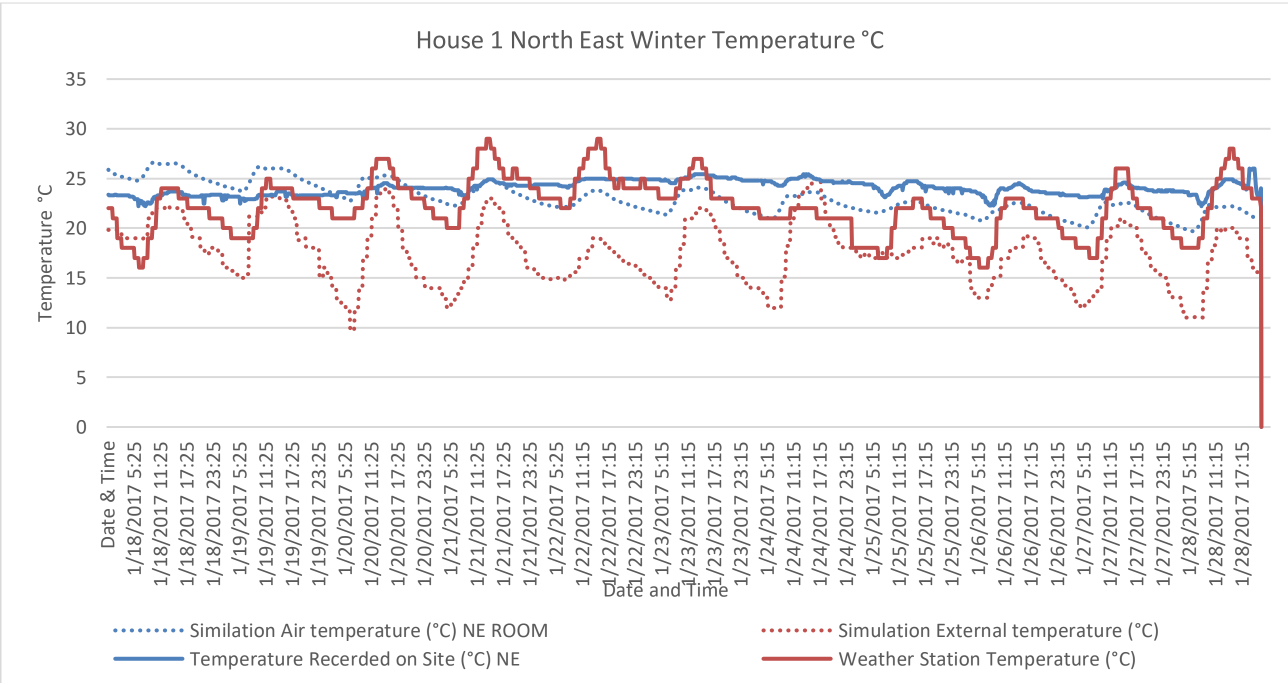

Figure 7.5 House 1 Simulation Temperature Comparison Winter – NE

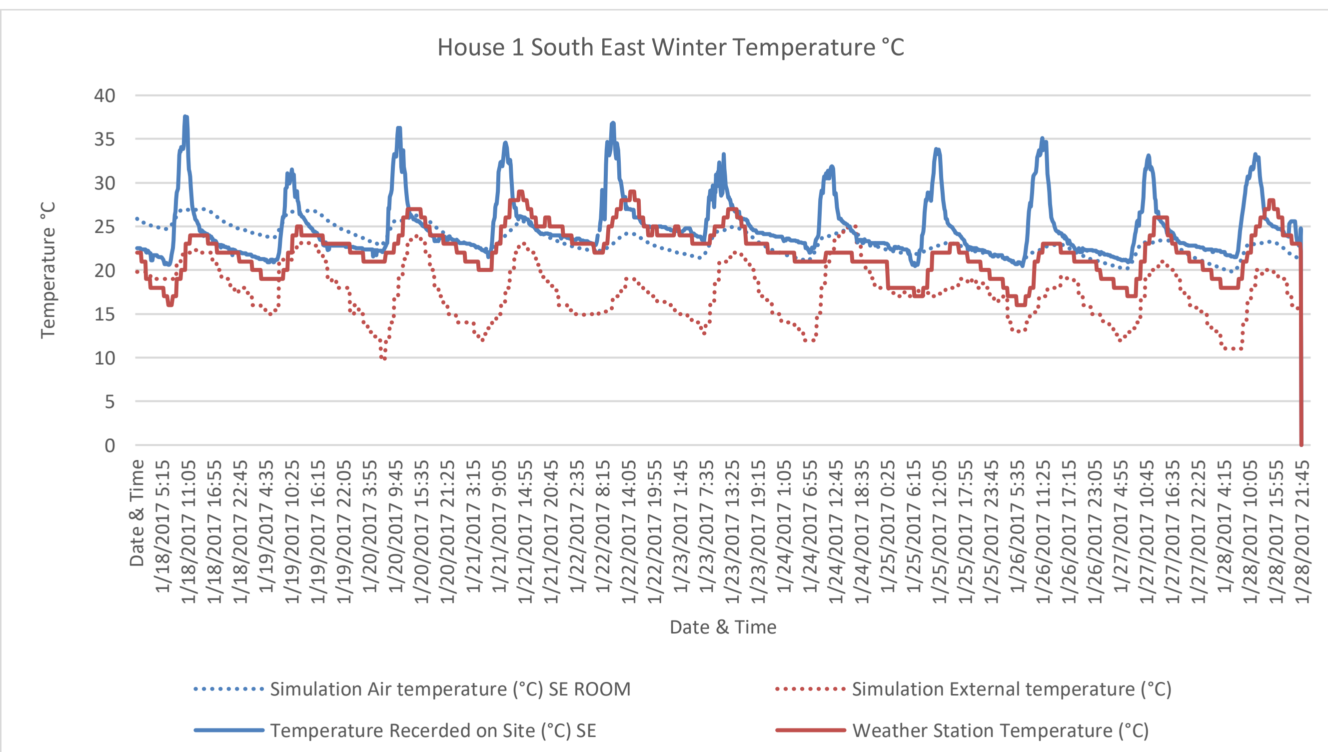

Figure 7.6 - House 1 Simulation Temperature Comparison Winter – SE

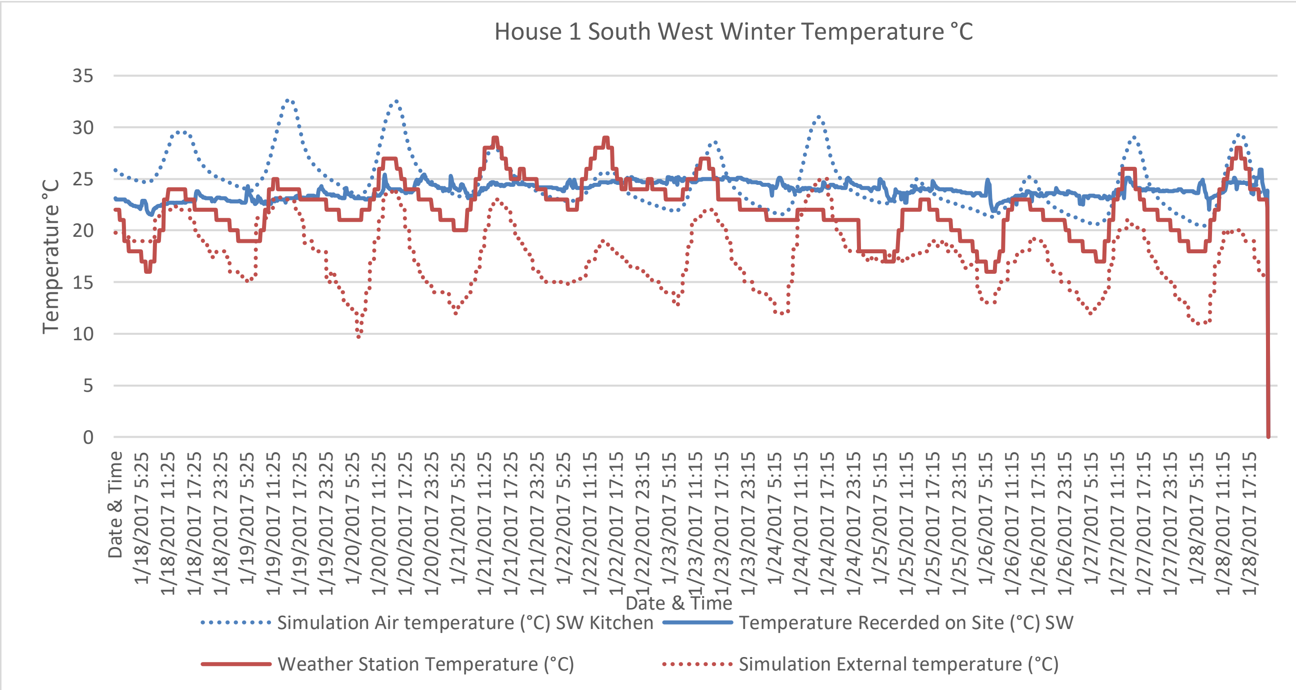

Figure 7.7 - House 1 Simulation Temperature Comparison Winter – SW

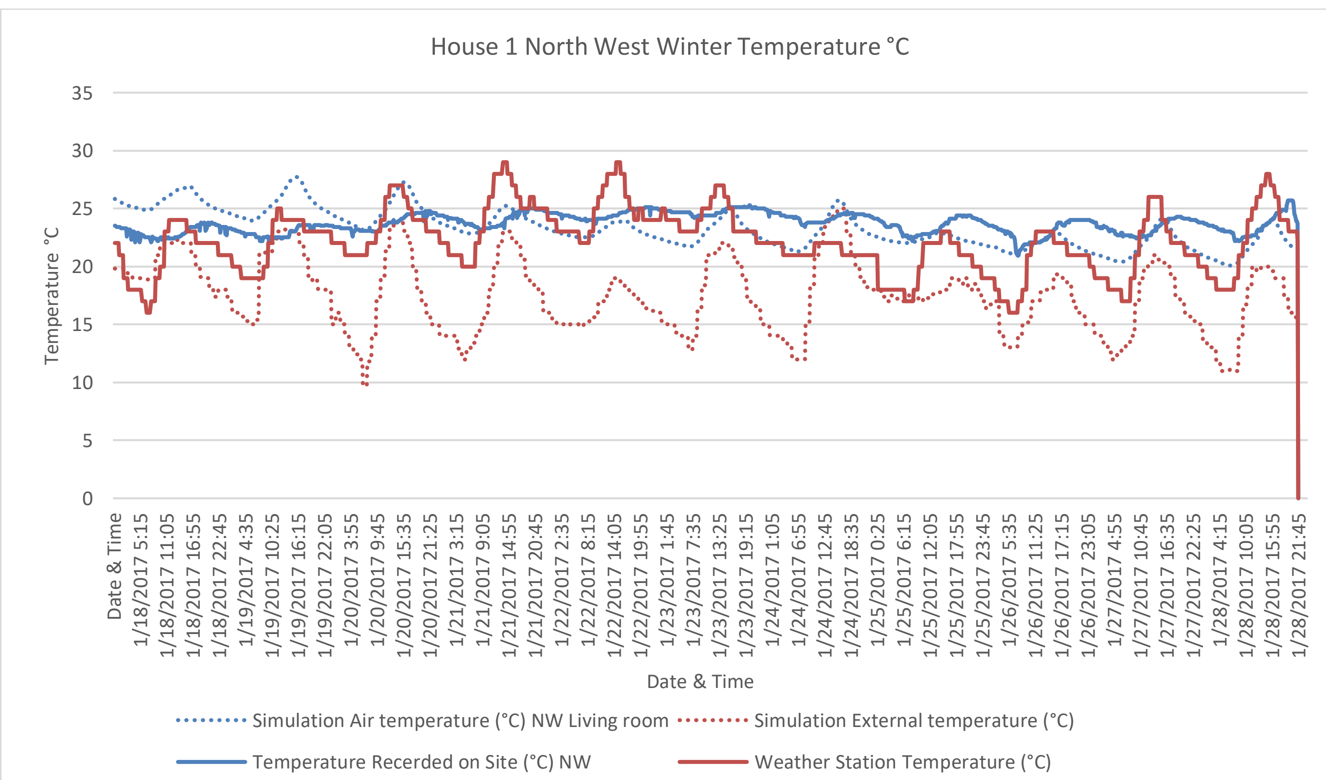

Figure 7.8 House 1 Simulation Temperature Comparison Winter – NW

Case Study 2 (Winter)

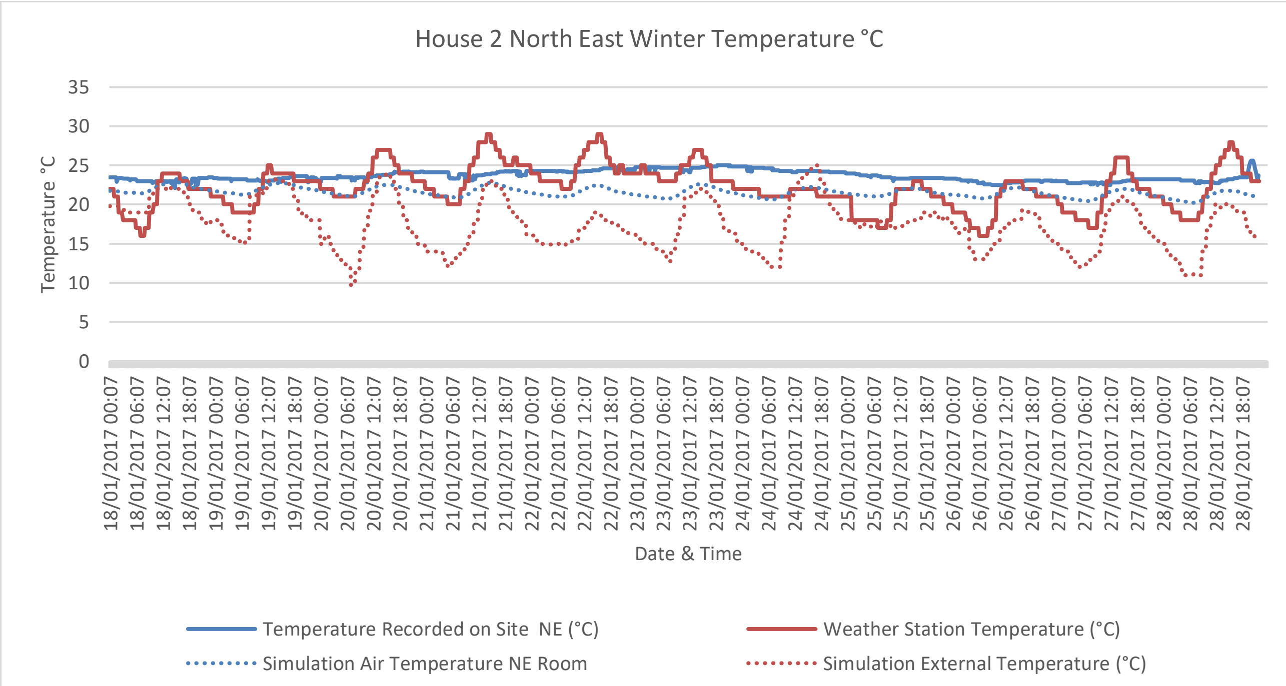

Figure 7.9 -House 2 Simulation Temperature Comparison Winter – NE

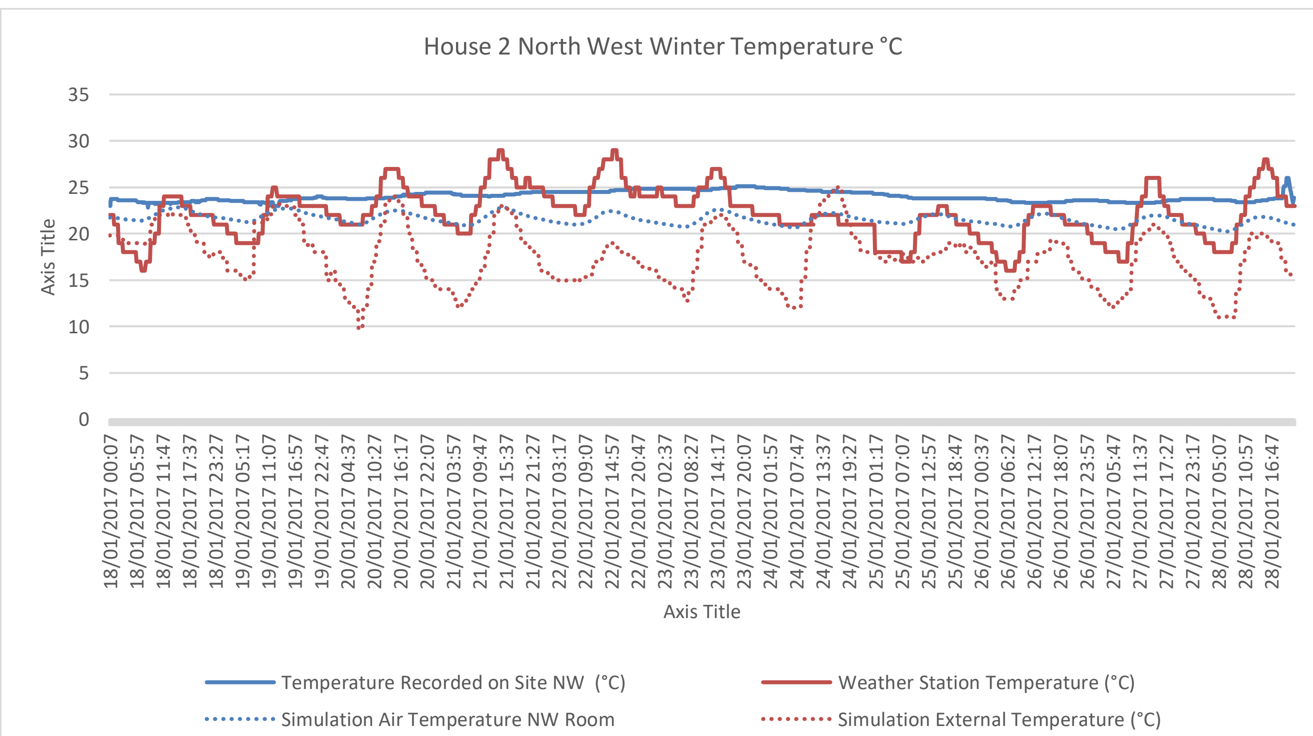

Figure 7.10 House 1 Simulation Temperature Comparison Winter – NW

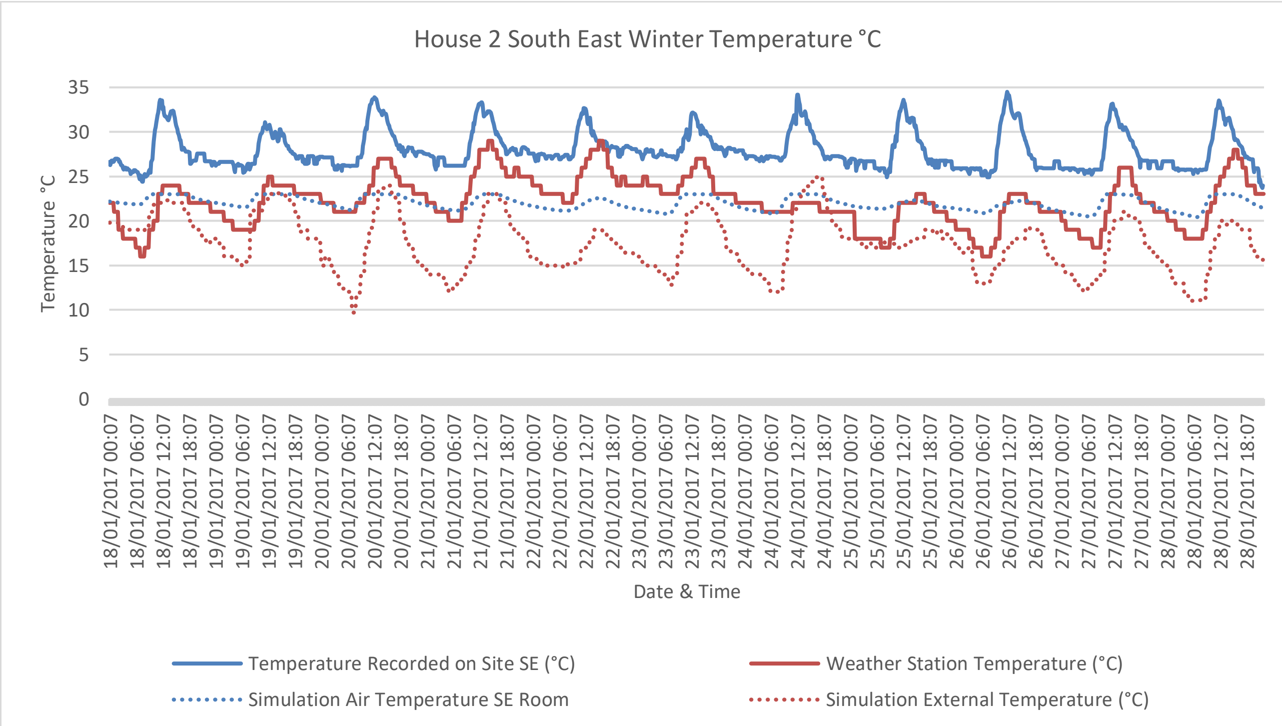

Figure 7.11 House 2- Simulation Temperature Comparison Winter – SE

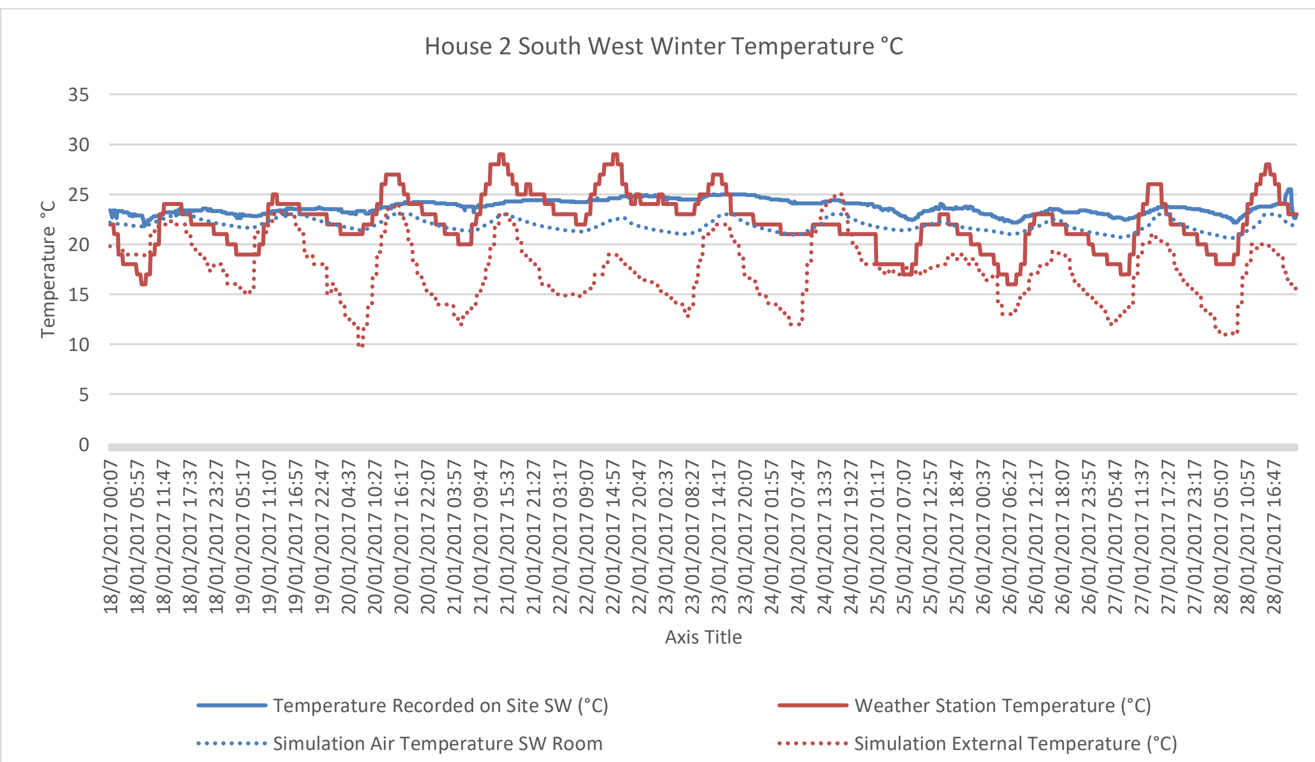

Figure 7.12 -House 2 Simulation Temperature Comparison Winter – SW

Case Study 3 (Winter)

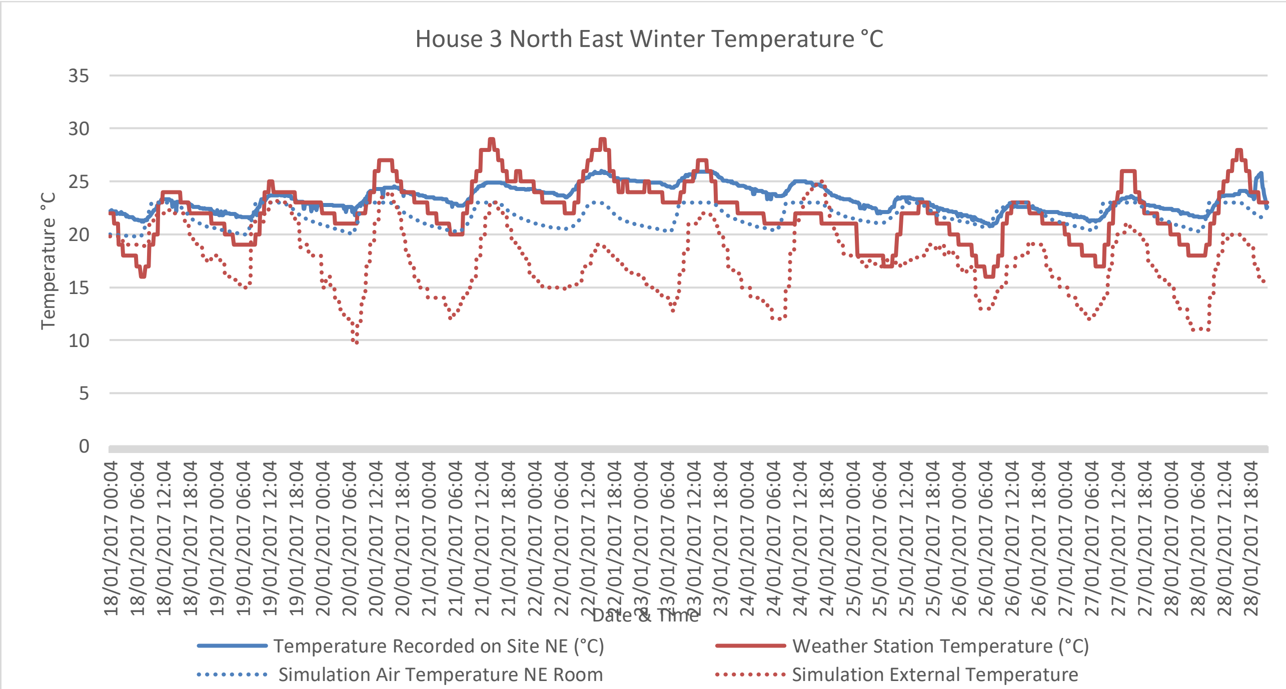

Figure 7.13 - House 3 Simulation Temperature Comparison Winter – NE

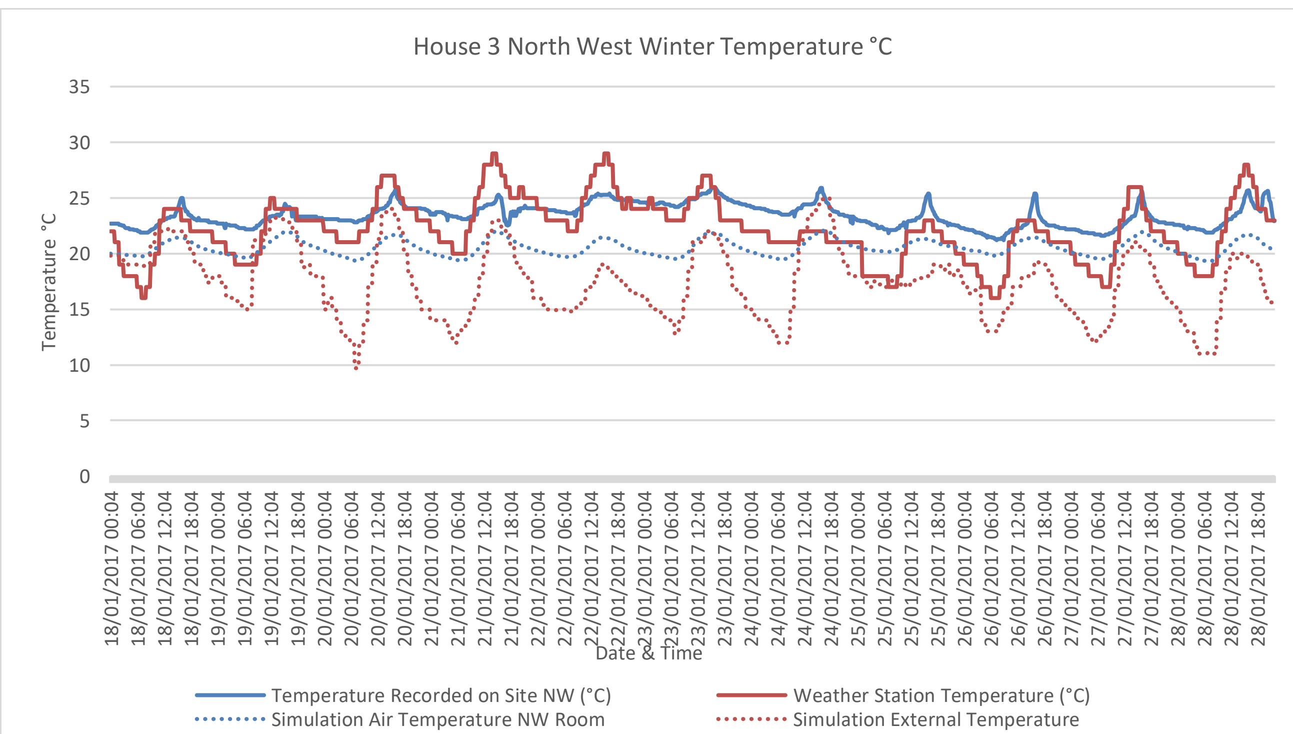

Figure 7.14 - House 3 Simulation Temperature Comparison Winter – NW

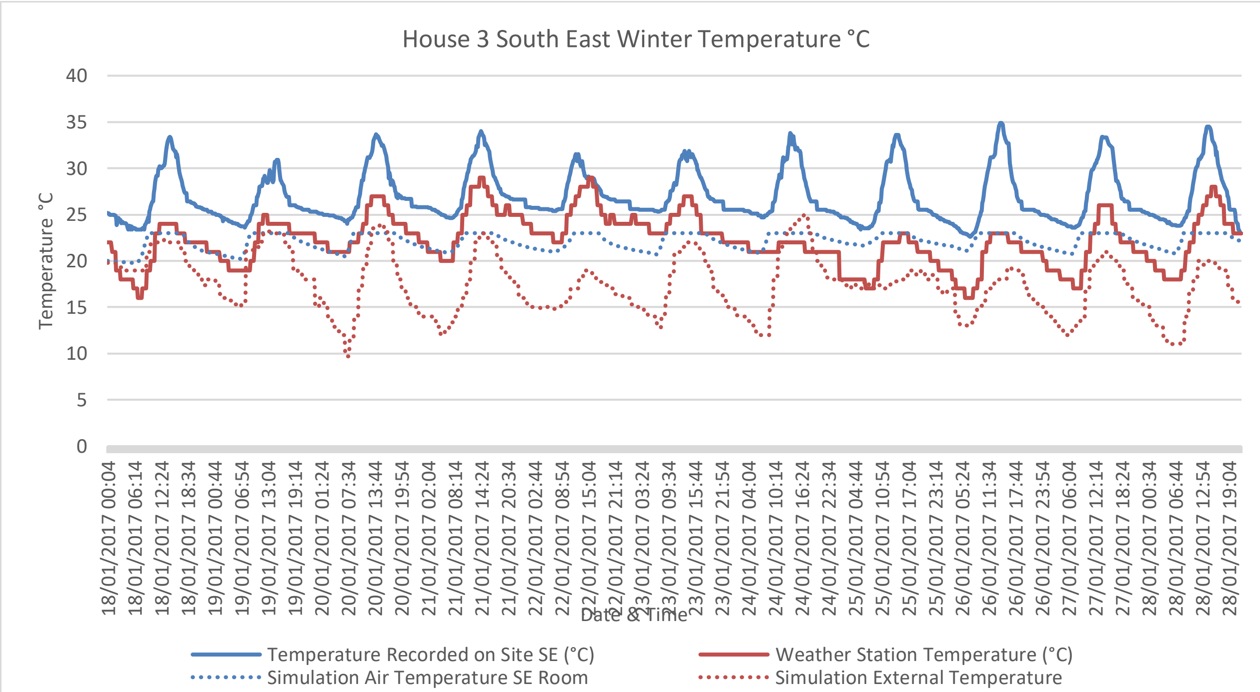

Figure 7.15 -House 3 Simulation Temperature Comparison Winter – SE

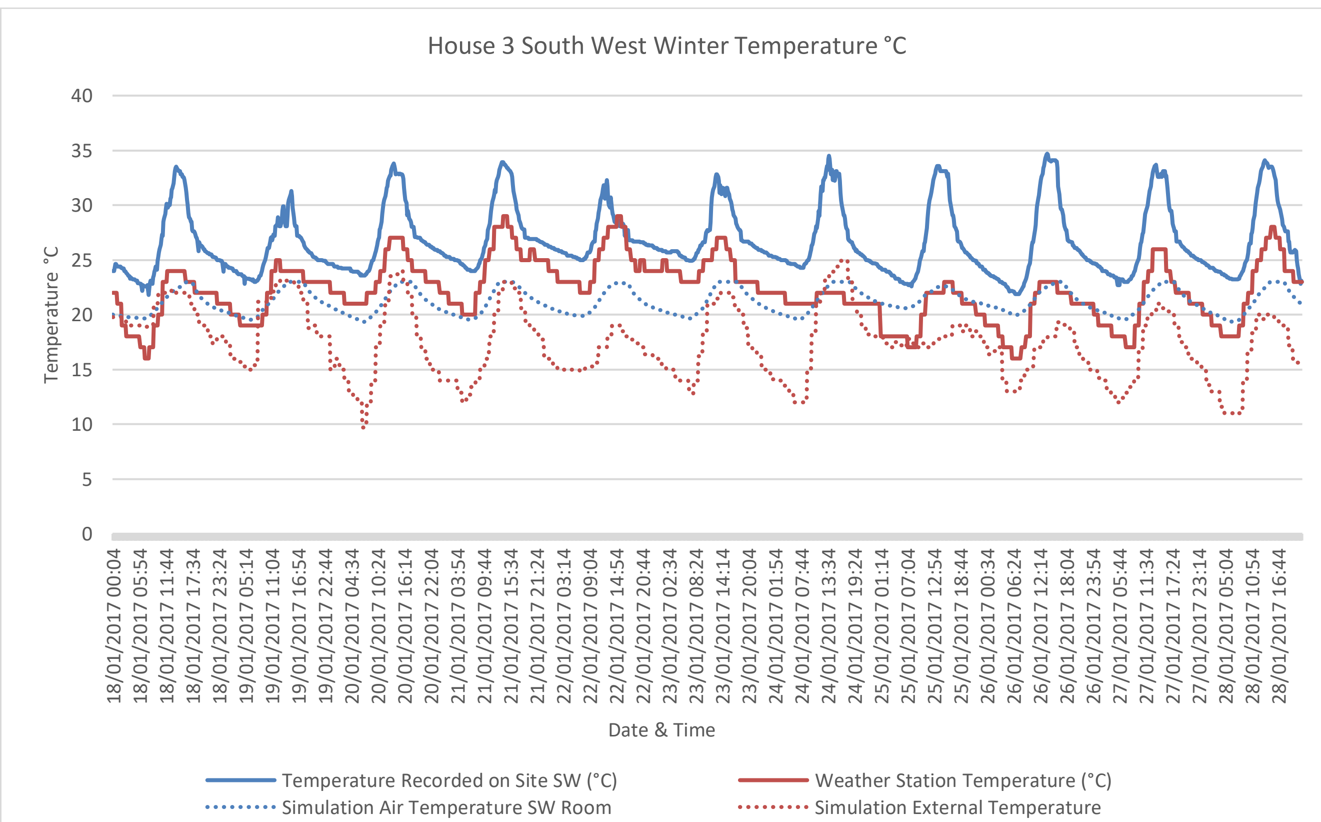

Figure 7.16 - House 1 Simulation Temperature Comparison Winter – NW

Case Study 4 (Winter)

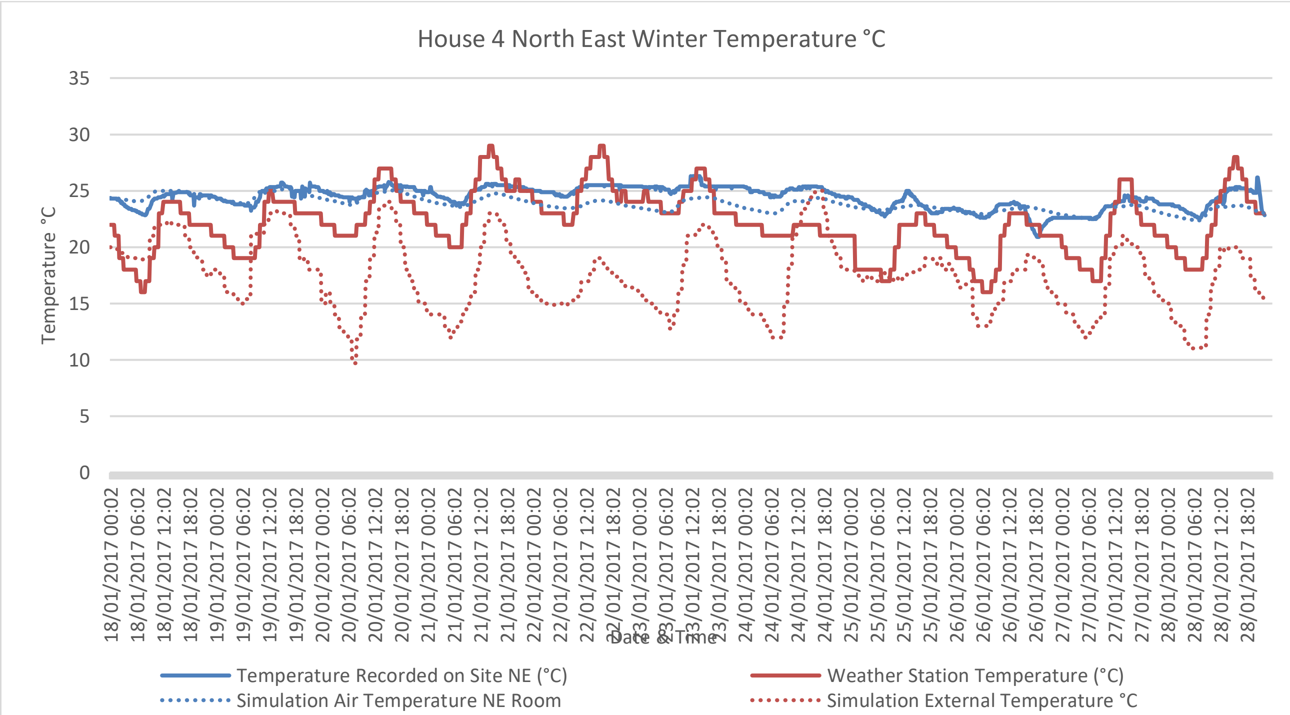

Figure 7.17 - House 4 Simulation Temperature Comparison Winter – NW

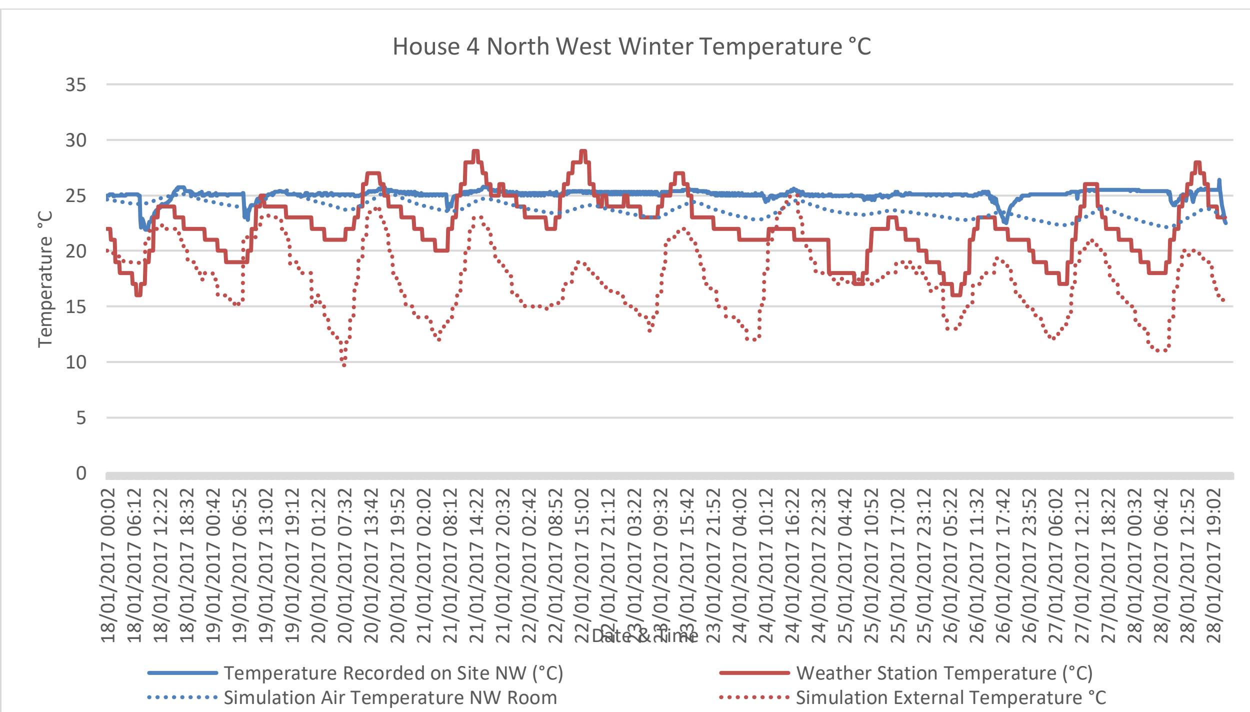

Figure 7.18 -House 4 Simulation Temperature Comparison Winter – NW

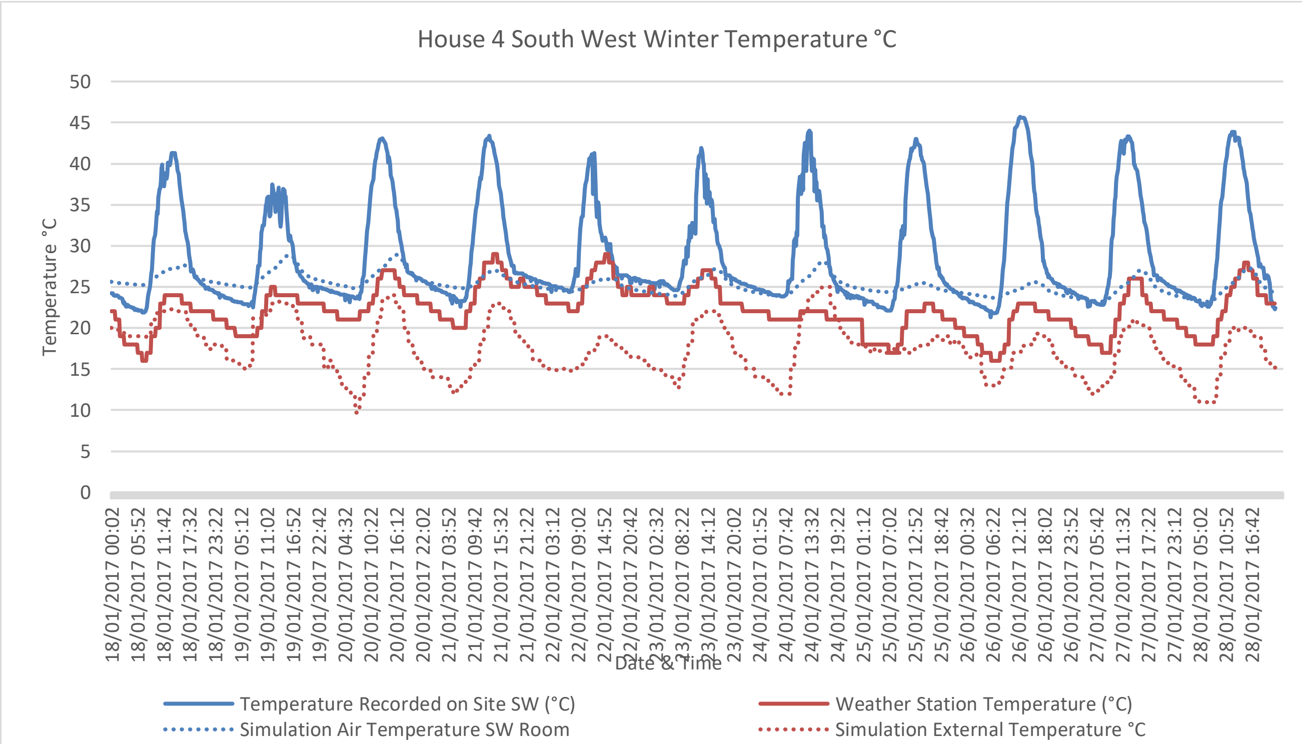

Figure 7.19 -House 4 Simulation Temperature Comparison Winter – SW

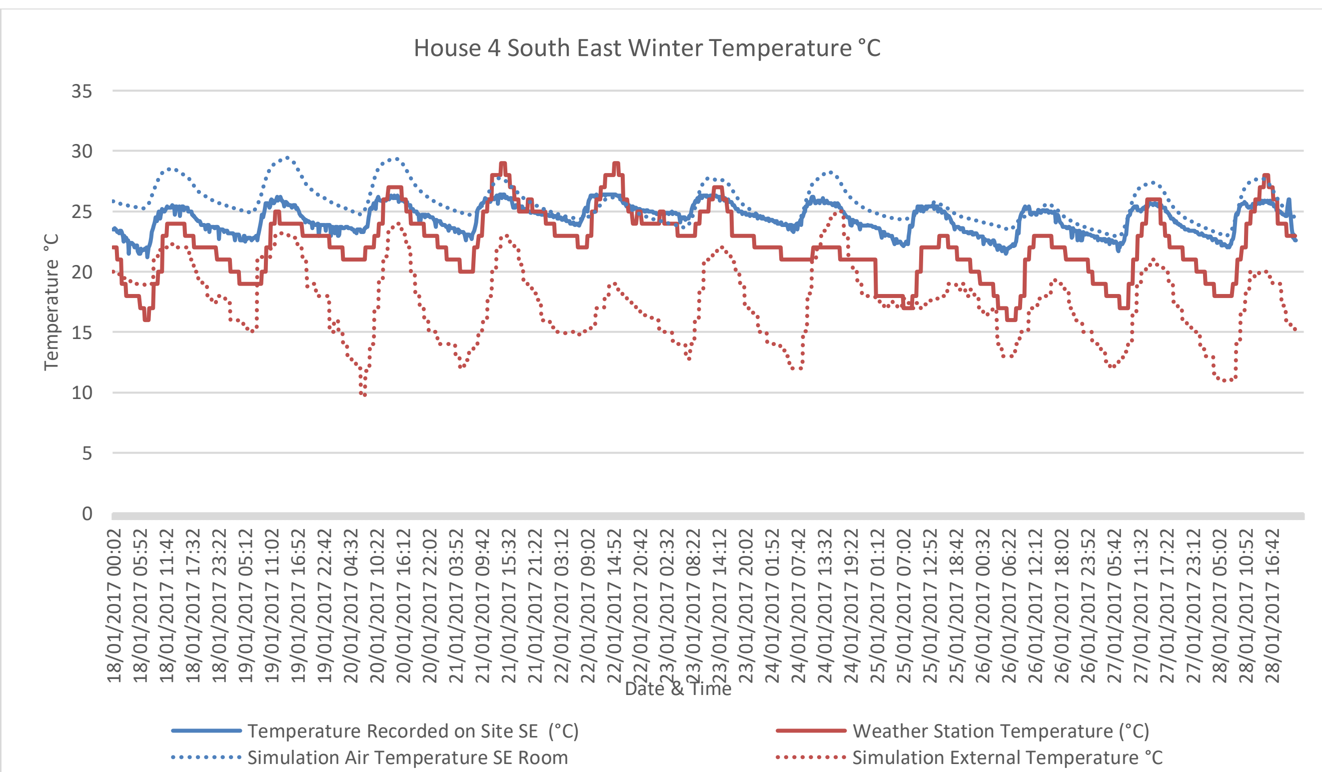

Figure 7.20 - House 4 Simulation Temperature Comparison Winter – NW

Case Study 5 (Winter)

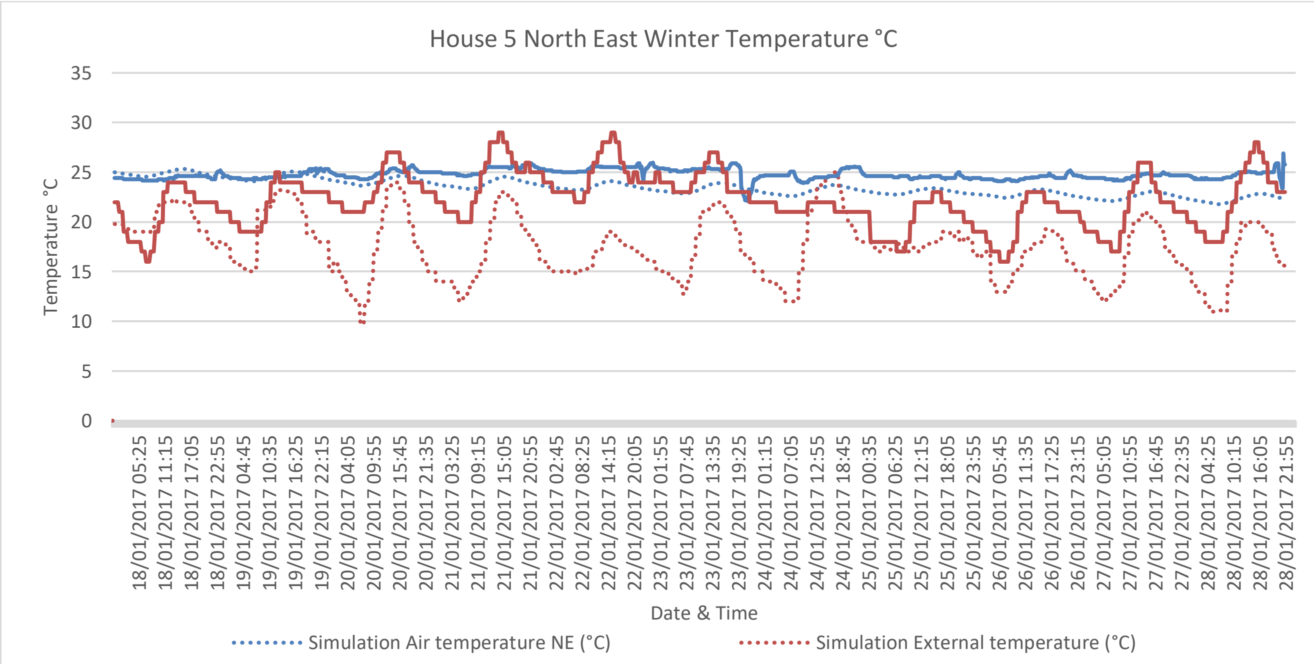

Figure 7.21 -House 5 Simulation Temperature Comparison Winter – NE

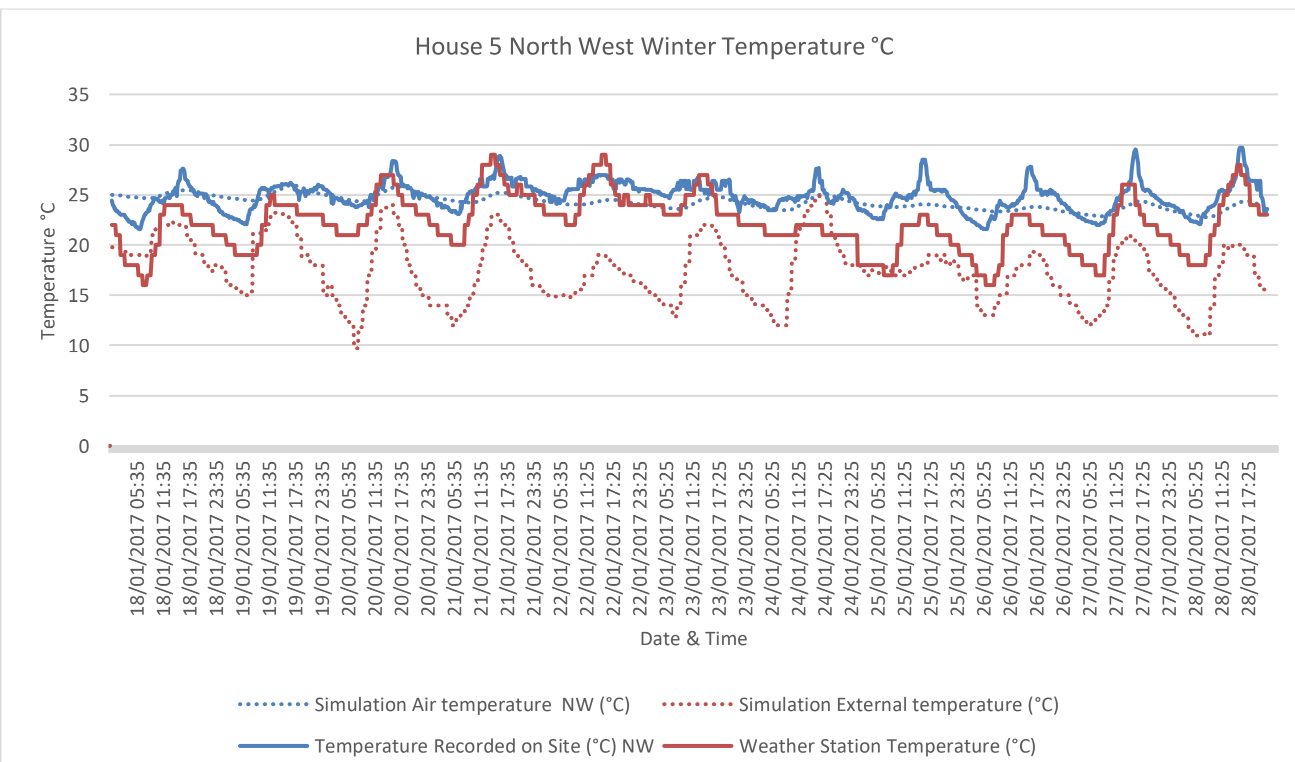

Figure7.22 - House 5 Simulation Temperature Comparison Winter – NW

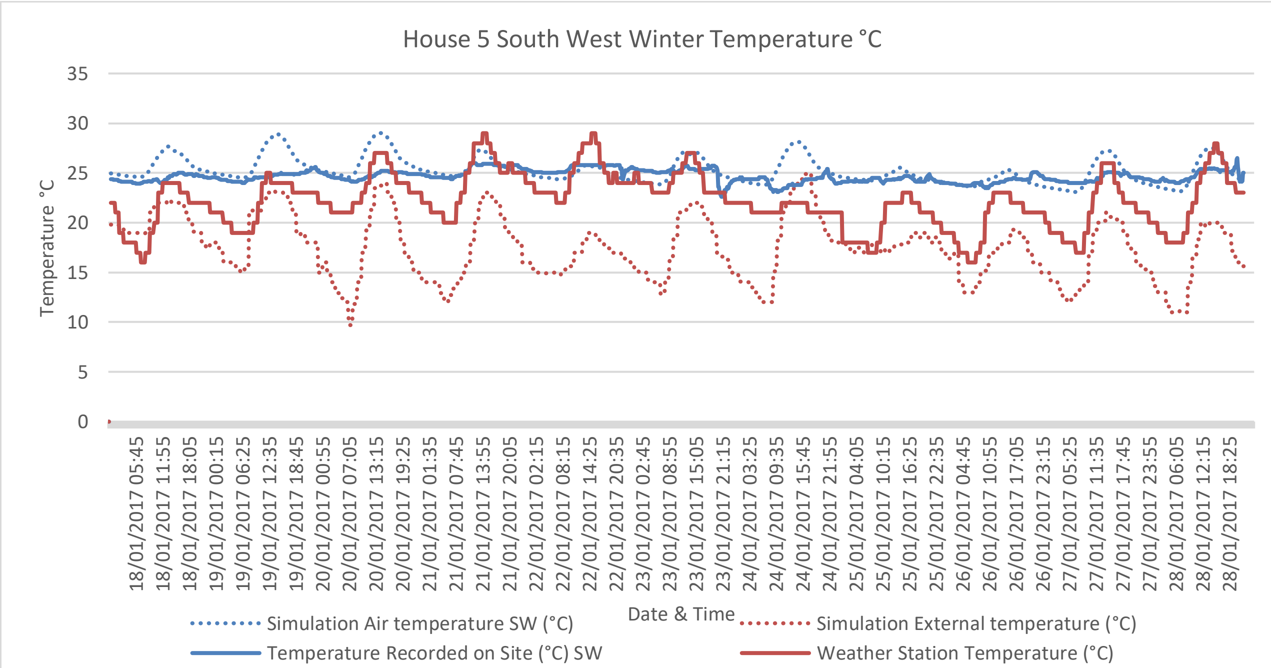

Figure 7.23 House 5 Simulation Temperature Comparison Winter – SW

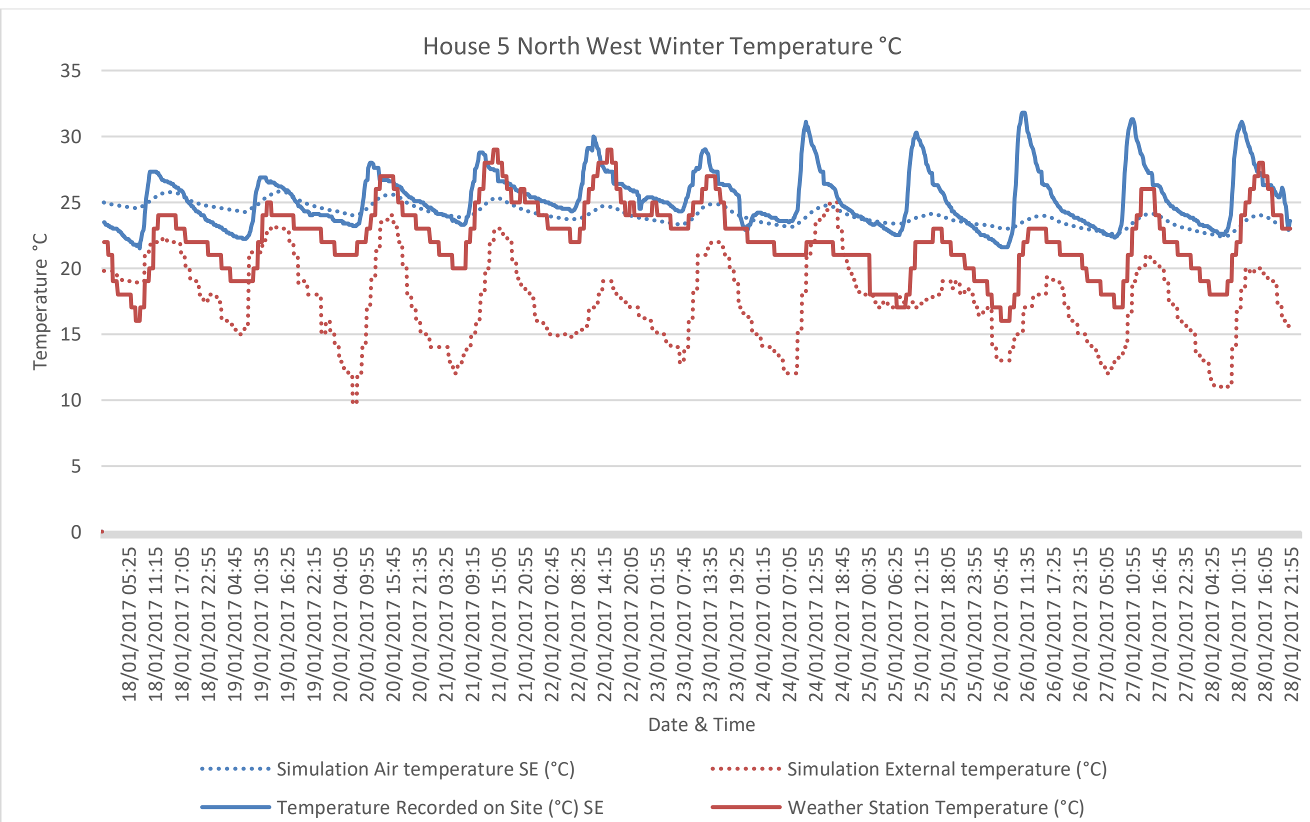

Figure 7.24 House 5 Simulation Temperature Comparison Winter – SE

7.3 Testing the principles using the software

Main principles of *Vaastushastra* were tested on case study 1, to investigate the impact on the internal temperatures using simulation software. One of the key principles of *Vaastushastra* is the orientation of the building which states that the building should align with the cardinal directions. The house in case study 1 was aligned 15° off the north axis, which is acceptable as per the principles of *Vaastushastra*.

7.3.1 Orientation of the house

The first modification tested on the house was the orientation of the house. Using the simulation software, the north direction was modified 3 times by rotating the house 90° each time which would test the impact on the internal temperature and humidity levels. Simulations on the house were run during the summer month of June because case study 1 was monitored in June without the use of air-conditions. This would make the results comparable to the data that was recorded on the site. Design of the house was kept the same, to understand the impact the modifications. Following data was collected from rotating the house in the simulation-

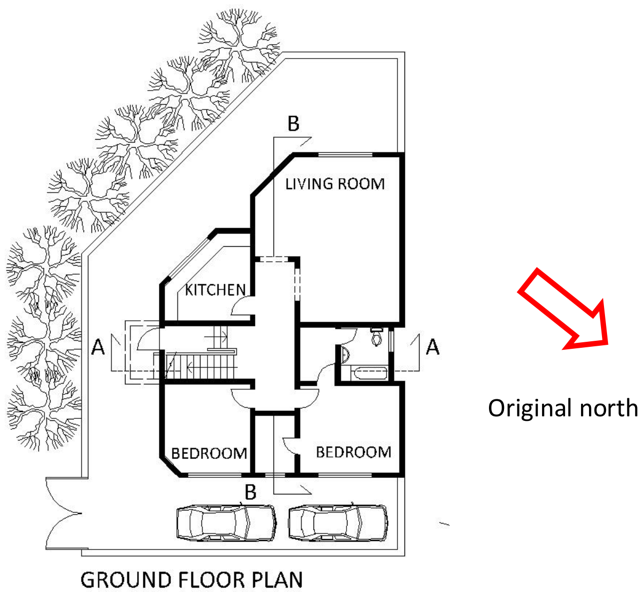

Figure 7.25- Original North location of Case study 1

Figure 7.25 shows the original north alignment of case study 1 as it was recorded on site and used for this thesis. Using simulation software, the house was rotated 90° each time and the effect of the rotations of the north axis are shown as below. The graphs (fig. 7.29- 7.32) below show the temperature of each of the four corner rooms if the orientation of the house was changed. The graph in fig 7.30 shows the average change in temperatures measured in each corner when the orientation changes. North arrow rotation is shown on the right-hand side of the plans (fig. 7.25- fig 7.28) indicates the how much the north arrow was rotated. The northeast and southeast rooms have the lowest temperature reading when the north of the house is in the original position. The southwest room has the lowest temperature when it is rotated by 90° west as shown in case study 1. The northwest room measures the lowest reading when the north is rotated to 270° west from its original orientation.

This is probably because the orientation of the house is along the east to west axis which is the correct orientation of the house. Rooms in the northeast and southeast have the best reading in this orientation because the proportions of these rooms are almost square which is the recommended in *Vaastushastra*. The southwest room has an incorrect shape which was maintained the same in this simulation and therefore this room has a lower temperature when the house is oriented by 90°. In the next few simulations the geometry of the room will be changed and the impact of that will be seen. Similarly, the northwest room has an odd geometry, even though it is roughly rectangular. The geometry of this room will also be changed in another simulation.

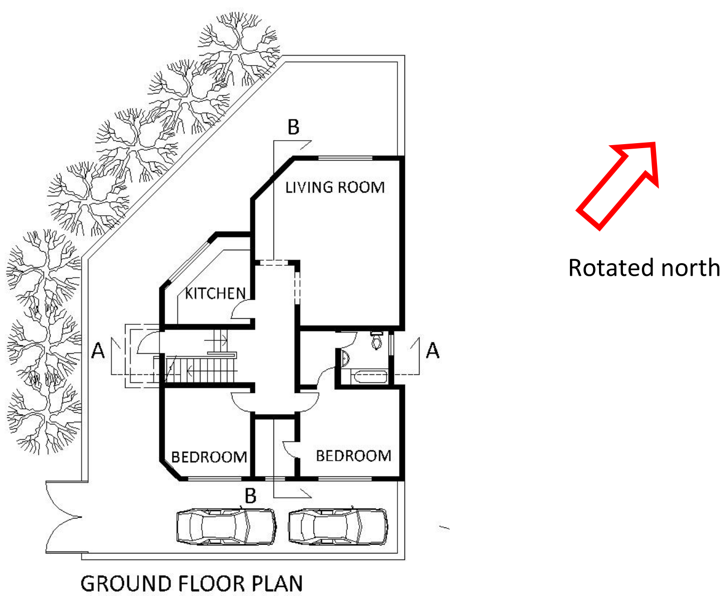

Figure 7.26- North Arrow Rotated 90° West – Study 1

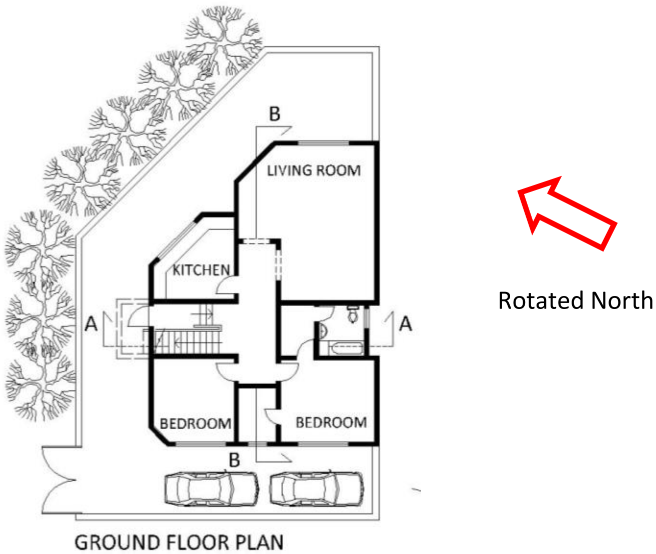

Figure 7.27 North Arrow Rotated 180° West – Study 2

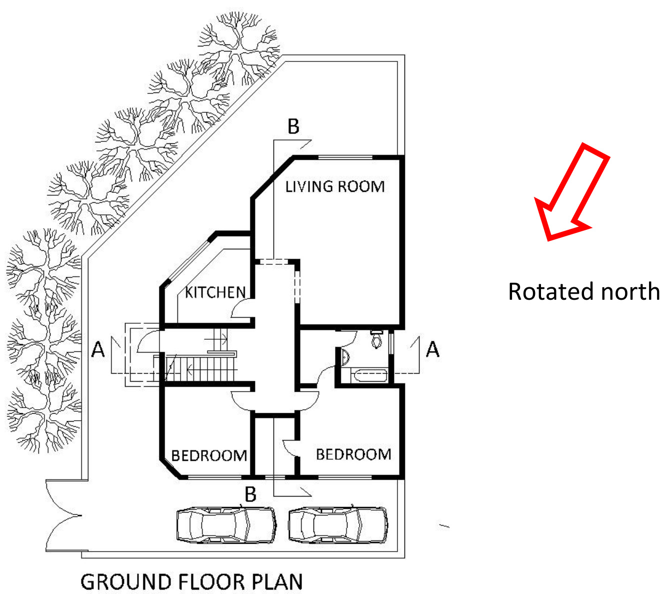

Figure 7.28 - North Arrow Rotated 270° West – Study 3

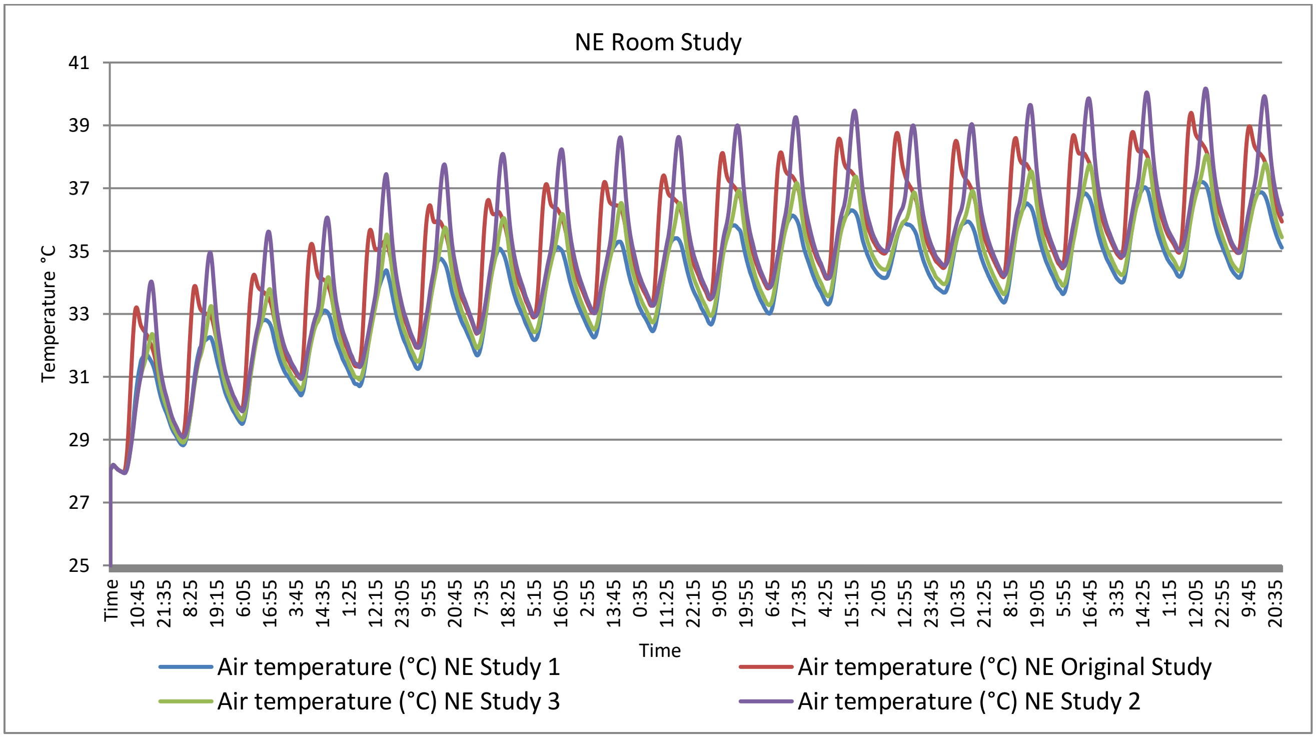

Figure 7.29 - Simulation study of Temperature in NE Room

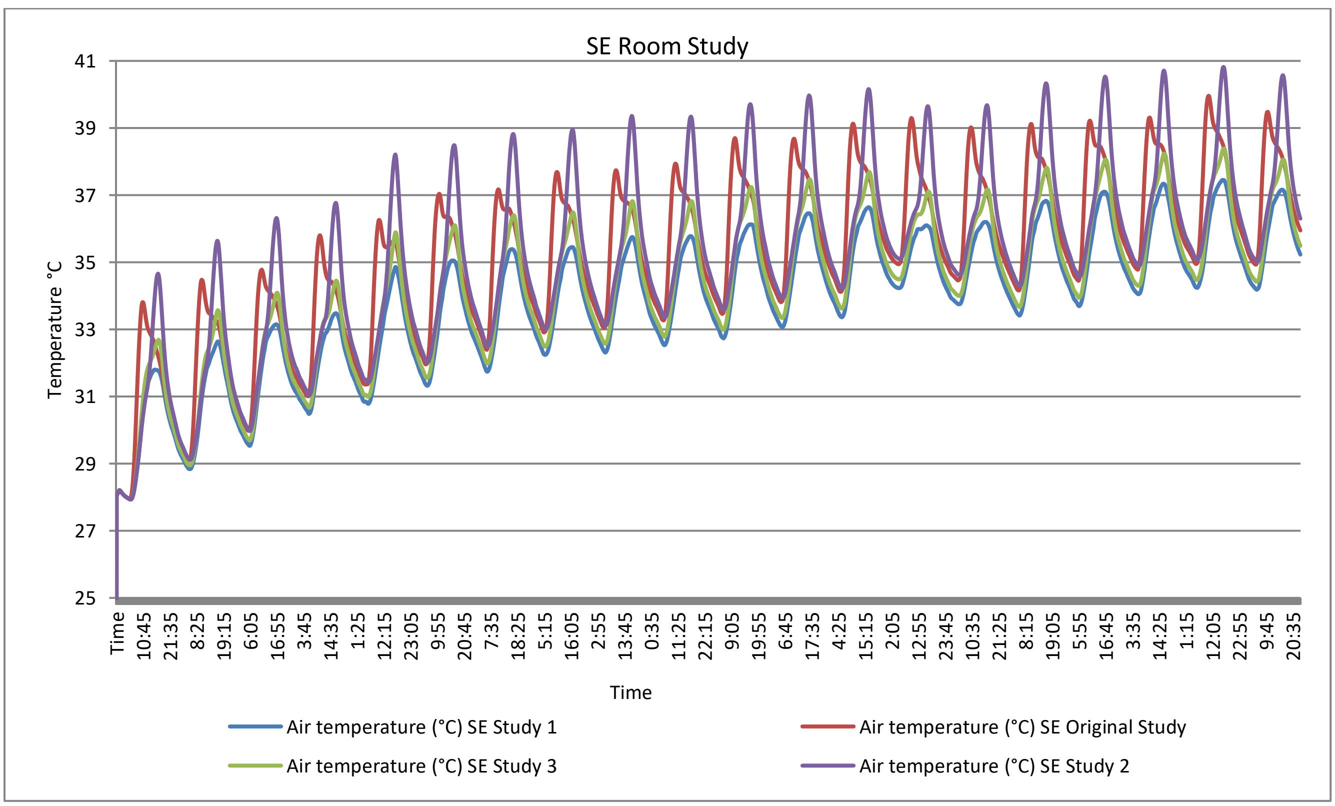

Figure 7.30- Simulation study of Temperature in SE Room

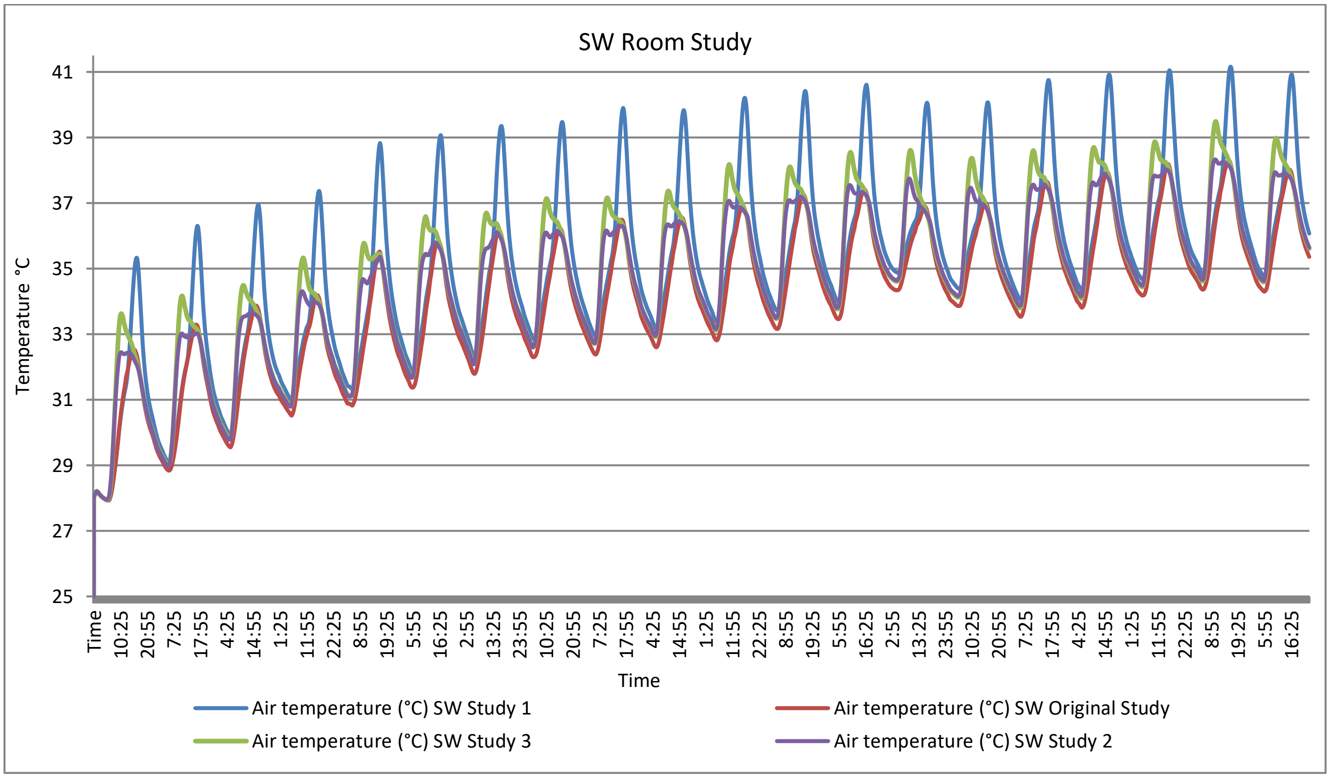

Figure 7.31 - Simulation study of Temperature in SW Room

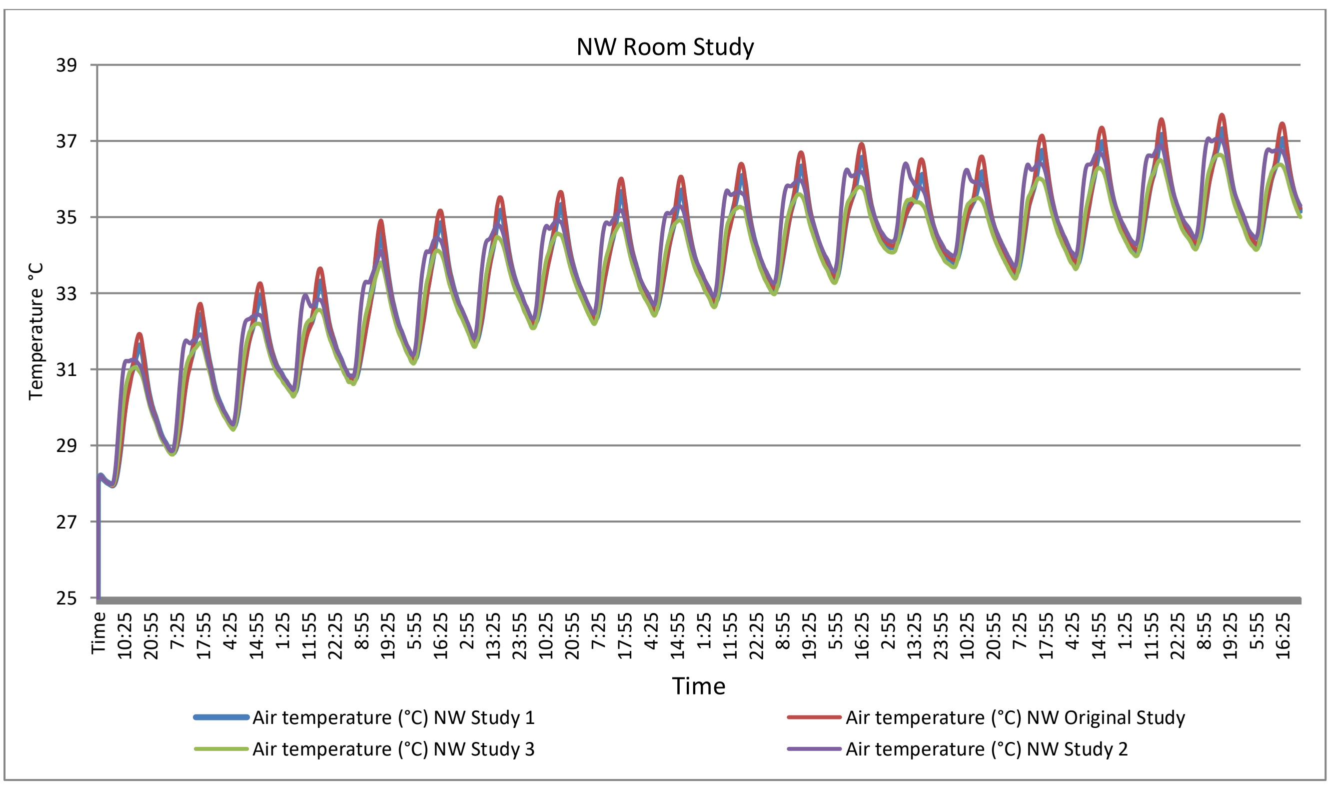

Figure 7.32 - Simulation study of Temperature in NW Room

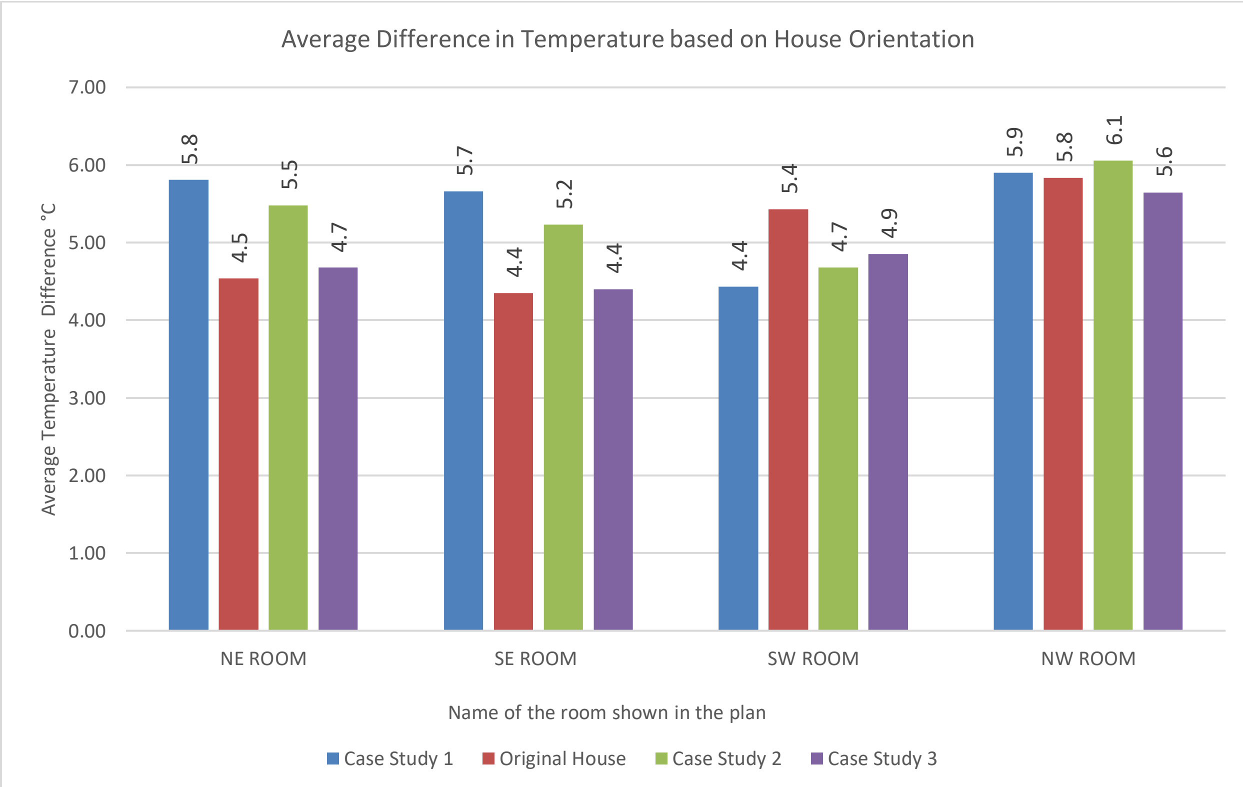

Figure 7.33 - Temperature Difference Compared to Weather Station Temperature

The graph above shows the temperature difference between average external and internal temperature for each space based on the rotation of the north axis. From the data gathered through stimulation it is hard to know which is the best orientation because all the temperature averages are similar (table 7.2)

	Original	*Modification 1*	*Modification 2*	*Modification 3*
NE	35.0	33.7	34.8	34.0
SE	35.2	33.9	35.1	34.3
SW	34.1	35.1	34.7	34.8
NW	33.7	33.6	33.9	33.5
Average	34.5	34.1	34.6	34.2

Table 7.2- Simulation Temperature Comparison 1

Northeast and southeast rooms have the lowest temperature reading when the north of the house is in the original position. The southwest room has the lowest temperature when it is rotated by 90° west as shown in case study 1. The northwest room measures the lowest reading when the north is rotated to 270° west from its original orientation.

This is probably because the orientation of the house is along the east to west axis which is the correct orientation of the house. Rooms in the northeast and southeast have the best reading in this orientation because the proportions of these rooms are almost square which is the recommended in *Vaastushastra*. The southwest room has an incorrect shape which was maintained the same in this simulation and therefore this room has a lower temperature when the house is oriented by 90°. In the next few simulations the geometry of the room will be changed and the impact of that will be seen. Similarly, the northwest room has an odd geometry, even though it is roughly rectangular. The geometry of this room will also be changed in the simulation in which the geometry of the room is changed.

7.3.2 Orientation of windows

Next adaptation that was experimented with in the simulation was to remove all the windows of the house while maintaining its original orientation. This was an exercise to understand the how much the temperature can drop by eliminating all windows. It would not be a practical solution to implement as natural light is needed in every house. The average temperature differences between the same sides are noted below in table 7.3 –

	Original North	*House w/o windows*	*Difference in temperature °C*
NE	35.0	31.8	3.2
SE	35.2	31.8	3.4
SW	34.1	31.7	2.4
NW	33.7	31.7	2.0

Table 7.3- Simulation Temperature Comparison 2

Maximum difference in temperature is seen when all the windows of the house are removed, but this would not be a plausible reality because every house would need natural light which is typically provided through windows. The next simulation was to test the house with the north along the length of the house (Study 1) without windows on the east or west facades. The following were the temperature difference –

	Original House	*No windows E or W*	*Difference in temperature °C*
NE	35.0	33.2	1.8
SE	35.2	33.3	1.9
SW	34.1	32.8	1.3
NW	33.7	32.8	0.9

Table 7.14-Simulation Temperature Comparison 3

7.3.3- Geometry of the rooms

The next change made to the model was to make all the rooms of a square geometry and the north rotation of the house was kept as the original study since that was the correct orientation of the house.

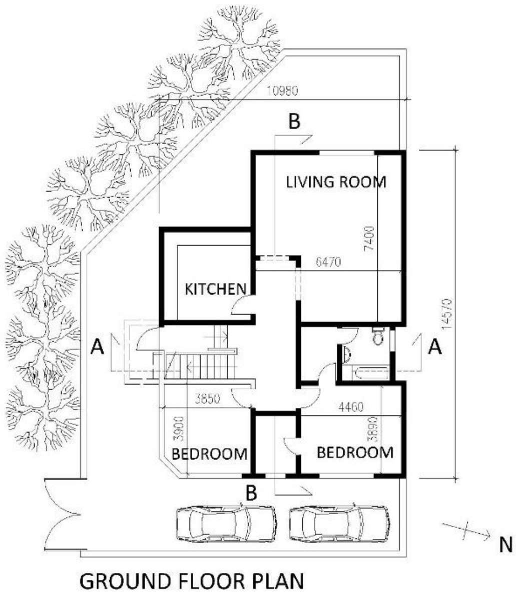

Figure 7.34- House with square rooms

	Original House	*Square rooms*	*Difference in temperature °C*
NE	35.0	32.8	2.2
SE	35.2	33.2	2.0
SW	34.1	33.1	1.0
NW	33.7	33.2	0.5

Table 7.15 -Simulation Temperature Comparison 4

The changes in proportion are made to the northeast and northwest rooms but the temperature the highest temperature difference is seen in the southeast room, followed by the northeast room. This could show that rooms in the house are interdependent in terms of temperature, since the northeast room has become square in proportion and larger at the same time the change in size and geometry could cause the room itself to be cooler but also could cause the southeast room to be significantly cooler too. The southwest and northwest rooms are cooler but the south side window in the southwest room could case the heat gain. In the case of the northwest room the cause of the heat gain could be due to the size of the window based on the proportion of the room.

7.3.4 Addition of courtyard in the house

A courtyard was added to the house to understand the impact it might or might not have on the internal temperature. The first courtyard added to the house was longer in length and maintained the proportion of the circulation corridor.

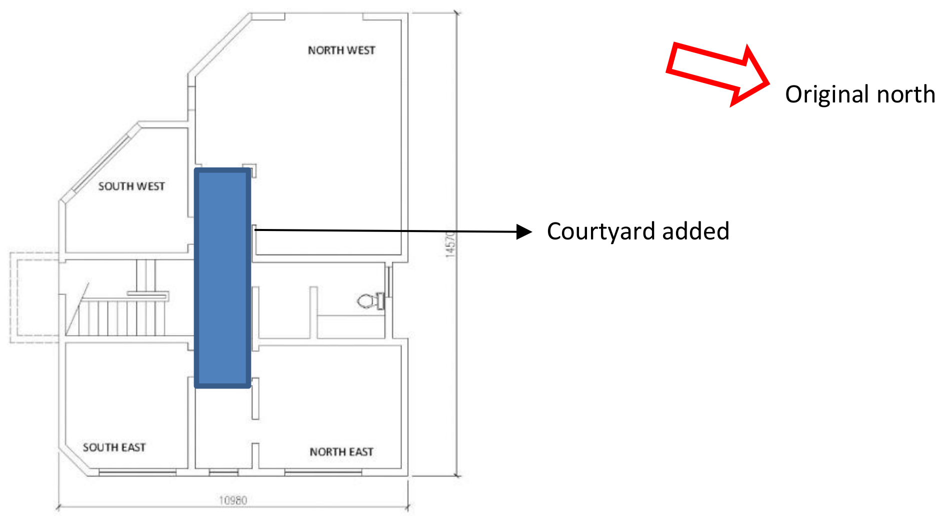

Figure 7.35 - House with long corridor

	Original House	Courtyard N 245°	Difference in temperature °C
NE	35.0	35.4	-0.4
SE	35.2	35.6	-0.4
SW	34.1	33.9	0.2
NW	33.7	33.7	0.0

Table 7.16- Simulation Temperature Comparison 5

The table above shows that when the courtyard was added the impact seem on the internal space was that the temperature increased rather than decreasing which was unexpected. Southwest corner however did show a decrease in temperature from the original. Therefore, further investigations were needed to understand the possible cause of this. This was possibly because of the proportions of the courtyard added to the study.

Next option was to add the courtyard when the north south axis was aligned with the length of the house. The change in orientation of the house and the addition of the courtyard shows for a reduction in temperature in the house.

	Original House	*Courtyard (Study 1)*	*Difference in temperature °C*
NE	35.0	33.9	1.1
SE	35.2	34.1	1.1
SW	34.1	33.7	0.4
NW	33.7	33.2	0.5

Table 7.17- Simulation Temperature Comparison 6

The next change was the reduce the length of the courtyard and to examine if the reduced proportions would have an impact on the temperature. There is a further reduction noticed in temperature with a higher impact seen on the southwest and northwest sides. The possible cause if this could be the square proportions of the rooms but further investigation would be needed to understand this.

	Original House	*Small Courtyard (Original Orientation)*	*Difference in temperature °C*
NE	35.0	33.9	1.1
SE	35.2	34.1	1.1
SW	34.1	33.6	0.5
NW	33.7	33.0	0.7

Table 7.18- Simulation Temperature Comparison 7

The next variation was to check the impact the geometry of the rooms and courtyard has on the temperature recorded. To test this all the rooms were modified to have square geometry and the internal courtyard which is also square in shape.

	Original House	*Square Courtyard w sq. rooms (Original Orientation)*	*Difference in temperature °C*
NE	35.0	33.4	1.6
SE	35.2	33.4	1.8
SW	34.1	33.4	0.7
NW	33.7	32.9	0.8

Table 7.19- Simulation Temperature Comparison 8

In all the examples above the courtyard was only added on the ground floor but the findings seemed to suggest that if the courtyard would be carried through to the first floor the internal temperature might be cooler.

	Original House	*Square Courtyard both floors (Original Orientation)*	*Difference in temperature °C*
NE	35.0	33.7	1.3
SE	35.2	33.8	1.4
SW	34.1	33.5	0.6
NW	33.7	33.0	0.7

Table 7.20 - Simulation Temperature Comparison 9

The findings were not as expected; the temperature was cooler than the original house which didn't have a courtyard but was slightly warmer than the courtyard that was placed on the ground floor only. The reason for this could be that the house (both upper and lower floors) might be gaining heat due and open courtyard. Direct exposure of the sun could cause the rooms on the ground floor to gain heat.

The next change was to add windows on the east side. The house was rotated so that the north aligned with the length of the house and the windows were added to the East side. The expectation was that adding east windows would not have too much of an impact on the temperature and the findings are shown below –

	Original House	*Windows on East wall (Study 1)*	*Difference in temperature °C*
NE	35.0	34.9	0.1
SE	35.2	35.2	0.0
SW	34.1	33.8	0.3
NW	33.7	33.6	0.1

Table 7.21- Simulation Temperature Comparison 10

The orientation of the and the layout of the house are maintained as original with the addition of windows on the east side. Negligible temperature difference is seen in all the rooms. This shows that adding windows on the east façade of the house doesn't create heat gain.

7.3.5 Windows on west and south façade

The next adaption to the house was the add all the windows that existed in the original house but add shading structures to prevent from excessive heat gain. The data recorded from the simulation showed that the internal space is still warmer even though shading structures were added to the windows on east and west sides.

	Original House	*Windows on E & W with shading (Study 1)*	*Difference in temperature °C*
NE	35.0	35.1	-0.1
SE	35.2	35.5	-0.3
SW	34.1	35.6	-1.5
NW	33.7	34.7	-1.0

Table 7.22- Simulation Temperature Comparison 11

7.3.6 Other modifications

Other adaptations of the house included addition of windows on all sides, windows that were 0.90m high, full height windows and full height windows with the orientation of the building aligned with the length of the house. The results of the temperature readings are seen as-

	Original House	*Windows all sides 0.90m (Original orientation)*	*Difference in temperature °C*
NE	35.0	35.5	-0.5
SE	35.2	35.7	-0.5
SW	34.1	35.0	-0.9
NW	33.7	34.9	-1.2

Table 7.23 - Simulation Temperature Comparison 12

	Original House	*Full height windows - all sides (Original Orientation)*	*Difference in temperature °C*
NE	35.0	40.1	-5.1
SE	35.2	39.2	-4.0
SW	34.1	38.2	-4.1
NW	33.7	38.3	-4.6

Table 7.24- Simulation Temperature Comparison 13

	Original House	*Full height windows - all sides (Study 1)*	*Difference in temperature °C*
NE	35.0	39.7	-4.7
SE	35.2	39.1	-3.9
SW	34.1	40.5	-6.4
NW	33.7	40.1	-6.4

Table 7.25- Simulation Temperature Comparison 14

The above temperature recordings prove that when glazing is added to all sides of the house the internal spaces are warmer than the readings of the original house.

The next changes that were made to the house were the change of materials of the external walls of the house. The existing structure is made of concrete and the proposed changes were to test the same built space with traditional materials such as brick, timber and stone. The material changes were carried out on the original design and layout of the house and the findings are shown below –

	Original House	*Single layer of Brick*	*Difference in temperature °C*
NE	35.0	35.7	-0.7
SE	35.2	35.7	-0.5
SW	34.1	34.9	-0.8
NW	33.7	34.7	-1.0

Table 7.26 - Simulation Temperature Comparison 15

	Original House	*Double layer of Brick*	*Difference in temperature °C*
NE	35.0	35.3	-0.3
SE	35.2	35.4	-0.2
SW	34.1	34.5	-0.4
NW	33.7	34.2	-0.5

Table 7.27 - Simulation Temperature Comparison 16

	Original House	*Timber*	*Difference in temperature °C*
NE	35.0	35.2	-0.2
SE	35.2	35.3	-0.1
SW	34.1	34.3	-0.2
NW	33.7	33.9	-0.2

Table 7.28 - Simulation Temperature Comparison 17

	Original House	*Stone*	*Difference in temperature*
NE	35.0	35.9	-0.9
SE	35.2	35.8	-0.6
SW	34.1	35.2	-1.1
NW	33.7	35.1	-1.4

Table 7.29 - Simulation Temperature Comparison 18

Simulations were created to test if the house would be cooler with the use of traditional materials such as brick, timber and stone. Use of local materials is emphasized in *Vaastushastra* since it is suggested that these materials create more comfortable space. When traditional materials were tested using the simulation software the results showed that the spaces become warmer. The difference in temperature is less than 2°C which could be due to inaccuracy of the software simulation. Since Dubai is a hot climate concrete might be a better material to use since the concrete specified is suitable for this climate.

7.4 Core concepts, key findings, and barriers

Core Conepts

- Orientation
- Builing form & Proportion
- Placement & size of windows
- Proprtion of rooms
- Courtyard
- Placement of funtions
- Architectural features affecting user comfort

Key findings

- Functions of the house should be laid out based on the orientation of the house and the duration the will be used
- The proportions of the building and the rooms should be square or rectangular
- Courtyards are not essential in small to mid-size homes, but are required in large homes.

Barriers

- Limited number of mid- size homes that are designed based on *Vaastushastra*
- Home ownwers were not keen to participate in the research
- Budget restriction limited the purchase of buying additional devices that would measure sound and light

Figure 7.36 - Core concepts, key findings, and barriers

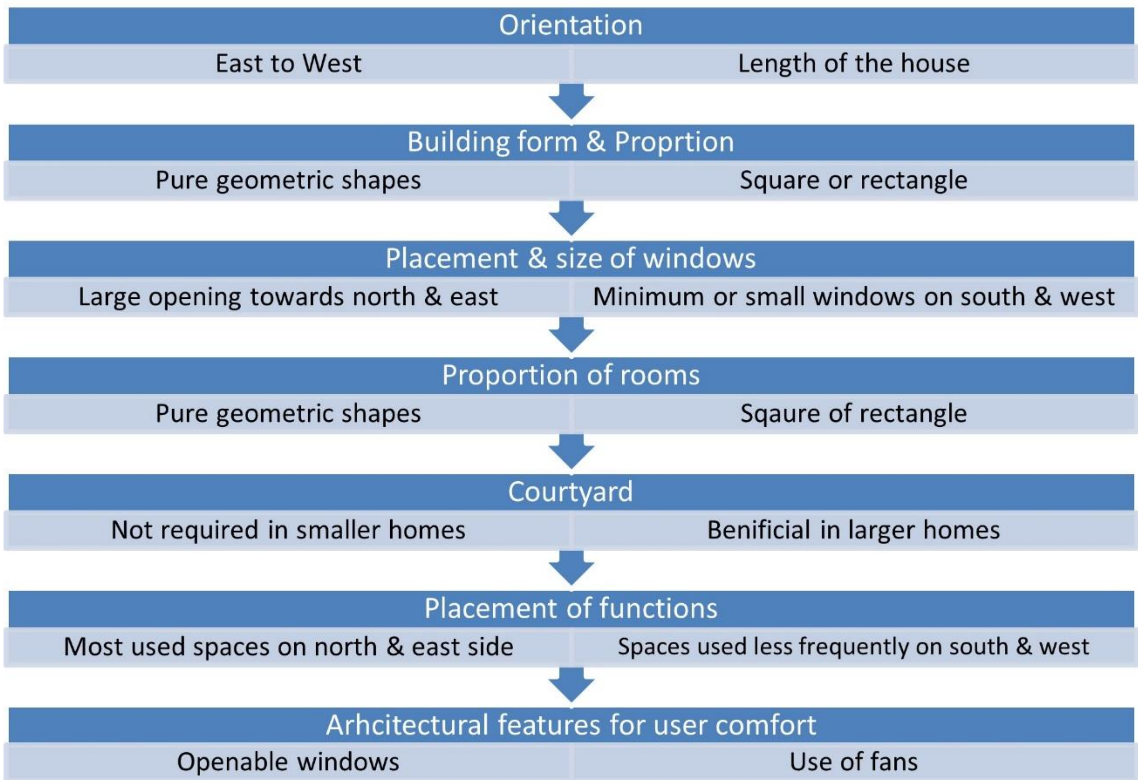

Figure 7.37- Core concepts

7. 5 Key findings compared to international scholars

This thesis consists of two key components firstly Vaastushastra and secondly user's comfort in homes in the Middle East region. Vaastushastra has always been studied within the context of India therefore most authors writing about this subject write in an Indian context. There are other studies done on user comfort in the Middle East, but these are predominantly focused on office spaces.

AS Dili, MA Naseer, T Zacharia Varghese have written a series of papers on user comfort in traditional homes in Kerala. The house used for these papers is a traditional vernacular house were as the homes used for the thesis are contemporary homes built in Dubai. The weather in Kerala is different since Kerala experiences a monsoon were as in Dubai the summer is hot and humid. Common results of both are that users are comfortable in homes that are designed on the principles of *Vaastushastra*. Another similarity is the use of materials for the construction of the homes, since both use locally sourced materials for the construction of the building shell. The difference in the results of both is that the papers do not corelate users' comfort with the direction that the space that they are using is located; for example, living rooms should be placed in north east since it is naturally cooler. One of the main principles of comfort in *Vaastushastra* is its association to direction which it is places in the house.

A.M.A Alshaikh, is an author who has written a thesis on *Design principles for thermally comfortable and low energy homes in the extreme hot-humid climatic Gulf region, with reference to Dammam, Saudi Arabia*. Alshaikh mentions the key principles of designing homes for the region as orientation, placement of windows, proportions of internal rooms, use of appropriate shading devices and the use of suitable materials and these are common factors between both theses. The difference is that user's comfort isn't connected with the location of the space within the house.

7.6 Villa designs in U.A.E

There are things that work well, things that need to be changed and somethings that need to be abandoned from villa designs in the UAE. The construction material that is used in majority of the construction is concrete which works well for the region. Some of the villas are oriented along the east to west axis, which works well in creating comfortable spaces and we should see more villas applying this principle. Some of the villas are rectangular or square in plan which is another aspect that should be used more often. Some villas have openable windows and ceiling fans which allow for alternative cooling methods which works well.

Placement of windows is an important factor in creating comfortable indoor temperatures even with the use of double-glazed windows. All the houses in the case studies have windows on the south and south west façades and this creates heat gain in those spaces. It is inevitable that homes will have windows on the south and west façade, but these should either be kept at a minimum or have appropriate shading devices. Internal layouts of homes need to be thought about and developed based on the orientation of the house amongst other aspects. Space planning of some of the houses works well while other homes need to develop the space plan of the house in relation to the orientation.

Many villas have large windows or glazing on their south and west and there isn't any shading device attached these and this should be abandoned. In this region exposing the south and the west side by using glass causes heat gain within the house which either makes internal spaces uncomfortable or needs more use of air-conditioning. Many villas don't have openable windows and therefore natural ventilation in the house is not possible and this shouldn't be the case.

In the future villas should be designed in line with passive design principles. The layout of the internal spaces should be developed to suit the site orientation. It is crucial that internal spaces are laid out based on the use of the functions so that spaces that are used most frequently are placed in the north, east or north east side of the house. By doing this the users will naturally feel comfortable in the house.

7.7 Conclusion

This chapter checked the accuracy of simulation models and compared it to the temperature and humidity recorded on site in five test homes. It was established that simulation modelling can be used to calculate the temperature and humidity of internal spaces since the simulation generated data within a comparable range. To understand the impact of the principles of *Vaastushastra* simulation modelling was used to modify the parameters of one of the case studies to understand the impact on the internal temperature and humidity. The factors that have an impact are –

Orientation of the house in relation to the length. The house seems to have lower internal temperature if the length is oriented along the east west axis. Orientation of the house in relation to the width. The house seems to have higher internal temperature if the length is oriented along the north south axis. Proportion of the rooms of the house. Overall lower internal temperatures are recorded if the rooms are square or rectangular in plan, based on recommended proportions and possibly if the house follows the same proportions.

Locations of windows in the house. It is known that the windows shouldn't be on the south or the west side, but if the windows are placed on these sides there should be an overhang, a shading structure or similar prevent heat gain. The ideal location of windows is on the north and east sides. Addition of a courtyard, if the house is large enough to include a courtyard, then this feature can help reduce internal temperatures. The courtyard should be proportionate to the length, width and height of the house and there should be a circulation corridor around the courtyard which prevents placement of windows onto the courtyard and therefore helps lower temperatures.

Chapter Eight: Conclusions and recommendations

8.1 Introduction

The purpose of the research was to investigate if the rules of *Vaastushastra* would help to create comfort levels in residential spaces in the Dubai (UAE). The research questions that were asked in the thesis are –

- Was *Vaastushastra* successful in addressing the sensory connections between the user and the built space?
- Which principles of *Vaastushastra* helped in creating comfortable internal spaces? (if any)
- Is there a significant temperature difference in the four sub-cardinal locations in a house?
- Can the principles of *Vaastushastra* be adapted into Dubai homes to support user's comfort architectural spaces?

This thesis goes through the theory of *Vaastushastra* and the methodology used to determine the impact that the principles of *Vaastushastra* might have on the comfort levels of homes in Dubai. It was essential to identify key principles of *Vaastushastra* and the principles which help create comfort in residential spaces, both these aspects are evaluated in chapter 2. Human senses are one way in which people feel comfortable in various spaces. Four of the senses can be linked to comfort in residential spaces which are touch, smell, sight and sound. Of these, touch is unique to each house as the temperature and humidity of each house is different. Smell is stable in the house if it is adequately ventilated, sight (daylight) is based on the location and the size of the windows and changes are seasonal whereas sound is typically very low in residential areas, especially residences, therefore touch which related to temperature and humidity were the measured variables. Five case study homes in Dubai were selected to test these questions. The criteria for selecting these five houses was based on adherence to principles of *Vaastushastra* discussed in chapter 3. Three different methods where used to collect information, first process was to collect data from real case studies in Dubai (chapter 4), second process was to ask the occupants of the selected homes to complete questionnaires (chapter 5) and third was to test various principles of *Vaastushastra* using simulation software (chapter 7). Since two different methods of collecting data were used in the studies chapter 6 includes a discussion about the findings from both sets of data. The conclusions of the finding from the information gathered are discussed in this chapter. The findings from each of the house will be mentioned first after which is the conclusion.

8.2 Case study set up

To investigate the impact of the principles data loggers were placed in all five houses to measure temperature and humidity levels. Since there are two main seasons in Dubai – summer and winter the loggers were placed in the houses during both seasons. External temperatures are very high touching 40°C and above in Dubai during the summer months which means that indoor spaces use air-conditioning all the time. One house was found in which the air-conditioning would be switched off for two weeks as the residents were travelling, and the house was unoccupied. Data loggers were placed in this house over the summer period as a test case study which establish if the principles were related to comfort levels. The findings from this first data collection helped to understand that there was a link between *Vaastushastra* and comfort levels which were –

- Even though the air-conditioning was switched off the internal temperature remained lower than the external temperature.
- Internal temperature doesn't rise above 38°C even though the external temperature climbs above 40°C at peak house during the day.

- The north side of the house is cooler than the south side of the house even though the house has maximum windows on the north and east side and minimum windows on the south and west sides.

8.3 Case study findings

The test case study showed that the principles could possibly have an impact on the comfort levels of the house. To investigate this further, four other houses were selected based on the criteria mentioned in Chapter 2. Data loggers were placed in all five houses in the summer, this would examine the principles further and determine the adherence to the principles outlined in the introduction. Since it was summer all the houses did have air-conditioning switch on. Even though the results are modified due to the use of air-conditioning the study was carried out to understand the trends in the temperature and humidity ranges. These results were mapped against the principles of *Vaastushastra* to recognize any similarities and differences caused by the architectural design.

8.3.1 House 1

In the summer the coolest room is the northeast room which is expected but the warmest room is the southwest room which is unexpected. This could be because the southwest room has a cut corner which breaks the rule of square or rectangular geometry suggested by the principles of *Vaastushastra*. The winter temperatures of the house ranges within 24°C even without the use of air-conditioning which is close to optimum internal temperature of 23.5°C. The length of the house is oriented along the east west axis of the house, which is the recommended direction based on *Vaastushastra*. The simulation studies in chapter 7 verify that this is the best orientation, and to improve the indoor quality the house needs a courtyard and rooms with square proportions. Even though the southeast side of the house is shaded it is the warmest side of the house in the winter and second warmest side in the summer. The northeast side of the house stays the coolest in the summer but is not the coolest in the winter which is unexpected; the latter might be because of the odd shape of the room.

The occupants use artificial light during the winter months and less during the summer months which supports the fact the house is oriented in the right direction and there is adequate amount of natural light for the activities that take place in the house. Spaces that are used most on the ground floor are on the northeast and the northwest side, placement of the window is on the east wall of the northeast room and west wall of the southwest room and the window size in proportion to the room allows for adequate natural light. The occupants are comfortable without using air-conditioning during the winter months but require it during the summer months. Rather than only relying on air-conditioning through the winter, they open windows and use fans to keep the spaces cooler which suggests that the house is generally comfortable to use. The windows are placed such that cross ventilation takes place and the use of fans suggests that it needs to be supported to lower the temperature. Humidity is a concern which might be caused by the use of air-conditioning as lower temperatures usually mean increased humidity levels.

In summary house 1 is ranked 3rd out of 5 in terms of staying cool in the summer months with an average internal temperature of 30.8°C. During the winter months maintains the lowest average internal temperature of 24°C. The house seems to maintain a comfortable internal temperature during the winter but could be more comfortable during the summer. The questionnaires filled by the users show that they were not very comfortable in the house but they used minimum interventions to stay comfortable. The occupants of the house are comfortable because they use the northeast and northwest spaces in the house which are cooler. Orientation of the house and use of openable windows helps to maintain lower temperatures in the house in the summer and the winter months.

8.3.2 House 2

The length of the house is aligned with the north to south axis and the temperatures recorded from the house are as expected. The summer temperatures show a gradual progression from coolest to warmest which is the northeast room is the coolest, followed by northwest room, followed by southwest and the southeast is the coolest room. Temperatures of both northeast and northwest are similar because it is one large room. During the winter months, the house stayed at around 24°C without any air-conditioning in the northeast, northwest and southwest sides which can be considered optimum. The southeast side rises to 28.2°C which is predicted by *Vaastushastra*. Since the house is oriented around the north – south axis the southeast side is much warmer during the winter which could be due to the windows on the south wall. The northeast and northwest rooms are connected but the northeast side is cooler – this could be because the window in the northeast space is on the north façade of the house whereas the northwest side has windows on both north and west walls.

Occupants use artificial light equally during the summer and the winter which could mean that house doesn't receive too much natural light and therefore artificial light needs to be used. The orientation of the house and the placement of the windows could cause the natural light to be filtered such that artificial light is required more often. Best source of natural light is the north and east side of the house, in this case the north side has building and the living space which is in the east doesn't have a window. From the survey it seems that use air-conditioning primarily during the summer months, but during winter they rely more on opening the windows while air-conditioning isn't used too often. This house doesn't need fans or any supportive cooling techniques during winter months as there are no windows present on the south side of the building. The windows on the west side of the house are covered by a small overhang which helps cool the house in the winter but doesn't prevent heat gain in the summer. Humidity levels are high in the house during the summer months when air-conditioning is a constant requirement.

In summary, house 2 is ranked 4th out of the 5 houses in terms of difference in temperatures in the summer months with an average internal temperature of 34.1°C. During the winter months most of the house stay at an average internal temperature of 24°C except for the southeast corner. The questionnaires filled in by the occupants show that they were not too comfortable in the house and they used slightly more interventions to stay comfortable that used in case study 1. This is because the south side of the house has higher temperatures. Since the occupants use the cooler side which is the north side, they feel comfortable in the space. The internal spaces in the house are located as per *Vaastushastra* and therefore the users feel more comfortable.

8.3.3 House 3

The length of this house aligns with the north- south axis and similar to house 2 the trends of the temperatures are as expected but are at a higher average. Summer temperatures follow the trend of northeast recording the lowest temperature, followed by northwest, then southwest and finally the southeast is the warmest. Even though the northeast and northwest rooms are separate the average temperature is in a similar range. Winter temperatures are an average of 24°C on the north side, but the south side is an average of 27°C which seems to be on the warmer side which is predicted as per the principles of *Vaastushastra*. The north temperatures are lower in the winter than in the summer months, this supports the fact that the north side of the house is naturally cooler than the south side. Similar to house 2, this house is also oriented around the north- south axis but the average temperature is higher than house 2. The reason for the higher temperatures could be that house 3 has windows on all sides and windows placed on the south and west facades without appropriate shading seem to increase the internal temperatures.

Even though all the tenants said they rarely have problems with natural sunlight they are using artificial light equally during summer and winter (slightly more in the summer). Location and size of the windows play an important part in the amount of natural light received. This shows that the orientation of the house doesn't support natural light into the house. The survey shows that the air-conditioning is always on during the summer and less often in the winter but is still used much more than seen in the other houses. The orientation of the house helps to keep the house cooler during the winter but the placement of the windows on all sides of the house keep the house warm. Since the house doesn't have any architectural features such as overhangs, or courtyards the temperature of the house tends to stay high even with the use of air-conditioning (in the summer months). With the use of the air-conditioning the humidity levels of the house rise which is noticed by the occupants.

In summary house 3 is the house that stays the warmest during the summer with an average internal temperature of 36.1°C. Even though it stays cooler during the winter months with an average internal temperature of 25.3°C. The occupants rely on the air-conditioning throughout the year since the average temperatures are higher than the accepted norms. Since the house isn't aligned as per the ideal principles of *Vaastushastra* the internal temperatures are high possibly because windows are located on all sides, there is no courtyard and the south and west sides don't have an overhang. The occupants mention that they are comfortable in the house but use the maximum number of interventions to stay comfortable in the house. Occupants rely on use of artificial lighting, air-conditioning both during the summer and the winter months.

8.3.4 House 4

The length of the house aligns with the east-west axis; which is ideal as per *Vaastushastra* and is reflected in the fact that the house maintains lower temperatures than the other house especially in the summer. The northeast room is the warmest in the house and is exceptionally warm in the summer, which might be because of the proportions of the rooms and windows on the south façade that don't have a shading structure. Other than that, the northwest is coolest, followed by southwest and then southeast. The northwest is the coolest in the house because it has no windows, the southwest and southeast are warmer as expected. Winter temperatures for the house are similar to house 2 where the northeast is the coolest followed by northwest, followed by southwest and southeast is the warmest. The southeast temperature recorded in this house is the highest amongst all the houses. The possible explanation for this is that the proportions of the room are not as per *Vaastushastra* recommendation and there is a very large opening on the south façade. Even though the southwest room has a large window on the west façade the temperature is not too high possibly because the opening is on west side has an overhang to prevent heat gain.

Users of the space have mentioned that they never have problems with the natural light in the space. The use of artificial light is higher in the winter than in the summer which shows that the natural light in the space is adequate even though these is one space in the house which has no windows. Activities which need natural light are planned such that there are windows and therefore enough natural light. For example, activities that take place in the morning utilize either the northeast space or the east space which allow for maximum natural light. Similar to house 3 this house also relies heavily on the use or air-conditioning during the summer and frequently in the winter. The main difference is that during winter occupants' open windows of the house and use fans to cool the space. This supports that the orientation of the house and the location of the windows support natural cooling of the house. West side of the house is cooler because of the architectural features of the house, firstly the northwest space has no windows as is the coolest space in the house, secondly there is an overhang on the southwest side which has the large window which prevents heat gain but allows for ventilation and diffused natural light.

In summary, house 4 has the second lowest average internal temperatures at 29.2°C in the summer months. This is possibly due to the fact that the house follows the ideal orientation suggested by *Vaastushastra*. During the winter months, the house stays at an average of 24°C except for the southeast corner which maintains a much higher temperature. The users of the house think that they are completely comfortable in the house, but they use the maximum interventions to achieve this level of comfort. The occupants use more interventions such as use of air-conditioning even in the winter months because they use the warmer spaces in the house that are the northeast and the southeast spaces. Due to the proportions of these spaces they are warmer than they should be.

8.3.5 House 5

The length of the house is oriented along the east west axis of the house, has translated into lower temperatures recorded in the house. Similar to the expectations the house stayed quite cool during both the summer and winter months. During the summer months, the temperature measurements were as expected which is northeast was the coolest, followed northwest, followed by southwest and finally the southeast was the warmest. Compared to the other four houses the north side temperature was an average of 26.7°C which is the lowest of all the houses. The south temperature is also an average of 31°C which is again the lowest amongst the houses. The possible explanation for this can be that the windows are placed along the length of the house and the windows are placed on the sides with overhangs. The winter temperature of the house averages between 24°C and 25°C which is within the range of temperatures recorded in the other houses. The exception is that the southeast temperature is not too high. The house doesn't seem to gain too much heat during the summer or winter months, possibly due to orientation, position of windows, proportions of the rooms and the house and overhangs. The house overall is rectangular, and the rooms of the house are rectangular as well. This could be a possible reason for the overall cool temperatures recorded in the house. Windows on the ground floor are placed such that they are covered by an overhang which could be the reason why the temperatures recorded are lower than the other houses.

Orientation of the windows in this house are primarily on the east and west facades and limits the amount of natural light that enters the house. Use of artificial light is seen more during the winter than in the summer. The space that is used the most during the day is in the southeast side which is probably another reason why artificial light is needed in the house whereas the northeast corner which gets more daylight isn't used very often during daylight hours. Air-conditioning is used throughout the year in the house, more during the summer than in the winter. Additional methods of cooling the house such as windows and fans are used during the winter and the summer months, which supports the fact that house can stay cooler without constant use of air-conditioning. The house is long and rectangular with minimal number of walls in the centre, which allows for cross ventilation and helps to keep the space cooler. Even though there are windows on the South side of the house the overhang above helps to keep the house cooler.

In summary, house 5 is coolest house during the summer months with an internal average temperature of 28.7°C and during the winter months it maintains a comfortable average temperature of 25°C. In terms of feeling comfortable in the space the occupants don't feel very comfortable and use moderate amounts of interventions to stay cool. The occupants don't feel comfortable in the house because they use the southeast and southwest rooms in the house which average temperatures 30°C. If they used the cooler side of the house, they would feel more comfortable. The house is oriented according to the principles of *Vaastushastra* and there are windows on the east and west side, but since there is an overhang on the south side the house stays cooler during the summer months.

8.4 Conclusion

The findings of the research support that homes designed on the principles of *Vaastushastra* are comfortable for the users. There can be varying degrees of comfort based on compliant the house is with the principles of *Vaastushastra*. There are two aspects to comfort, one only refers to measurable temperature comfort (thermal comfort) and the other refers to the feeling of comfort (adaptive comfort). Case studies 4 and 5 are examples of the former, in which we see that these homes achieve comfortable temperatures, but the occupants are complaining about high temperatures in the house, which requires use of air-conditioning and prevents an overall comfort for the residents. Even though the architecture is designed based on the principles of *Vaastushastra*, the internal spaces aren't designed accordingly. In these homes, the internal spaces can be redesigned so that the house can be comfortable for the users.

Case studies 1 and 2 are examples where the users are comfortable in the house, even though the recorded temperatures of the house are high. These are examples of adaptive comfort because the occupants use the cooler part of the house. In case study 1, the geometry of the house doesn't follow the proportions of *Vaastushastra*, which causes the anomaly of higher temperature in the southwest. This example shows the impact that irregular geometry has on the temperature of the house. Residents of the house are comfortable in this house because they use the cooler spaces of northeast and northwest. If the overall geometry of the house is changed, it will create an even more comfortable space. In case study 2, the house aligns with the cardinal directions, but the length is aligned to the north south axis, which isn't suitable for hot climates. The occupants are comfortable in the house because they use the cooler spaces of northeast and northwest. If the orientation of the house is changed, the users will feel even more comfortable in the house.

In case study 3, the recorded temperatures of the house are high, and the users of the house feel uncomfortable. Due to high temperatures in the house, the air-conditioning is utilised all the time and similar to case study 4 and 5 the residents feel uncomfortable due to high levels of internal sound. The house is oriented along the north south axis but should have been oriented around the east west axis. There are windows on all sides of the house and the windows on the south and west don't have overhangs, which allows for internal heat gain.

Answers to the research questions that were asked in the introduction –

- Was *Vaastushastra* successful in addressing the sensory connections between the user and the built space?

There are many factors that can influence users experience of a space, some are tangible and measurable while others are intuitive and experienced. It is important that the former is addressed in homes even though it is intangible, but the former is a measurable and can provide some insight into positive experience of spaces especially homes. The tangible parts of the users' experience of a space are linked to the engagement of the users' senses which are based on sight, sound, smell, and touch in a positive and measurable manner. From the four senses, touch and sight are the senses that varies from space to space especially in a residential context.

Daylight is required in spaces to make the occupants comfortable but adding windows the wrong sides of the house causes gain in internal temperatures, as seen in the five case studies.

Temperatures recorded in the houses and data from users' questionnaires show that placement of windows, their size and orientation with the house has significant impact on the users' experience of touch. When the house has more openings (case study 3) there is ample natural light, but the temperatures of the house are warmer. When there is a lack of windows the space is cooler, but the occupants don't use the space as much as they should, because there is no natural light in the space (case study 4). *Vaastushastra* principles mention that windows on the north and east sides are encouraged and on the south and west are discouraged. The findings of the case studies support this rule and give evidence that if windows are placed on south and west walls providing overhangs or shading devices and help control internal temperatures.

Sound in the house is maximized when there are too many mechanical systems that are used to keep the house at a comfortable temperature. When the house can be naturally ventilated, as in case studies all the case studies except 3, the requirement for use of air-conditioning is reduced and therefore the sound level is reduced. Lack of air circulation causes stale air which causes smell. If the house has openable windows that can allow natural ventilation when the weather permits, then the occupants are happy with the smell in the house.

Temperatures recorded in the houses and data from users' questionnaires show that placement of windows, their size and orientation with the house has significant impact on the users' experience. When the house has more openings (case study 3) there is ample natural light, but the temperatures of the house are warmer. When there is a lack of windows the space is cooler, but the occupants don't use the space as much as they should, because there is no natural light in the space (case study 4). *Vaastushastra* principles mention that windows on the north and east sides are encouraged and on the south and west are discouraged. The findings of the case studies support this rule and give evidence that if windows are placed on south and west walls providing overhangs or shading devices and help control internal temperatures.

- Which principles of *Vaastushastra* helped in creating comfortable internal spaces? (if any)

Vaastushastra lists many principles which are interconnected and should not be applied to the design in isolation because each principle has an impact on the other. The orientation of the house relates to the proportions of the house and the placement of the windows. If the house is rectangular in proportion, and the length is aligned to the east west which means that windows on the south and west side can gain heat during the day as seen in case study 1. When the length of the house aligns with the north to south axis the windows on the north and east sides don't gain too much heat as seen in case studies 2 and 3 which is because when the sun rises over head the exposure of the east window is less. When the length of the house aligns with the east to west axis, any windows on the southeast and southwest side see a slight gain in temperature as seen in case study 4 and 5 (table 8.1 -8.2).

The proportions of the rooms have an impact on the comfort levels, as irregular shapes and proportions both cause heat gain as seen in case study 1 and 4. In case study 1 the house has two rooms which have a polygon shape and the impact of this is that the temperatures are warmer than the other rooms. In case study 4 the long rectangular room in southeast corner becomes the warmest room firstly due to tall windows on the south side and secondly because the room is longer in length which creates a disproportionate room. In the same case study the northeast temperature is higher than expected because the proportions of the room aren't correct, the room is too long and therefore records a higher temperature.

- Is there a significant temperature difference in the four sub-cardinal locations in a house?

Summer	*Avg. NE Temperature*	*Avg. NW Temperature*	*Avg. SW Temperature*	*Avg. SE Temperature*	*Weather Station Temperature*
CS 1	27.1	30.0	33.7	32.2	39.5
CS 2	31.4	31.7	34.3	38.9	39.5
CS 3	35.2	35.1	36.4	37.7	39.5
CS 4	31.4	25.1	29.1	31.1	39.5
CS 5	26.6	26.9	30.3	31.0	39.5

Table 8.1-Comparison of internal temperatures of Case Studies during summer

House	*Avg. NE Temperature*	*Avg. NW Temperature*	*Avg. SW Temperature*	*Avg. SE Temperature*	*Weather Station Temperature*
CS 1	24.0	23.7	23.9	24.8	22.6
CS 2	23.9	24.2	23.9	28.2	22.6
CS 3	23.7	23.7	26.8	27.0	22.6
CS 4	24.8	25.1	24.6	28.7	22.6
CS 5	24.9	25.1	24.8	25.3	22.6

Table 8.2- Comparison of internal temperatures of Case Studies during winter

The temperature differences noted in the case studies are seen in table 8.1 and 8.2. Architectural features of the house have an impact on the internal temperatures of the house. The principles of *Vaastushastra* mention features of the house that should be included and those that should be avoided. There is no explanation behind these principles and there could be different rationale applied to understand these. Through the case studies the understanding is that the design of the house has an impact on the internal temperatures.

- Can the principles of *Vaastushastra* be adapted into Dubai homes and create comfortable architectural spaces?

The rules of *Vaastushastra* vary from one location to another within India, this is probably due the variation in climates, as the rules are adapted to suit the specific region. Once the common principles of *Vaastushastra* are understood these could be modified to suit any local climate that is similar to a climate found in India. Dubai is a hot and humid climate most of the year which is similar to the climate of Rajasthan which is also a desert region but is different to Dubai because the winter season is much colder than Dubai. But the weather is comparable to Dubai and therefore the principles of *Vaastushastra* can modified and adapted to be used in intendent mid-size homes.

Based on the findings of this thesis the principles of *Vaastushastra* that could be used in homes in Dubai are –

- The orientation of the house, its length and width, should be aligned with the cardinal directions. Orienting the house east to west is favourable for hot climates like Dubai.
- Proportions of the house should ideally be square or rectangular and the proportions of the rectangle shouldn't be lower than 1:6.
- Windows in the house should be located on the north and east facades of the house, if there are windows on the south or west façade there should be a shading device or an overhang above it.
- The proportions of the rooms should be square or rectangular (specific proportions mentioned in *Vaastushastra*) that matches with the square or rectangular proportions of the house
- Mid-size and larger houses should have a courtyard at the centre of the house.

8.4 Limitations

This thesis was limited to testing five homes since these were the only *Vaastushastra* compliant homes that would allow for data to be collected from their homes (as discussed in chapter 3). It was difficult to find homes that complied with all the principles of *Vaastushastra* because homes are owned by typically owned by Emirati's who don't believe in these principles and are rented by expatriates off which many Indians believe in them. The policies have changed, and expatriates can now own their own homes, so more Indians are building homes that are compliant with the principles of *Vaastushastra*. Using a larger sample of villas would have created more data and would have reinforced the findings of the thesis.

Each of these homes was only used to gather temperature and humidity data. Further investigation can be carried out by monitoring natural light, sound and odour levels to understand the correlation with the other senses. Temperature and humidity loggers were available, but due to lack of funds the other monitoring devices were not available. Data gathered from these tests might help understand the principles of *Vaastushastra* further as the data can link back to aspects of the rules.

Another limitation was that since the temperature in Dubai is above 40°C in the summer it was not possible to conduct temperatures studies from the houses without the use of air-conditioning. The house could not be vacant during the study because it was important to know how comfortable the occupants felt when they were using the house. Temperature data collected from the house is compared with the occupants' reactions of whether they feel comfortable in the house or not. Measuring an empty house would provide temperature data but not data an understanding about the comfort aspects of the house. Due to limited time and resources this thesis was limited in the selection of the case studies.

8.5 Recommendations

The recommendations made from this thesis are as follows-

The principles of *Vaastushastra* should be introduced at concept design stage, so that they can be incorporated from into the design of the house rather than added onto the design later. Factors from the site determine how the rules will be applied to the house in terms of form of the house, its orientation, placement of windows, proportions of the rooms and shading devices on openings. The functions within the house should be organized such that spaces that are used the most are located on the cooler side of the house which is the north, north east and east of the house. At this stage simulation software can be used to test the conditions of proposed designs to work out which one creates a comfortable environment.

For homes that have been constructed some principles of *Vaastushastra* can be added on to modify and increase comfort of the internal spaces. Orientation and opening sizes of windows can be changed, which would prevent direct heat gain in the internal spaces. Shading devices can be added on the existing windows, these could be architectural structures such as shades or pergolas or landscape elements such us trees. Additional light can be added in the space through adding skylights where possible or sun pipes which can be added in the existing slabs. Orientation of the homes can’t be changed because that would mean the whole house would have to be reconstructed which is not a suggested solution.

Vaastushastra was traditionally followed by Indians and presently since Indians live in many parts of the world there is an awareness of the study amongst non-Indians. Many people are interested in following this vernacular belief even though it is popularly understood as mysticism. Through this study a link between *Vaastushastra* and comfort levels in homes has been established. This study shown that if more residential spaces are made using these principles, homes can be comfortable for the users’ experience.

8.6 Future Research

This research could be continued to investigate other types of housing such as row homes, apartment buildings and individual apartment layouts. Large apartment complexes could be studied to understand if apartments on the north side are cooler than those one the south side and to see if apartments on all four sides would have different temperatures recorded, similar to the individual homes. Depending on the size of the apartment a study into apartments could help to understand which size of apartment starts to record different temperatures on different sides of the apartment.

Another aspect that can be investigated is the comfort created in residences that are different in scale, either larger or smaller scale, to understand if the same principles have the same impact. Individual rooms can be studied in detail to examine all the fours senses together and to map out in detail the comfort levels individuals experience in the space.

Vaastushastra is the ancient study of architecture and cover all aspects from urban planning to city planning to designing various types of buildings. Other aspect of research could be to investigate the application of the principles to office towers, health care facilities, retail spaces and other such non-residential spaces. The recommended size and shape of building and other principles change based on its use. Application of *Vaastushastra* principles can be used to understand if the users comfort levels are dependant on the design features.

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Appendix - Questionnaire

- The year your house was built/ when you started living in the house ___________
- Area of house _______________________m^2
- Location of house?
  a. Urban b. Suburban
- How many residents ___________________
- People present during the measurements ____________
- Is the house raised form ground level?
  a. Yes b. No
- Cooled by central air-condition?
  a. Yes b. No
- Cooled by individual air-condition for each space?
  a. Yes b. No
- Cooled by ceiling fan?
  a. Yes b. No
- Cooled by table/ floor fan?
  a. Yes b. No
- Are there openable windows in the house?
  a. Yes b. No
- Number of carpeted room __________________
- Percentage of furniture < 3 years old _________________
- Percentage of furniture covered in textile _______________
- Number of carpeted rooms _____________________
- Frequency of vacuuming per week ________________
- Do you hear city traffic?
  a. Yes b. No

- Which spaces are occupied the most in the house? ____

- Which spaces are occupied the least in the house? ____

- Which spaces are rarely occupied in the house? ____

- Problems with lighting?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with noise?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with high temperature?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with low temperature?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with air/ bad smell?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with unpleasant smells?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with static electricity?
  a. Often b. Sometimes c. Rarely d. Never

- Problems with humidity in the house?
  a. Often b. Sometimes c. Rarely d. Never

- Number of pets in the house? ________________________

- Type of pets _________________________

- How often do you switch on lights during the day (summer)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you switch on lights during the day (winter)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use air conditioning (summer)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use air conditioning (winter)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use fans (summer)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use fans (winter)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you open the widows to cool the house (summer)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you open the widows to cool the house (winter)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you experience noise when you open the windows?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you close the curtains of your house (summer)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you close the curtains of your house (winter)?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you close the curtains of your house to reduce noise level from outside?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use air fresheners in the house?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use your garden space for sitting?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use your garden space for exercise?
  a. Often b. Sometimes c. Rarely d. Never

- How often do you use your garden space for walks?
  a. Often b. Sometimes c. Rarely d. Never

Any other comments

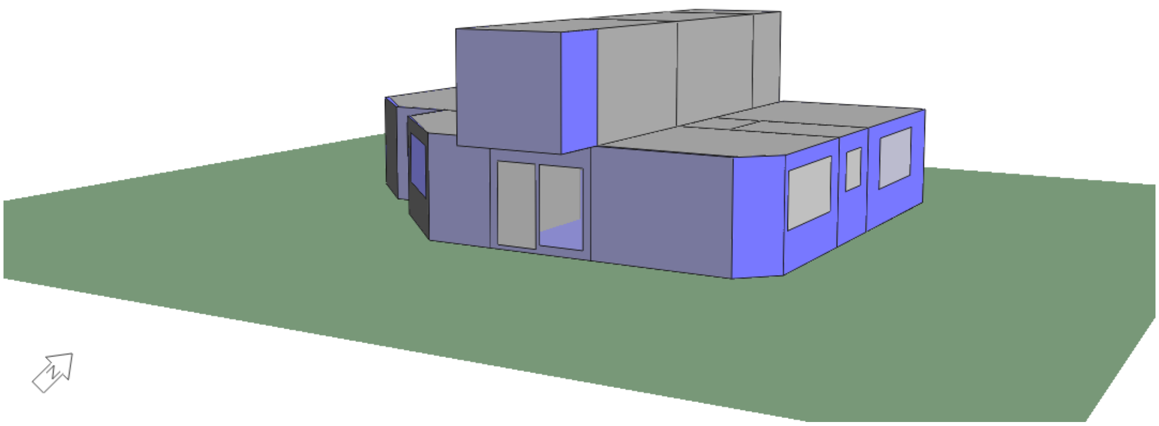
____

____

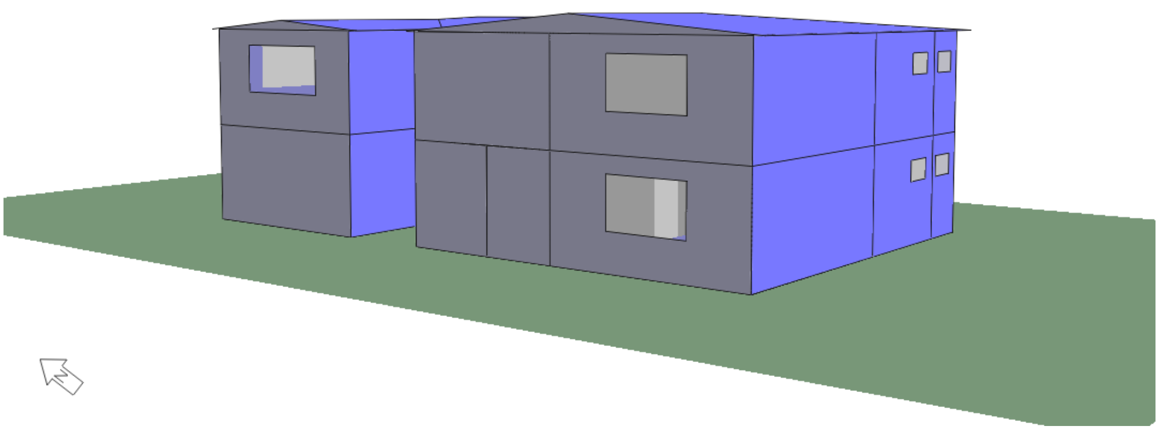
____

Appendix -IES software views

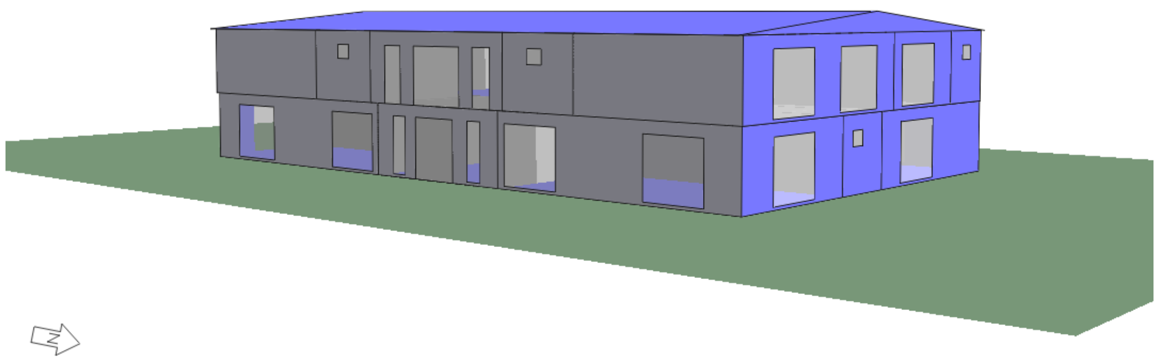
Case Study 1



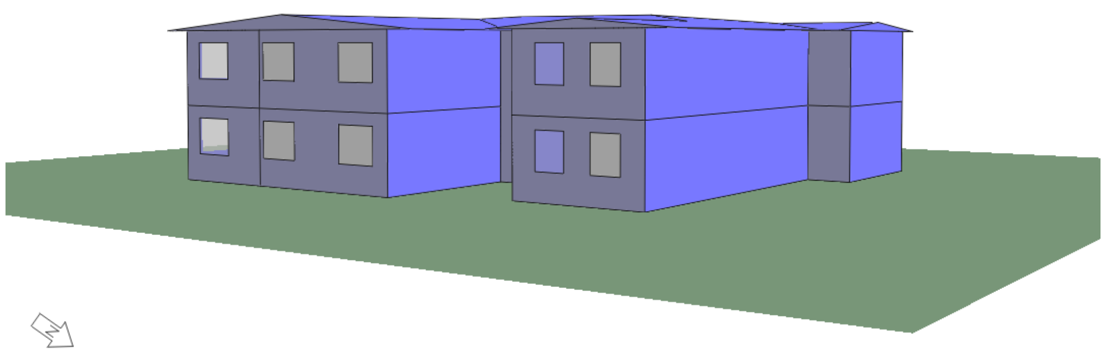
Case study 2



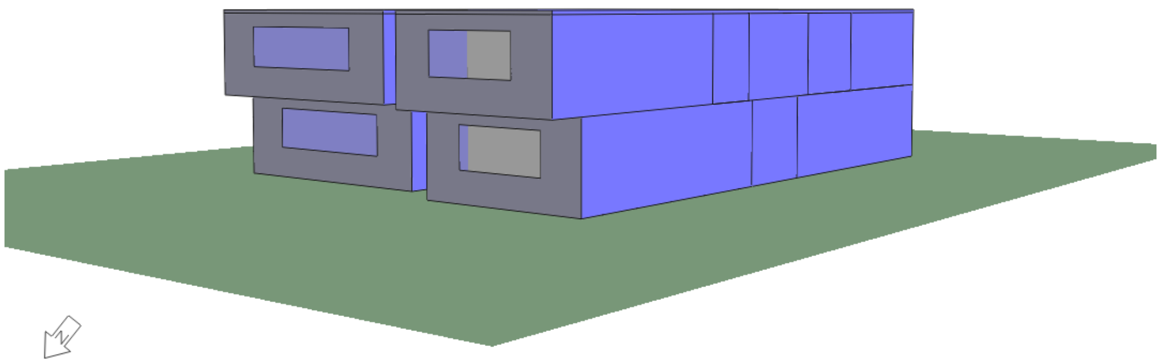
Case study 3



Case study 4



Case study 5



Appendix- Interview with Dr. Atchun

MK – Could you differentiate between the scientific aspects and the mysticism of Vastu?

Dr. Atchun- *Vastu Vidya* is projected as something mystic, which is totally wrong. It's pure evolved architecture of India. [There are] a lot of connections with architecture, especially in the Middle East and Far East. As we have borrowed quiet a lot from Persians, Persians especially. Persian influence can be seen, later days the Mugal, during the Mugal days especially and Buddisht influence from Tibet and this has spread to Indonesia, Thailand, Sri Lanka, all the places. So it's only an evolved traditional architecture. It's a systematic building science; it has got some kind of grammar [or] syntax. The basis of this is a theory of creation, which is part of Indian philosophy. It is called *Sankhya* philosophy (theory of creation). The cosmic energy is called *Purusha*. It's a union with *prakruti* (*prakruti* is the nature). It is the union of *Purusha* and *prakruti* is the beginning of creation. So here, land is considered part of *prakruti* (nature), where the energy, you have put in the energy and converting into a habitable place. Also as a part of the philosophy when you have a building you first laid the stone, that is the foundation. Foundation is considered to be -you are laying the seed in the womb of the earth and that stone step by step becomes a full person. House is considered to be a full person, which is created out of the seed, laid by the energy. This is the basic philosophy. It has three levels of operation. In the ancient days there were not many scientists, I'll call them scientists. So ordinary people cannot go and consult a scientist, as they can now, they can consult an architect, engineer, builder, but those days these people were rare. They are called *Stapati*, who is the master builder, they were far and wide apart, everybody cannot have access to them. So they usually evolved a code, a code of practice, which is followed by the artisans, strictly. An artisan cannot tamper with the code, a *Stapati* can. That's what makes the, what is called as mysticism, they say that this cannot be altered. It can be altered by a knowledgeable person. A pharmacist cannot change the prescription of a doctor. If that medicine is not available, you go to the doctor; the doctor will prescribe an alternate medicine. A pharmacist or a compounder cannot change the prescription. Similarly, a carpenter, an artisan cannot change. Now the people say that this cannot be altered. So, almost all the people who are practicing *Vastu Vidya* are operating at the lowest level of the artisan, not the architect. The second level after the operational, artisans' level-second level is that of creating a theory, *Sydantha*, (theorization). Where, depending upon the climate/ climatical changes, changes in the building material availability, all those things, all the variables they take into consideration and evolve theories of construction, building science. Third is what I first said, the philosophical level of considering this as something sublime. Three levels are there, actually, the first and second levels are important as far as construction is concerned. [At] the second level, where it is considered as a science, continually evolving according to space and time; as a practice here will not be the same as a practice elsewhere. For example we have copious rains, so in Kerala we have slopping roofs, were as in Rajasthan you can have flat roof. But here in Kerala they say, only if it is sloping roof it will be Vastu, otherwise it will not be Vastu. It is not correct.

It was an international class, where we had people from the Unites States, New Zealand and Australia, the entire spectrum was there, [even people] from Japan. So there I learned quite a lot, because their practices, especially from Poland, the traditional gypsy, Romanesque and Baroque traditions. There was a girl from Iran. We have a lot of things in common between Iran, that's why I said Persian influence. So in India, a particular stream was developed according to the climate, even here, in South India and North India there may be slight differences, so it developed accordingly [with] space and time. According to space there are space variations and the time goes on, there are time variations. And now, because of its flexibility, in India almost all the so called pundits, the scholars, they say that evolution stopped in the 15th Century. Evolution cannot stop then it is not dynamic evolution, its static evolution. So 15th Century, most of the books were written in the 14th and 15th Century, before that it was mostly in the form of Vedas, part of religious things [text]. But pure architecture, Vastu Vidya was written, textbooks, several textbooks, about 330 odd have been listed by, I forgot the name, a scholar in Calcutta, of which at least 5 or 6 are very popular. Rajvallah? I think is in Rajasthan and Gujrat. Here we follow mostly what is called the *Manushalaya Chandrika* and *Mayamatam*; *Mayamatam* mostly in Tamil Nadu, *Manasara* in Bihar, Madhya Pradesh and such places. There is something else in Assam and you can find differences according to space and time, differences will be there. So there, what we are trying to follow is a certain grammar, that is you do this first, you do this first, you do this first, it's a systematic way of building up, schematic way of putting up a building, [the] building maybe anything. The said building, Vastu, need not be [a] house; it is where any living being stays permanently or even temporarily, because this chair is a Vastu because we are remaining here for a few minutes or a few hours. The train that I came is a Vastu because I have been in it for 1 day. All these are Vastu, even a platform that you build around a banyan tree, to protect it is a Vastu because it is something to protect the banyan tree that [is the] broad definition of Vastu. For all these there are certain procedures. The whole cosmos of the world is considered to be, I mean just as you can see that you can see the sun, in a drop of water or a mirror, it is reflected there. The whole *Prakriti* , which is nature, is represented if you take a small plot of land and that plot, where it is taken is divided into several aspects, East, North etc. different spaces and converted, mostly it is converted into a grid and each grid, or a groups of grids, is assigned to a certain forces. So one grid is for sun god, one grid is for so called Indira, who was the god of heavens. So here some sort of mysticism comes in, and certain qualities are assigned to these grids.

MK - Are we still talking theory here or we moving on to mysticism?

Dr. Atchun - Mysticism, [in the sense] that is how it has been built up, on the basis of that the mysticism has been developed.

MK - as soon as you introduce a deity then there's…you're departing from space ….

Dr. Atchun- The quality of the deity is the spot is ascribed to this [deity]. Actually both are intermingled, mixed. Mysticism and reality are mixed, cannot fully separate it. Usually you follow [a] dimension system, cause size, shape and even orientation has got a value. The direction of the building, size and shape, of course we know. For building size, follow octal system, not decimal system. Octal system is followed because; in the ground it is easier than decimal system. Most of the calculations are based on octal system. Because if you are measuring a particular distance and if you want to take half the measure, you are doing it with a cord and you don't have a scale, what do you do? If it is a rope you can fold into two, again fold it into two and again fold it into two and you get one eighth. And that practice, that is why octal system. Octal system is followed in traditional Indian Vastu. Now it has been converted into SI system. Our calculations are done in octal systems and converted into SI system, that's what is being done now it's a practice. And then certain shapes, for example circle is the most perfect shape, the square is the next one and then all regular polygons are considered to be perfect. Irregular ones [shapes] are not considered, rectangle is not perfect.

MK - What about the third dimension?

Third dimension I will come [to]. So, as far as two dimensional shapes [are] concerned, certain shapes are considered sacred and important. As far as sacred building, temples and things like that only these shapes can be followed cannot have irregular shapes for them. Regarding the third dimension the world is considered to be an octahedron, a square, on that a pyramid at the top and a pyramid at the bottom, octahedron with eight faces. So in height zoning, if you take a village or a town or a city, for example, the central portion, you can have higher buildings, when you go to the sides you can have lower buildings. Because it should be confined within this octahedron, who's height will be a diagonal of the square, that's the property of octahedron. So heights are generally limited, if you want to go higher, you must have a bigger plot in which is it being put up, for example, the Brihadeeswarar Temple, its set up in a large plot that it can have any heights. And regarding the two dimensional planning, centre of the……. The central portion is generally not built up for ordinary buildings, but it can be built up as far as important buildings like town hall or things, public buildings and sacred buildings. This is considered to be the building in the hatched, shaded area is considered to be the building area. Even when you take a plot that is how they [determine the height]; the building that we saw yesterday, which has four different main [courtyards] and a central courtyard [is an example].

MK - Can a house be extended by repeating the grid?

Dr. Atchun -Yes, sure it can be repeated. So we have this will be repeated on this side and this will be repeated on this side and five different courtyards. It can be two, it can be three it can be four or five.

MK - When the house has two courtyards, the evaluation should be two squares joining each other?

Dr. Atchun - Yes, in Kottakkal we proposed it today, that is two [is to] one, with eight sheds, eight halls. (Dr. Atchun points to the two halls in plan). It is typical two courtyard house. A larger one, Tamil Nadu Chettinad, they are mostly three or four courtyard houses. Even Jodhpur palace two courtyard are there, if I remember correctly. That palace, part of it is converted now to a hotel.

MK - If my observation is correct, you are showing nine modules.

Yes, the whole structure is divided into grids and the important lines of the grid, central lines, diagonals and things like that, when they meet each other those point… the concept of the grid is that. When the plan is laid out the field and when you want to alter it a little, modifications or alterations, we didn't have drawings at that time, probably Palmyra leaves and things like that. So you have to again lay out the plan on the grid in the field. So if you want to lay down the structure strength, the measurement will be written somewhere or it will be based on the *Stapati*, so he will say, to find out exactly what it is and how to extend it, he will have to just [use the] major axis, he will have to stretch this thing. And the junction points of those major axis, if there is a structure there you cannot stretch it, if there is a pillar or a wall, so those will be left free. When you build, it will either be left free or there may be an opening - a window or a door or something like that. These are further details into how the space is being treated systematically so that the buildings are always restricted to certain bases only; you are not free to put up anything everywhere. Some restrictions are there. But as far as small plots are concerned the major restriction they say is that the centre of the building and centre of the plot should not coincide, it should be shifted to one side, because, probably what we have developed is centre is the most important place, where the centre of the land and centre of the building, two entities cannot occupy a single seat. I cannot occupy your chair so long as you are sitting there. That is a very crude way of explaining it, of course. There are certain things we are not able to explain even now, we have tried to explain most of these so called mysticism in our books, most of it. Some of them we are not able to explain. Then regarding orientation, even this dimension, this is more or less same as Da Vinci's Universal man, where height is equal to breadth and this is divided into eight and this is again divided into eight and it goes on like that. And these subdivisions probably will be like this, these are subtleties.

MK - So if this were the owner of the property, then?

Dr. Atchun - Yes, but now we standardize.

MK - So, in theory there should be a scale for the owner.

Dr. Atchun - It is called Purshaparma. But now we cannot have different scales, we must have only one standard scale. So this is standardized now, in practice it is standardized. Height is generally considered 192cm, even though India probably in Punjab and Kashmir you have the tall people, but 192cm is considered to be the standard height.

MK - So when was that scale accepted? Was there a definitive moment in history?

Dr. Atchun - Actually that is what we did. I was associated with the National Institute of Technology, by that time I had retired and my students became the professor of architectural engineering there. So he had sent several student colleagues around Kerala and Tamil Nadu and asked them to measure the yard sticks followed by the carpenters in all these places. Say about 90 or 100, around 100 of famous carpenters of Tamil Nadu, they measured and we standardized this statistically and came to a common statistical average of the yardstick, not their height and that was near this 192 [cm], that's how we came to this 192 [cm]. Advantage of 192 it is easily divided by 8. This is our elementary text for, we conducted special classes early, for them we wrote a book. This is a book written for our students.

Purusha, is supposed to be lying like this. Again, another concept is, for a human being, most important place is head. So if you are building a house or any other thing, most important thing, what you think is the most important thing should be placed here. Example, I am a professor, my library is the most important thing for me, so I will place my [library here], my wife will say, my place is in the kitchen so kitchen should be here. Businessman will put his wealth there and of course that is our interpretation. Depending upon the scripts, certain functions are assigned to certain portions. Again, they are according to what you perceive.

MK - So how does this allow for something practical, like say a kitchen? Where would you decide the kitchen should go?

Dr. Atchun - Kitchen should be, see! Old Indian custom, most important function of a householder, (householder means a person), is to feed others, it is considered to be the most important function and most holy function of a person who is living in a family. So for him the feeding place and the kitchen are connected and that should be placed here. That's why they say that Northeast there should be kitchen, but in several places Tamil Nadu for example they follow Southeast because Southeast concerned with the place of fire, *Aagni*. South is generally associated to be inauspicious, so it should not be South, it should be Southeast. So in Kerala temples, you see the kitchen here. There are variations from locality to locality.

MK - Is it not a rigid rule?

Dr. Atchun - It can't be, because you can't fight over it, because Tamilians and Keralites fight over it.

MK - Just to finish on the mysticism level-

Dr. Atchun - Mysticism again is built up on the concept of *Purusha* and *Prakiti* and ascribing qualities to the spaces based upon the grid division, also the limitations of lower level practitioners, who do not have the knowledge to modify. Some of them are practical ones. See, you are not to follow the code [blindly]. Even old economics theories, they say that if you don't do this, your head will be blown off, or your wife will become impure. So that you will do it, it's a threat. Tell you one simple thing. It's a restriction that your front door should be of a single type of wood, do not use combination woods. Those days, two shutters closed together and they are secured by two fasteners like this (shows image). So if you use different types of woods, then there will be proportionate shrinking and there will be some cracks through which you can put a knife like this and probably open the sliders. So that they say that, (probably, this is our interpretation) if you have door of different wood, your family will be impure, cause somebody will come and attack your personal family, so you should not have it. Instead of saying this, wood science, they will say it the other way, so many of these things have crept into it- beliefs. And that depends again on the locality. From place to place, it will defer, they don't have much meaning, actually. From place to place it will defer, mysticism and superstitions, you can't call it superstitions. Probably some of them are, as I said, they are based on science.

MK- What are the prescribed setbacks in Vastu?

Dr. Atchun- The larger your plot the setback will be more, in architecture. Today it is said that it should be 2 meters [or] 3 meters, whether you have a large building, large plot or a small plot. But then, small plots can have smaller setbacks, large plots can have larger setbacks and they have a procedure by which in whatever way you build it if you build it according to this one, the building are will not exceed 50% of the plot area, ground coverage will always be 50% or less, which is generally prescribed in most of the towns, usually 50% sometimes 60%. Now, Kerala it is 60% because of pressure of land. Instead of prescribing it as 50% you say a certain rules and therefore you will never dare to exceed 50%, because if it exceeds 50% your son will be in danger. So that is mysticism.

MK - Are there any examples in history of how things can go wrong and a house may have been built using to many variations in the formulae and something dreadful has happened, you know, a fire has started or whatever. Do they rationalize it through mysticism, or through – level one – you haven't built it correctly?

Dr. Atchun - In a limited manner we have tried to investigate this, by going to certain buildings. But no conclusive proof has been established. So, as far as we are concerned, we do not agree. You cannot scientifically establish this; it can be an accident or a coincidence. This temple that you saw, the large one, it's not complete even now, the compound wall. I don't know the reason. I think it was ruined by Tipu, but it has not been renovated. I don't know, because I don't deal with mysticism too much. I can't explain that. Also they say that Delhi is a city of tombs, so many memorials and tombs. So, my professor of architecture used to say that Delhi is a doom city. You cannot build in a burial ground, it's a burial ground. There is always trouble in Delhi. You can say that [it is linked], but I don't say that.

MK - we make mistakes in history and you can sometimes have real disasters for our buildings, especially high rise buildings, for example. This is how building codes get re-examined and improved. You either learn from mistakes, like, how does fire travel vertically, break through into sections, so on and so forth. So they devise all sorts of systems, to try and protect against that, relatively rapidly in the last 100 years or so. But Vastu, on the other hand, has been around for such a long time. Could it be analysed as a building code system/ a development system?

Dr. Atchun – Yes

MK – Does it [Vastu] allow for introduction for new systems and material? Or is it a fairly rigid system peculiar to the region?

Dr. Atchun- Yes, definitely, because as I said, according to space and time it is always developing. The original Vastu text speak of thatched roofs, tiled roofs and things like that, whereas now thatched roof Vastu cannot be accepted for tile roof , or flat roof cannot be used for flat roofs. It is nothing like that. I will tell you one typical example- India, generally was following the post and lintel system, till the Persian invasion were arches, domes and vaults, only after the invasion of Alexander. Except in South [India], deep South, that is Kerala and Karnataka, where we have the space frame. This sloping roof is a space frame, which is connected by so many small members, connected to a space frame. So when the arch came, North India readily accepted because it is a superior mode of construction, much superior than post and lintel, it can have larger spans and things like that, whereas in South India, especially in Kerala and the coastal Karnataka, they did not accept. It came only after the Portuguese. Till the 15th Century, it did not enter Kerala and Karnataka that is arch and lintel system, because space frame is a far more better technology even the arches. So, when the new technology comes, it can be adapted into Vastu practise. Now we have so many types of roofing, structural systems. Our central theme is that develops and it evolves and it continues to evolve.

MK- can you explain the association of the elements with the specific directions?

Dr. Atchun – only the sun I can explain, other things I can't explain.

MK- does this association change based on where we go?

Dr. Atchun- No – that is mostly stagnant throughout India

MK- because there is another book that I read that says, based on the location, this mandala rotates, so it mirrors itself. Water and fire elements are interchanged, but I don't know if that is actually written

Dr. Atchun- I have not come across that. Only directions. For example in Hariyana, in a temple, the deity was facing Southeast, usually except the four cardinal directions, the deity should not face any other direction- that is a general rule of temple construction. So, the priest explained to me that in Hariyana the sun is always on the South, not on the East, South of East, which is Southeast, so it is facing the sun. The deity has to face the sun.

MK- Can Vastu be applied outside of India, as it is?

Dr. Atchun- that question was asked by a New Zealander. In southern hemisphere what will happen? We have worked together but not come to a conclusion. But, Northern hemisphere, the lady from Iran, Poland, they all said their old gypsy rules, or even China. China they have a courtyard house, which is very similar to our courtyard house.

Appendix- Interview with Dr Padmaja Yadav

MK. Could you differentiate between the scientific aspects and the mysticism of Vastu?

Padmaja- In my opinion and experience, I feel Vastu is more a science, but because it is not as well known or probably the finer details of the science are not really known- so it is actually… people probably regard it more as mystic because of the awareness towards Vastu. I mean, if I have to say, I would say Vastu is actually more of science and less of mysticism.

MK what are your thoughts behind saying that it is more science than mysticism?

Padmaja – the principles of Vastu, when you try to look deeper into them, you realize that it is an absolutely environment friendly science. Basically the principles of Vastu are only working towards one thing and that is conserving the energies, or what in today's world everyone is trying to do- save earth, save our planet. So Vastu is actually indirectly only working towards that, though at a smaller level. But, when you try to understand it that is when you realize that it is actually something that people are working towards now. So the principles are totally in sync with the environment and nature and whatever we are advised to practice in these days.

MK can you give any example to illustrate this?

Padmaja – yes, the biggest example in today's time for me, I would say, where people can actually relate to Vastu as a science are the five elements that is one of the pillars of Vastu, when you are trying to understand the Vastu or analyse the property on the basis of Vastu. Five elements of life- that is how it is called – these are fire, earth, air, water and space. Now when we look at it from a scientific point of view, Earth is the only planet which has life on it, none of the other planets have life, or at least it's not been proven. So this is a planet which is friendly for human life, or survival of human life. Now when you look at these five elements, they are present on Earth in correct balance, in the right proportion with respect to each other. So, when we look at these five elements, how do these five elements actually play a very important role when it comes to Earth? Biggest example in today's time is global warming. What is global warming? Simply it's an absolute imbalance in these five elements, which is creating so much of havoc. I mean talk of life on Earth, simple thing – depletion of ozone layer, it's an imbalance in the space element, and because of this depletion of ozone layer there are harmful radiations which are entering our planet. Because of which there are change in temperatures all over the world, there are unexpected weather changes, and this is nothing but an imbalance of the fire element. The water level rise on our planet is nothing but an imbalance in water element. Pollution, which is of course created by us, is nothing but an imbalance in air element. And then so many natural disasters that occur these days, is nothing but an imbalance in earth element. So if an imbalance in these five elements at such a big level can make life difficult for human beings on earth, so when we try to consume these five elements at a much smaller level, within a property, we are only trying to save the energy. So this is, I think, one of the biggest links where I could say that- yes, Vastu is a science. Unfortunately it's not really been translated well, because of which the mysticism aspect is attached to it.

MK. What do you mean when you talk about the elements and the energies from the elements?

Padmaja - yes, energy or the 'feel good factor' that is created within a space, which every individual can identify with. So that is what energy is for me.

MK Do any of these energies convert into measurable energies?

Padmaja- they do translate into something measurable over a period of time. But if it is about an immediate understanding of those energies, it is more to do with an individual understanding or realizing a space that just by adding a fire element a person has become more energetic, or a person has become more aggressive, based upon how the element is used. Because every element, depending on how it is used, has a positive side to it and a negative side to it, but over a period of time you can definitely see the change in behaviour of a person. So that is where the tangible bit comes in that over a period of time, because it is not something that you can immediately measure. But, I mean it could be something as quick as 24 hours.

MK One aspect of Vastu which we can link to sustainability is using local materials. So what are the local materials that you can link to Vastu in India and UAE?

Padmaja – I guess again, you know the kind of materials you use for construction is completely dependent on the environmental conditions, like even if I talk of India, up north there are extreme winters, if I talk down south it's a tropical climate. Or any other part of the world, if you go to Japan, where there are a lot of earthquakes, people build houses in wood, so that even if they demolish they are easier to construct. If we come to the Middle Eastern part, you know sandstorms are very high, the temperatures are very high. Sand is the…. and obviously because Middle East is where you can't grow anything because of its weather. So, the best is, whatever you have, that is sand which they have ample off, to build your architecture based on something related to sand which comes very naturally in this part of the world. So the materials used change from one place to another depending upon – one the natural resources and two the weather conditions there.

MK. So what are the materials you would recommend to use in Dubai or the Middle East?

Padmaja – sand would be the biggest contributor and then of course, you would need to get more detail into it from a scientific approach, to create a stronger base. Probably an engineer or somebody with knowledge of that bit would be able to create something, or probably they are using it. But yes, the main contributor for me would be sand.

MK. So what about concrete? While concrete has a sand element, there are two schools of thought- some say it's sustainable and some say it's not. Would you say concrete is a recommended building material?

Padmaja –see again, probably using concrete I wouldn't say that ok its outright rejected kind of thing, because again, for a place like this where we don't get a lot of natural disasters like earthquakes etc., probably it wouldn't be a bad decision to use it, based on again the environmental conditions and the history of this place till now. So, it could be, depending again on how environmentally friendly it is.

MK - A lot of people say that because of the use of water concrete is not sustainable. The counter argument being that you can reuse it, so then you can make it …

Padmaja – yes, so the whole idea of sustainability is about reusing. So, it again as I said it depends based on, probably the content of the concrete, I'm sure there would be different proportions and ratios again with respect to when they are laying of the concrete, the land here is obviously initially very soft. So I think there a lot of things that it does depend on. So to outright say it's bad or good, I don't think it's fair.

MK – It's a matter of further investigations. The idea behind my research is to find the comfort aspect of applying Vastu into contemporary designs. So there are things that we understand, like daylight, if we don't have enough natural light coming to your house for example, you are going to get depressed, your stress levels will increase, these are measureable and these have been studied. Which are the tangible factors of Vastu, according to you which have an impact on the way a person feels while they are using a space?

Padmaja – of course natural light, ventilation or circulation of air which makes a big impact on, I would say human subconscious mind. These are the biggest aspects, which are more related to direction. Then of course comes in the elements and one of the biggest ways of these elements I would say is colours which again scientifically have been proven that they have a strong impact on human subconscious mind in terms of changing the way, if not changing at least fine tuning the way an individual thinks are reacts in a particular situation. I would give a lot of importance to elements in addition to sunlight and air.

MK. Ideally, according to you, which element should be placed where?

Padmaja – so the zoning of elements. Ideally if I have to look into the distribution of elements with respect to the space, north or northeast goes to water element, again there are scientific reasons for that, south would go for fire element, west would go for air element, south west would go for earth and center would go to space.

MK why do you make this association? You mentioned that there is a scientific explanation?

Padmaja – for example when we say water – the morning sun, because it rises from the east/ northeast, there is a slight tilt in the earth because of which it's actually more towards northeast. Morning sun has beneficial UV radiation, again scientists have proven, colour therapists which is a science by itself that when this beneficial UV radiation passes through water the water gets energised which is further used for treatment as per colour therapy. Even if you go by ancient Indian practices, they would place water in a copper vessel and keep it in the northeast and they would drink the water first thing in the morning, because with the morning rays of sun the water has been energised by copper which is a very good conductor of energy. So the water was very well towards the north, northeast, east or rather towards a direction where there is morning sun falling in. Again as the sun in moving, as it comes towards south which is the fire element, or as per Vastu we say southeast is an ideal kitchen, the infrared radiation which are also hottest, during the sun cycle, is in south southeast, which makes it a very good zone for fire or kitchen for that matter and west with air because of the north-westerly winds. This is a science because of the winds that are found in India. So with respect to the north-westerly winds that is if the kitchen is in the northwest, which is an option that can be considered. So because of the flow of the wind direction, it is something which supports fire, if required. Based on a lot of these understandings these elements have been spaced out. There could be a certain variation in placement from here to there, but it will not change drastically with respect to direction.

MK. Why do we place space in the centre?

Padmaja- this is because is the spot within any property- what we call as Bramhasthan in Vastu, where the energy is circulating from that the central focus point. Now again, I would relate it to human body, when a child is born its only point of contact is the naval. The naval is the centre of the human body again. The cord which connects the child with the mother is the only point of contact. The moment that cord is pressed or rather it's not given the amount of space required the child may not survive. Similarly the Bramhasthan of a property is associated with space because you need to keep it open; you need to create space there for the energies to circulate properly. The moment you supress it with anything from a furniture to a load bearing column you are actually supressing the connect between the property and the energy flows which can further lead into issues like stress and frustrations.

MK. So there are various stages at which Vastu can be applied, you can start from scratch or you can have it adapted later. How much flexibility do you adapt in either?

Padmaja – see if you apply it right from scratch, it is very simple to apply. I would say it is actually as simple as making your design and putting them forward. But when it is already there, then sometimes applying can get a little difficult, depending on the flaws that are existing in the property. If it's a major flaw then probably yes, it is difficult to apply then the course of treatment becomes a little bit longer and complicated. But if it is simple then probably just a change here and there, placing an element here and there could make the difference.

MK. What are your approaches for designing independent homes and apartments in high rise buildings?

Padmaja- in a villa, environmental factors play a very important role, because a villa is generally open from all four sides, if not four sides definitely three sides which is giving a lot of exposure to the environment. So obviously the environment factors there are much stronger. But when it's an apartment the exposure could probably be two sides or even three sides. But what is happening is the direct link with earth makes a lot of difference in terms of creating a certain channel for flow of energies. For example, if one is living in an apartment, I would say the higher you go, the environmental flaws are not bothering you as much. But if you are at a lower level, then the environmental factors play a strong role. For example let's say – I live in a villa and my neighbourhood plot is empty. One fine day my neighbours come and they want to build a villa so obviously they start with extraction and excavation of the plot etc. which means when they are doing that they are actually disturbing energies within the neighbourhood. So when there is an excavation happening in my neighbourhood obviously the energies surrounding the plot are immediately getting disturbed or there is a certain change in wavelength. That disturbance is coming to my villa as well and disturbing the flow of energies within my property. But if a similar thing happens if I'm living on let's say a 25th floor or 30th floor and my neighbourhood plot there is some excavation happening or some construction on let's say some school is coming up or anything. There is a certain disturbance of energies but that is not coming up to as high as the 25th or 30th level. So the disturbance of environmental factors reduces the higher I go. It is there in an immediate environment when it comes to villas. So the chances of energies getting disturbed at the drop of a hat are much higher for a villa than for an apartment- the higher you go the better.

MK – So one of the basic rules of Vastu is that you can't go beyond a certain height. But then you are saying the higher you go the better. Please explain.

Padmaja- again Vastu is a science which is more to do with the environment. In today's time when we talk off multi-stories, yes it is fair enough to stay closer to the earth because that way you are connected to earth. But with times changing and so much of construction is happening and different kinds of construction happening, different techniques of construction happening there is a constant disturbance of energies within the environment. So the safest bet in such situation is to go high so that at least you are not disturbed by that. Else even if you are living in a Vastu compliant property but if you're immediate neighbourhood is undergoing disturbance it is bound to affect you. So that is a change with time.

If you look at behaviour patterns of animals that are living in high rise residential buildings there is a higher tendency for these animals to commit suicide. We can't be sure if this is suicide or a slip.

Padmaja- I will definitely add a point to it. When we talk of animals and animal instincts- animal instinct is much stronger than human instincts. This is again something which has been scientifically proven, for example if there is a natural disaster, animals- be it birds or land creatures they all are aware of a storm or an earthquake coming. So they are more susceptible to the environmental flaws much more than human beings. So they reacting in a different manner at a higher level or a lower level have to do with the environmental disturbance of energies. As I said if you are living on the 25^{th} floor, probably you wouldn't get disturbed. But there is some bit of disturbance coming up to that level. It is not as much as it would be if you are on the first or second floor. So that disturbance probably the animals are reacting to it which we can't even sense.

MK. So many people believe that the higher you go you lose the connection with earth and since the five elements are important, it is important to stay connected with all five elements. Unless you kind a way to compensate or mimic the earth element.

Padmaja- by disconnecting earth you cannot survive and so you have to find a way of connecting with earth in a very natural manner because sometimes there is no choice but to do it. So if you have no choice does that mean you give up? We still have to live and if we still have to live, we have to live in a way that is more comfortable to you. Not everybody can afford a villa, so does that mean if you can't afford a villa you don't live a good life? Vastu is all about human convenience. It is a science which is designed only to make your life better. So there are other ways to look at it. So you need to recreate the element. Of course the recreated element is not a substitute for the natural element. But, I would say it's a poorer cousin.

MK How would we recreate an element?

Padmaja- colour being the strongest aspect then there are paintings, pictures, some kind of visual displays, wall murals. And then of course there are other things when I say colour I think most of the things are taken care off, be it furnishing or interiors. So these are some of the biggest aspects where I can kind of try to recreate a certain element for a certain impact.

MK– Anything else you would like to add?

Padmaja- With respect to?

MK – we can look at Vastu as a low tech sustainable solution and then create awareness around that. Because there are potentially 1 billion followers of Vastu and if it is followed correctly we are developing a sustainable community.

Padmaja- I would totally agree with what you have said- Vastu is all about sustainability. It's just that Vastu is term for sustainability or rather it's an alternative term for sustainability because Vastu is only talking about environment friendly community or an environment friendly property. It could be right scratch that is what kind of construction material you are using, how are you capturing the energies of the environment be it your sunlight, be it the rains, it could be anything, or the snow depending on which part of the world you are in. How you are capturing the best of what that environment has to offer you and how you are recreating those energies. So when you say solar or when you say wood, these are all with respect to the environment. So Vastu for me not about sustainability but Vastu is sustainability. Because Vastu is all about your environment, so it's nothing different from sustainability, for me- that's how I look at Vastu.

MK- So if we want to take this a step further. If we want to start incorporating modern technology – such as solar panels or anything like that…

Padmaja- Rain water harvesting..compost

MK- A lot of traditional houses, especially in Kerala do have rain water harvesting, because it was a part of the architecture.

Padmaja- See you would find this in Kerala because it is high on rains. But you wouldn't find it in Rajasthan or any other part of India where rains are not so high. So they have created a natural way of getting the water that they are getting from the environment to re-use it for their own sake. So it is nothing but Vastu and sustainability, or rather it is the same thing.

MK – How would you use something like solar panels? Do you think there is an optimum direction or something like that?

Padmaja- yes, southeast, as I said south. If you look at all the solar panels in general also they are mostly facing southeast because of the high amount of infrared radiation or the temperature being high at that point. So if you see they are all attracting energy from that side. And once you use solar panels your usage towards conserving energy. And especially in this part of the world, I think solar panels work very well because heat is something in great abundance here. So why not cash on it? I mean if you have got it as part of your environment or weather, the best is to make most of it.

MK – could you summarize what your thesis was about?

Padmaja- I have been fortunate enough to practice this outside India and I do get mixed feedback mixed response when it comes to Vastu. Because obviously living here there are many people who have not even heard about it. But then, they have ended up being my client by shear understanding of the science. Practicing here has taught me one thing, whatever we believe as principles it works. It's not something that you follow blindly; it's about applying those principles within a certain environment. If the flexibility is not there then Vastu for me is not a science and it is something only limited to India. But if I understand the principles of Vastu I realize it is not only for India and it is not related to any religion. It is about sustainability. Sustainability is about human life whichever part of the world you belong to doesn't matter. Therefore applying those principles with respect to wherever you are living, it actually makes a lot of difference. And living in this part of the world where Islam a religion which is followed very strongly. Trying to find a connection between both of them is something which has worked very well. Because this has also changed my outlook towards Vastu, probably if I hadn't practiced here, I would also look at it from a different point of view in terms of its applications in India. But practicing here has given me a completely different outlook and that is why when people say does it help? I point blank say yes it helps; there are no discussions on this. Discussion comes on how we apply it.

MK – your thesis was after 8 and a half years of practice and that's two years ago now. How has your understanding of Vastu come about?

Padmaja-my basic understanding of course when I learned it from my teacher, I learnt it in Gurgaon and I was lucky enough to follow a more of a one on one learning system, where I spent time with him for almost a year. I learnt from his experiences, he was quite an elderly gentleman. Then there was a lot of research that I did on my own. I haven't really followed any scriptures, but I have followed a lot of books here and there and collected my knowledge overall these years and just trying to practice and a lot of on-site research. Moving to this part of the world the on-site research is much higher than the knowledge of theory which is what I have accumulated. So there have been times when I have seen both of them contradicting so I that is where I realized that it is to do with the environment than just knowledge of theories, it's about translating it.