# An Analytical Study of Thermal Comfort in Syrian dwellings

A case study of a Social Housing Flat in Damascus

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## A case study of a Social Housing Flat in Damascus

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**Declaration**

No portion of the work referred to in this thesis has been submitted in support ofan application for another degree of qualification of this or any other university or other institute of learning. I hereby declare that this thesis entitled ‘An Analytical Study of Low Energy Social Hosing Design in Syria ‛represents the results of myown work except where specified in the thesis.

## Abstract

As a result of the Syrian conflict that began in 2011, individuals remaining in Syria face challenges in accessing energy services and struggle to cover their domestic energy expenses. Consequently, chronic electricity cuts have become commonplace in the country. This situation has left both low-income and middle-income groups unable to afford the costs associated with domestic energy, leading to fuel poverty. As a result, these households often have to prioritize other essential needs overachieving optimal levels of domestic comfort. In light of these circumstances, it is crucial to examine the environmental performance of the current Syrian model of social housing, where a significant number of middle- to low-income groups reside. This research project aims to investigate the factors influencing thermal comfort in social housing within the Syrian context, with a particular focus on bio-climatic design features that can help alleviate the burden of fuel costs for vulnerable groups who cannot afford conventional energy prices.

The thesis develops a socio-contextual understanding of building performance in social housing in Syria, focusing on climate, energy supply, and envelope characteristics. The research methods included a comprehensive climate analysis of Damascus, combining subjective methods (diary studies) and objective methods (environmental modeling). These methods were used to analyze the indoor environment of a case study flat in a social housing dwelling in Damascus and the thermal experience of its residents.

The thesis demonstrates that residents in Syria are significantly impacted by their indoor conditions, which directly and indirectly influence their spatial decision-making. Additionally, the study investigates how social drivers can directly affect residents' spatial decision-making, thereby indirectly shaping the thermal indoor environment in the dwelling. Finally, the study thoroughly discusses the limitations and provides recommendations for further research.

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# Chapter One

## 1. Introduction

## 1.1. Background- The Challenge

The long and challenging situation of power and fuel shortages over the last ten years in Syria has been one of the consequences of the dramatic infrastructure destruction due to the Syrian conflict, which started in 2011. Chronic electricity cutshave become part of the Syrian daily conversations about inconvenience and discomfort. On the one hand, the fuel shortage in the heating season, which extends from December until February, has become a pressing problem. According to Haddad (2019:23), the typical Syrian family spends more than 40% of their incometo perceive an acceptable level of warmth in the dwelling per year. As a result, notonly have low-income groups in Syria been left unable to cover the domestic energyexpenses but also the middle-income groups are also considered to be fuel poor households (Haddad, 2019). Both groups often have to compensate their level of domestic comfort against other household needs such as the need to spend moneyon food and clothing.

The quality of modern housing design in Syria also contributes to these issues (Al Khalaf, 2014). The Syrian Code for Construction (Ministry of Local Government, 2008) includes energy-efficient building measures that are required for obtaining building permits. However, the implementation of these measures in practice is not widespread (Keshkeh et al., 2008). As a result, the majority of domestic buildings in Syria suffer from poor thermal performance (Ozarisoy & Altan, 2021). Additionally, the current model of 'modern' architectural production in Syria tends to overlook the environmental and social aspects that were integral to the traditional vernacular architecture in the region. The current 'formal' housing design process according to Ismail (2015:2) fails to reflect changes in the cultural and social life ofthe residents. Aside from the poor quality of housing, the Syrian housing sector suffers from a huge supply gap with more than 1,5 million in needed of housing units (Ministry of Housing, 2009), so much so, that they eventually have to accept inadequate units. While there have been several strategies and programs to tacklethe housing need and produce an affordable alternative of housing, increasing social housing has emerged as one of the strategies that can tackle the affordability crisis.

Besides talking about the quality of the Syrian housing units, many questions needbe addressed such as the impact of the performance of social housing on occupantsthemselves and how residents respond to the spatial dimension of their everyday practices.

This research aims to explore the factors associated with thermal comfort and discomfort within social housing in Syria, considering both technical and social perspectives. The literature review highlights the limited studies on the thermal performance and comfort in Syrian dwellings, necessitating further research in this area. To address this gap, this study presents an in-depth case study focused on the domestic comfort of a family residing in a 4-storey domestic block in Damascus. The case study begins by analyzing the environmental performance of the dwelling and subsequently involves the residents as active participants. The residents are asked to keep a diary, recording their activities and experiences related to comfort over two typical days in either summer or winter. However, while individual diaries typically reflect the perspective of a single individual, this research seeks to investigate the inter-relationships between different spaces within the home and capture the voices of multiple family members.

Therefore, the diaries of the various family members in the case study are integrated as part of a multi-layered analysis. This analysis seeks to present the written content of the diaries in a visual-spatial format. The aim is to narrate a collective story of the case study building and analyze it in conjunction with the results obtained from the environmental modelling of the dwelling's performance. The research concludes by raising questions, concerns, and proposing further avenues for future research regarding the housing design model and its alignment with the social and environmental needs in the context of Syria's ongoing reconstruction debate.

## 1.2. Aim, Objectives, and Research questions

The aim of this research project is to investigate factors associated with thermal comfort in social housing within the Syrian context in order to answer the research question of how a typical social housing building in Syria perform environmentallyto seek thermal comfort. This study attempts to achieve the following objectives:

1) To develop a systematic review on the factors associated with domestic

comfort in Syria in order to inform the low energy design process, by reviewing the following literature studies on:

- Factors affecting Thermal Comfort and discomfort.
- Factors associated with environment performance of dwelling.
- Domestic energy resources in Syria and the problems associated with it.
- The impact of occupant behaviour on the perceived comfort in dwellings.
- Thermal standards in Syrian dwellings.
- Social housing Schemes and typologies in Syria.

2) To develop a contextual understanding of the building performance of the case study flat in Damascus in terms of climate, energy supply and envelope characteristics, by analysing the following aspects:

- The climate characteristics.
- The bio-climatic design strategies within the climatic zone.
- Current energy efficiency measures and thermal Standards for thermal Comfort in social housing.

3) In order to investigate the thermal performance of the case study social dwelling, the third objective of this research is aimed at analysing the inter-relationship between occupant behaviour and the social housing performance through a case study building in order to examine the building characteristics contributing to the energy injustices in social housing.

## 1.3. The structure of the thesis

Chapter One: Introduction

The introductory chapter describes the motivation of this research and provides anoverview of the purpose and context of the study on a broader view. By describingthe aims and objectives, this research sets out the methodological framework of evaluating the building performance of a case study social dwelling in the city ofDamascus.

Chapter Two: Theoretical framework: Housing, comfort, and occupant behaviour

This chapter attempts to set a theoretical framework for this research by reviewingthe available literature studies about thermal performance in dwellings. Thisincludes the concepts of thermal comfort and discomfort and factors affecting them.Although the programs of energy efficient homes in Syria are very limited and bio-climatic design in architectural practice is still limited to some pilot projects in the region without any national implementation of low energy building, this study has critically discussed the available implemented projects of energy efficient dwellingsand reviewed the current literatures on the concepts of dwellings performance in the Middle East (within the context of this study). Finally, the thermal performanceof social housing in Syria is analysed.

Chapter Three: Investigating Comfort Levels in Syrian dwellings: Methods

This chapter sets out the implemented methodology of selecting the case study approach and the description of the case study selection criteria, its limitations, and the case study characteristics. However, in order to quantify the impact of climate zone on buildings design, the climate of Damascus was analysed by examining the outdoor climatic variables using open-source environmental analysis plugins (Ladybug & Honeybee) for the environmental analysis programme, Grasshopper based on the secondary data collected for the Damascus climate database. Since the current literatures lacks guidelines for bioclimatic building design strategies for Damascus, an experimental design approach was conducted. A shoebox analysis was tested to rapidly generate a thermal massing model in order to give a general understanding of the impact of Damascus’s climate on design decisions.

By focusing on the case study from both objective and subjective aspects of comfort represented by the thermal performance of the envelope and the subjective aspects of comfort/discomfort and how the family uses their space on a daily basis, environmental simulation has been conducted to quantify the thermal performance of the envelope. Second, the personal diary format was explained and the benefits of using this method to capture the comfort-related occupant behaviours and drivers were identified. This chapter provides a user-centric framework for the analysis model of investigating domestic thermal comfort in Syrian dwellings.

Chapter Four: Searching for Comfort: Results and Discussion

This chapter outlines the results of this study in three main sections. First, the results from climate analysis and shoebox analysis. Second, the resulted simulation data of the case study is presented through looking at the percentage of the comfort levels and heat/cold stress in order to evaluate the envelope thermal performance. third, the findings from the family members' diaries are illustrated through three main behavioural snapshots. The behavioural snapshots are presented in visual snapshots associated with the various members' diaries in the residential space to discuss the impact of the dwelling performance on the daily activities of the participants. By reflecting on both methods and results of the evaluating the case study approach, analysis of the researcher is integrated in this chapter as a performance gap. The performance gap analysis consists of a detailed reflection of how the building performs based on both objective and subjective aspects of domestic thermal comfort by analysing the building according to three main aspects, design vs as built, occupant behaviour and the effect of microenvironment. This chapter illustrates the findings of the adopted methodology and reflect of these results in the light of the theoretical framework.

Chapter Five: Conclusions and a Reflection on further research

This chapter seeks to reflect the results of this study on broader aspects of domesticcomfort in the housing delivery in Syria. Later, it raises questions and concerns, about the future of housing design model in the light of the current debate of Syriareconstruction in responding to the social or environmental needs and proposes further potential research. It finally reflects on the research process and findings ofundertaking this MPhil project.

(Figure 1) summarises the followed structure of this thesis including introduction, theoretical framework, methods, results, discussion, and conclusion and how they are related to the thesis aims.

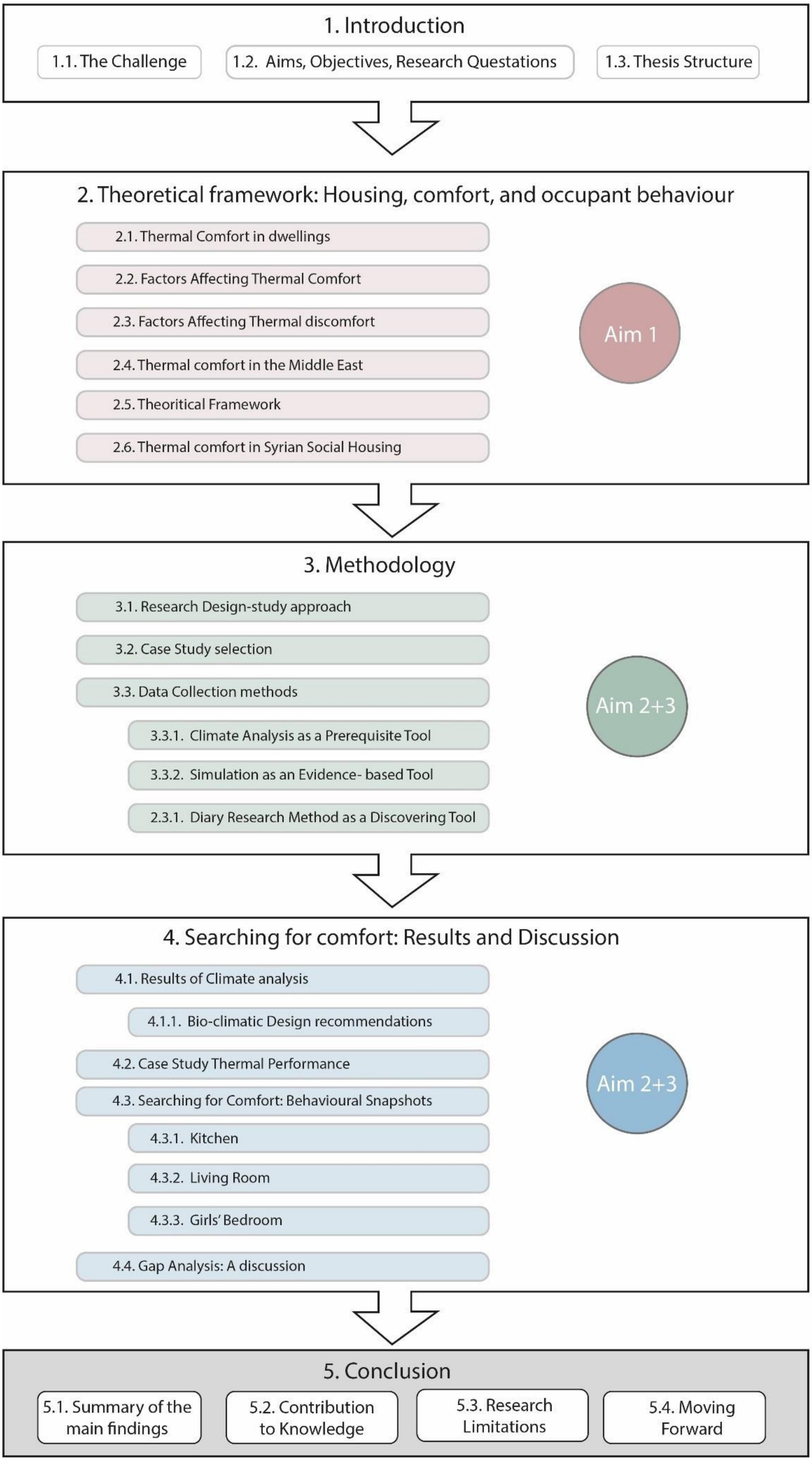


*Figure 1. Structure of the thesis.*

# Chapter Two

## 2. Theoretical framework: Housing, comfort, and occupantbehaviour

The main aim of this chapter is to present a systematic review of the factors associated with domestic thermal comfort that inform the low energy design process. Thus, a review of the literature was conducted to focus on the wider perspective of thermal comfort. This includes the analysis of physical aspects as well as objective aspects in the dwellings that lead to indoor comfort/discomfort. All contributing aspects to domestic thermal comfort were combined in a theoretical framework that informs the analysis of the thermal performance in the field study.

First, the concept of adaptive comfort was reviewed in its relation to naturally ventilated dwellings, where windows are operable and no active heating/cooling is reliable. Second, the factors that affect thermal comfort are discussed through threemain factors: the impact of climate, the energy performance of the dwelling and theoccupant behaviour. While thermal comfort in dwellings is significantly affected by the way occupants utilize their spaces and their energy services, both drivers and actions of the occupant behaviour in domestic spaces were discussed in order to setout the behavioural adjustments of residents to maintain comfort levels in the space.

Although the aim of the dwelling is to provide comfort, discomfort is an observed phenomena in multiple studies while discussing domestic comfort in more disadvantaged communities, where access to energy is not always guaranteed. Therefore, apart from the factors affecting thermal comfort, this study has discussed further aspects, which cause unacceptable indoor environment and result in occupant's discomfort in the conditions of thermal environment, daylight, and natural ventilation in the building. Furthermore, in order to discuss the studies associated with thermal comfort standards in the Middle East, studies about domestic energy and low energy dwellings in the region can assist this study since the literature about thermal comfort in the Middle East is very limited. Therefore, the current situation of thermal comfort in the Middle East and North Africa (MENA) region was reviewed.

Finally, this chapter concludes with the production of an adapted theoretical framework that combines all reviewed literature studies about discomfort and both drivers and actions of occupant behaviour to inform the evaluation of thermal performance of Syrian dwellings.

## 2.1. Thermal Comfort in dwellings

Occupant comfort demonstrates one of the essential conditions of providing livable indoor environment in a dwelling. Nevertheless, the concept “domestic comfort” is far from defined. In some cases, it may be used mainly in the objective sense of thermal comfort or other subfields including visual, acoustic, and respiratory comfort as Heijis et al. (1987:331) argued. However, comfort according to Burris et al. (2012:2) is 'a state of physical ease or well-being'. Moreover, the most common definition for thermal comfort is the one defined by ASHRAE Standard 55 (2004) as “that condition of mind which expresses satisfaction with the thermal environment”.

In addition, multiple definitions for thermal comfort have been developed based on various disciplines whether it is from an engineering perspective or physiological one. Earlier research strongly related the concept of thermal comfort with thermal balance (Fanger, 1972; Gagge, 1986), which explains that both physical and personal aspects of thermal comfort impact our thermal sensation. Fanger (1970) (Figure 2) combined both environmental and personal factors in his argument about the factors associated with thermal comfort.

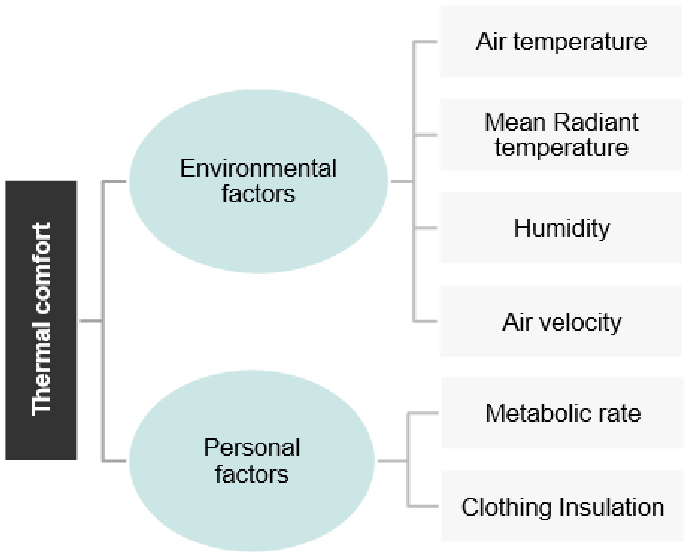


*Figure 2. Factors affecting thermal comfort based on Fanger (1970)*

Multiple methods have also been developed to measure the levels of thermal comfort sensation. Most importantly is the Predicted Mean Vote (PMV) model by Fagner (1970). The PMV model became a world-wide recognised model to assess thermal comfort in buildings and later standardised by ASHRAE Standard 55 (2004) and ISO international standard (1984). According to the PMV model, heat balance is maintained by multiple physiological processes such as sweating, shivering, regulating blood circulation. This model can be considered as a "static thermal comfort approach", where personal aspects were standardised, and it is defined by the human sensation. According to Gilania et at. (2015:1374) PMV is an index, which aims to predict the mean value of votes of a group of occupants on a seven-point thermal sensation scale. (Table 1) shows the thermal sensation index as the value of 0 considers sensation as neutral while +3 value considers it as hot, and the value of -3 as cold.

*Table 1. Thermal Sensation scale, adapted from (Gilania et at, 2015:1375).*

| Index Value | Thermal Sensation |
|---|---|
| **+3** | Hot |
| **+2** | Warm |
| **+1** | Slightly warm |
| **0** | Neutral (Comfort) |
| **-1** | Slightly cool |
| **-2** | Cool |
| **-3** | Cold |

As a result, the PMV model has been considered as a globally recognised index forassessing thermal comfort. However, multiple studies criticized this model becauseit considers the occupants as passive recipients of their response to their immediate environment. While air-conditioning has enabled controlling the indoor temperatures, not all buildings provide a controlled indoor environment. Field studies have found a significant difference between monitored data and PMV model prediction while assessing thermal comfort in natural ventilated buildings (Nicol et al., 1998; Nicol & Humphreys, 2002).

As a result, while the dominant framework of thermal comfort was for several years based on the concept of thermal neutrality i.e the absence of discomfort from excessive heat, cold or humidity, the concept of adapting to the thermal environment was introduced by (Nicol et al., 1995) through the adaptive approach.

The adaptive approach assumed the active role of the occupant in two main adjustments to secure comfort. First, adjustment to the optimal comfort changing in clothes and activities. Second, adjustment to the indoor environment by use of control such as windows and blinds.

### 2.1.1. Adaptive comfort Model

Nicol & Humphreys (1998) developed the "adaptive comfort model" which argues that comfort temperatures depend upon the circumstances in which people live, such as the climate and heating or cooling regime.   people actively control their indoor environment to secure comfort. As an alternative for the predictive model PMV, the adaptive comfort model introduced that people will always react to thermal changes in order to restore their comfort and avoid discomfort (Nicol & Humphreys, 2002: 563).

Adaptive comfort considers that the principle of comfort cannot be independent from people's actions. This has particularly relevance to the naturally ventilated buildings, where windows are operable and controlled settings are unreliable in real-case scenario. As a result of associating the comfort levels to the occupant behaviour, the adaptability principle correlates the comfort temperature to the context in which people respond differently. Therefore, the adaptive comfort model has agreater dependence on outdoor temperature ranges to predict comfortable indoor temperature levels. These levels rely on the comfort zone, which is definedaccording to ASHRAE 55 (2013:2) as the range of climatic conditions within when amajority of persons would feel thermally comfortable.

The comfort zone defines theacceptable boundaries of operative temperature and humidity on a psychrometric chart. According to Kumar et al. (2016), although the main purpose of psychrometric charts is to design the indoor environment of conditioned buildings, it has been alsoadopted in evaluating the indoor environment in buildings which are naturally ventilated. Subsequently, different climates zones have different comfort zones, which has greater benefit for architects and environmental designers who have more design flexibility with naturally ventilated buildings to enhance comfort and reduce energy use (ASHRAE 55,2004). It can be concluded that while the PMV comfort model can be applied to the mechanically cooled building, thermal comfort in naturally ventilated buildings is more dependent on outdoor temperature. The adaptive model argues that people tend to accept a wider range of temperatures than the PMV model. The difference of acceptance is strongly associated to the psychological and behavioural occupant's actions in order to seek comfort.

However, the personal factors are not the only subjective contributors to the conceived thermal comfort. Psychologically informed perspectives also contribute to understand how people create comfort and consider the broader context of thermal comfort at home, which relates to understanding not only their attributes such as age and sex but also investigate their actions and the drivers behind these actions (Stephenson et al., 2010).

Therefore, it can be stated that not only the individual parameters affect the response of thermal comfort, but also cultural factors have an impact of thermal comfort. As a result of exploring the concept of thermal comfort from several perspectives, it can be said that the interdisciplinary approach has played a considerable role in shifting scientific research on searching for comfortto act as a leading determinant of energy- conscious attitudes and of patterns of domestic energy-use (Heijis et al., 1987:331).

In order to provide a comprehensiveunderstanding of thermal comfort, factors affecting thermal comfort are reviewed in this study to inform the evaluation of thermal performance of Syrian dwellings based on three main topics including the impact of the climate to secure comfort, the environmental performance of the dwelling and the interrelation of the occupants to their dwelling.

## 2.2. Factors Affecting Thermal Comfort

The interrelationship between the building components and the occupant impacts the response to thermal comfort/discomfort. While considering passive design strategies and using efficient services, understanding human needs (in terms of functionality, social and cultural practices) is also essential for securing comfortable indoor environments. This is reflected by the suggested new hierarchy of low energy design by (Kimpian, J et al., 2020), which needs to take into account human behaviour to bridge the performance gap. (Figure 3) shows both hierarchies (the old hierarchy of zero energy design (left) includes only the physical aspects of the building performance, while the new hierarchy (right) looks at low energy building from a bottom-up approach and prioritises the human factor in a feedback loop to secure a comfortable space.

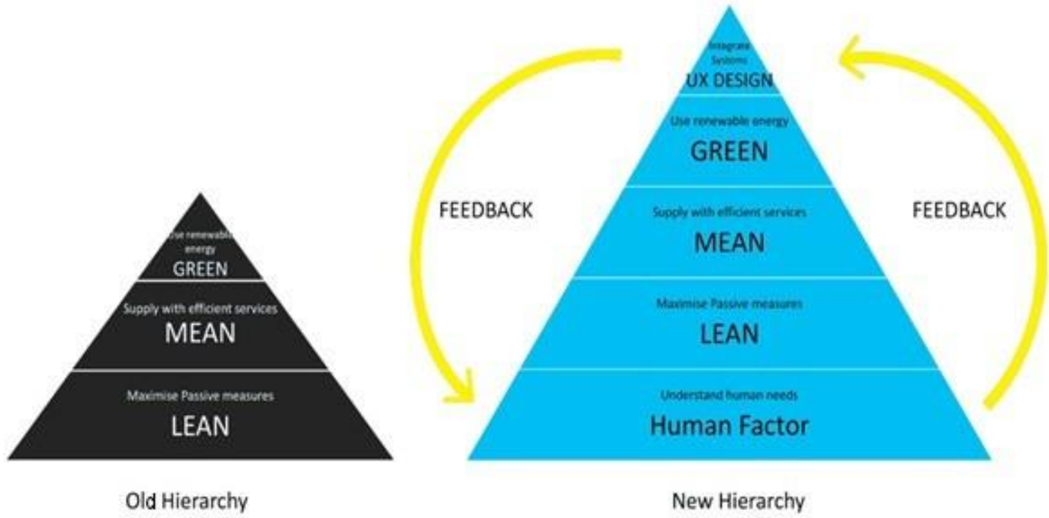


*Figure 3. The Zero Energy Design Hierarchy, prioritising passive design principle with the new feedback hierarchy including human factors. (Kimpian, J et al, 2020: 51).*

While energy performance of dwelling significantly contributes theperceived comfort, understanding the occupants' behaviour and drivers behind their behaviour is essential to have a comprehensive view of the issue of thermal comfort (Kimpian, J et al, (2020). The factors affecting thermal comfort were classified in the three main factors including the impact of climate, energy performance of the dwelling, and occupant behaviour.

#### 2.2.1. The impact of Climate

Climate analysis is an essential step to develop architectural design concepts as climate greatly influences the amount of building energy use including heating, cooling, ventilation, and lighting. According to Oktay (2002), the climate characteristics of each region should be the basis for architectural and urban solutions. Furthermore, considering climate characteristics allows appropriate level of natural lighting and solar radiation into buildings, which improves the quality of life of the local community.

In order to assess the impact of climate on the design strategies, multiple climatic variables can be examined in three main groups including macro climate, meso climate and microclimate. The climate that interacts according to geography is called macroclimate; while meso and microclimate are based on regional environment on a local scale (Biket, 2016:262).

Since this research is focused on the building scale within the built environment, understanding the microclimate and its effects on building design have a direct impact on creating a comfortable interior and exterior environment around the building. Iyendo Jnr et al. (2016) referred to the microclimate as the "mini climate" that defines the relationship between the climate, the site, and the building, which in turn generates a local environment around the building.

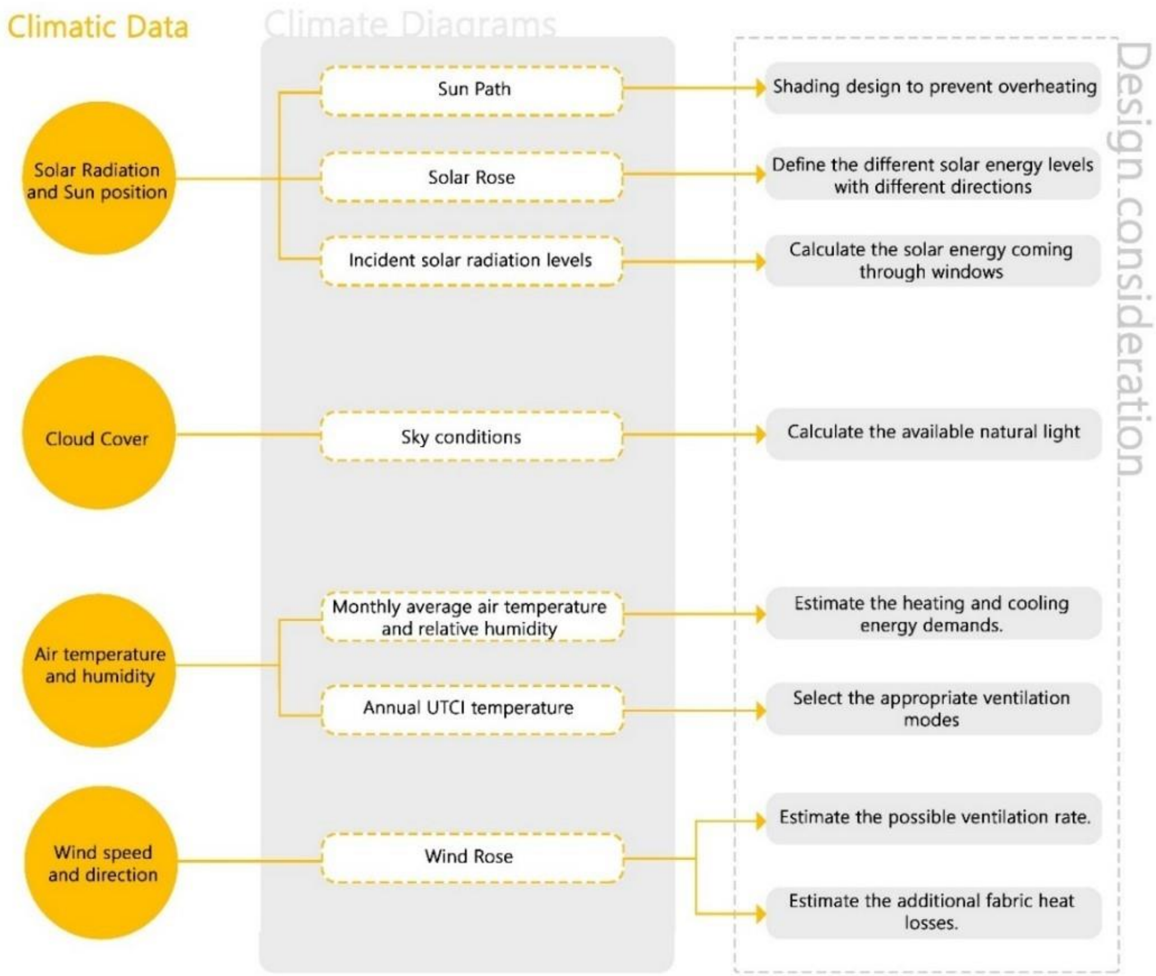


*Figure 4. The Climate indicators and design considerations to be investigated in this study based on (Lee et al., 2017; Fernández-Ahumada et al., 2019; Janda, 2011; Nguyen & Altan, 2011)*

In order to develop a deep understanding towards considering microclimate in bioclimatic architecture, major climate variables are reviewed in this study as they significantly affect energy-related design decisions Based on multiple studies (Lee et al., 2017; Fernández-Ahumada et al., 2019; Janda, 2011; Nguyen & Altan, 2011). (Figure 4) shows the climate indicators for climatic conditions and the resulted design indicators that should be considered.

Climate variables include solar radiation, air temperature, humidity, wind direction, sunshine, and cloud cover. Each variable has multiple assessment methods as discussed below.

- <u>Solar radiation and sun position:</u> While solar access directly affects the building, the quality of the daylight and sunlight levels varies throughout the day and according to the seasons. This can bearchitecturally expressed by the sun path. Determination the daily and annual sun path is essential to assess the effect of shadows cast by buildings and trees and calculate the solar intensity of radiation that reaches the building envelope (Hausladen et al., 2006 & Machdijar et al., 2019). In addition, solar radiation studyis considered an essential factor to determine times when comfort can be achievedoutdoors. It is also used to calculate the power generation of solar systems (Fernández-Ahumada et al., 2019:1).

- Cloud Cover: Besides, sky condition is equally important to solar variables for determining daylighting levels in buildings. Sky conditions are classified as either overcast, clearor partly cloudy (Loi et al., 2019:2). According to Park et al. (2021), identifying thesky cover in the microclimate is essential to determine the dominant daylighting design condition and reduce light levels as needed on clear and partly cloudy days and times.

- Air temperature and humidity: The third climate variable in which building design is affected is the air temperature.However, since outdoor temperature is affected not only by air temperature, but also by wind velocity and water vapor pressure, it is useful to determine the correlation between these variables in order to understand how the temperature will "feel" like. There are multiple methods for assessing outdoor thermal environments and each has its applications and limitations. (Table 2) summarizes the common outdoor temperature indices and its limitations. However, this study focuses on the Universal Thermal Climate Index (UTCI) method because this method provides an assessment of the outdoor thermal environment to represent air temperature but with considering factors including wind speed, solar radiation, and relative humidity, in contrast to other methods like OUTSET and PET which setsa reference climate conditions for wind speed.

*Table 2. Comparative analysis of the outdoor temperature indices based on (Pantavou et al. 2018)*

| Methods | Definitions | Limitations |
|---|---|---|
| **Physiological Equivalent Temperature (PET)** | equivalent air temperature at which, in a typical indoor condition heat balance of the human body exists | It sets reference indoor conditions (MRT = Ta; vapor pressure (VP) = 12 h Pa; wind speed (WS) = 0.15 ms−1). |
| **Outdoor Standard Effective Temperature (OUTSET)** | The thermal conditions can be compared to the conditions in a standardized room with a mean radiant temperature equal to air temperature and a constant relative humidity of 50%. | it sets reference indoor conditions: MRT = Ta; RH = 50%; WS = 0.15 $ms^{-1}$. Limited to low activity and light clothing. |
| **Universal Thermal Climate Index (UTCI)** | (UTCI) is to inform the public of how the weather feels, | uses environmental (air temperature, mean radiant temperature, humidity and wind speed). no information on the clothing insulation level of the surveyed population is required. |

The universal thermal climate Index (UTCI) was derived conceptually as an equivalent temperature for combination of air temperature, wind speed, vapor pressure and mean radiant temperature, which together represent the thermal stress of the actual environment, the UTCI is defined with the reference condition yielding the same dynamic physiological response. The thermal stress assessment scale was derived from the modelled physiological and psychological response (Fiala et al., 2012) and states that within range of 9-26 $^{0}$C people would have no thermal stress. However, when temperature falls below 9 $^{0}$C or rise above 26 $^{0}$C, this would cause a thermal stress ranging from moderate to extreme thermal stress.

*Table 3. Scale oft UTCI. Adapted from (Fiala et al., 2012)*

| UTCI (°C) | Stress Category |
|---|---|
| 38 < UTCI < 46 | Very strong heat stress |
| 32 < UTCI < 38 | Strong heat stress |
| 26 < UTCI < 32 | Moderate heat stress |
| 9 < UTCI < 26 | No thermal stress |
| 0 < UTCI < 9 | Slight Cold stress |
| -13 < UTCI < 0 | Moderate Cold stress |
| -27 < UTCI < -13 | Strong Cold stress |
| -40 < UTCI < -27 | Very strong Cold stress |

In conclusion, considering climate variables when investigating thermal comfort is an essential in order to develop a holistic approach in understanding factors affecting the occupant comfort.

### 2.2.2. Energy Performance of Dwellings

> *"In order to analyse performance, 'how well' a system meets the functional requirements, one needs to compare the measured performance with clear criteria"* (De Wilde, 2018:145)

Buildings are complex systems as they include typically a structure, envelope, infilland building services, which all perform as a whole system in order to provide multiple functions (De Wilde, 2018). One of these functions includes protecting theoccupants from environmental conditions, which is directly related to the concept of energy performance of a building. The energy performance of a building depends on three main components including building characteristics, building systems, and the operation of the building. The hierarchy proposed by (Singaravel & Geyer, 2016). (Figure 5) summarizes the factors associated with these components).

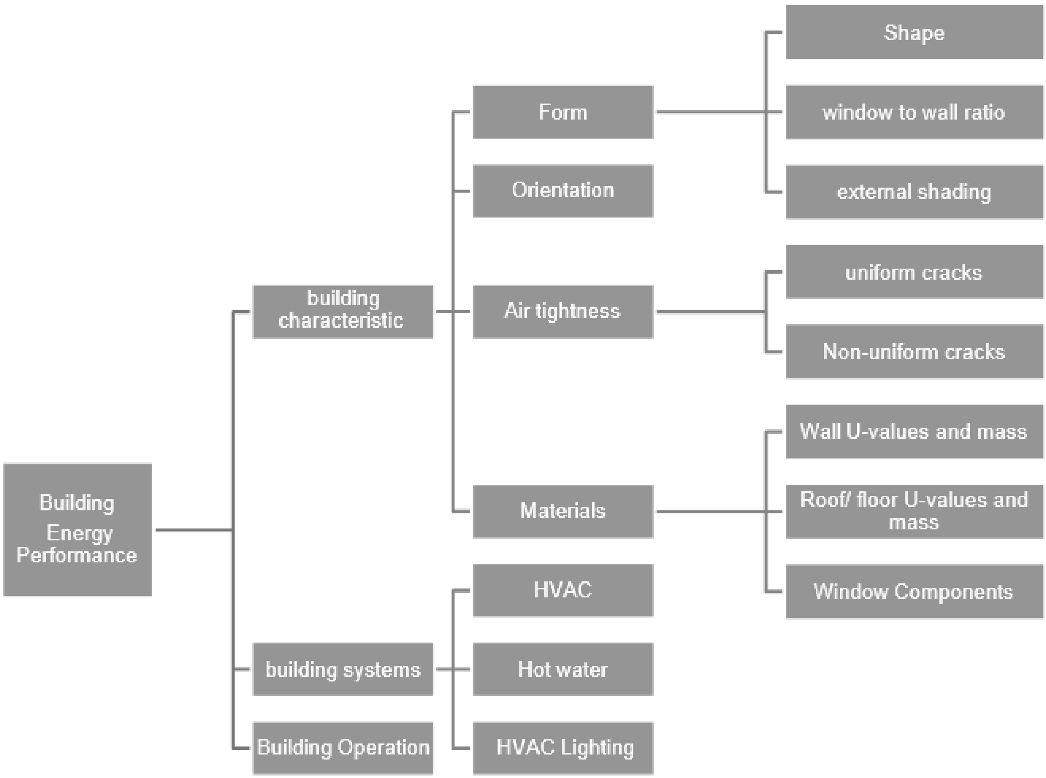


*Figure 5. Hierarchy of energy performance based on (Singaravel and Geyer, 2016:4)*

Building characteristics include considering the form, orientation, the building materials, which is according to Harrouni et al. (2018:2) predominant design variables affecting both indoor comfort and energy use. However, the most important factor is the building envelope design the separates the outdoor and indoor environment. The shape of the dwelling on the other hand affects the amount of heat losses and gains. Therefore, considering the climatic design strategies is the first crucial step to improve the energy performance of the dwellings. Second, energy services also affect the energy performance of the dwelling through the selection of efficient HVAC and lighting systems and the supply of hot water.

### 2.2.3. Occupant Behaviour

Thermal comfort in dwellings is significantly affected by the way occupants utilize their spaces and their energy services, which extremely impacts the energy performance (Tam et al., 2018). Various studies have argued that occupant behaviour has double effects on environment: (passive effects) due to occupants' presence and (active effects) due to their actions Including as manipulation of building control devices for heating, cooling, ventilation, and lighting (Hong et al., 2015). Furthermore, several occupant behaviour models were developed to predict the patterns of occupant-related energy use and the interaction of occupants with the building's systems and controls such as control of window blinds and electric lighting or simple control of windows, lighting, fans, and heaters by occupants of naturally ventilated buildings or heating and cooling services by occupants of mechanically ventilated buildings (Tetlow et al., 2015). This can be summarised in (Figure 6).

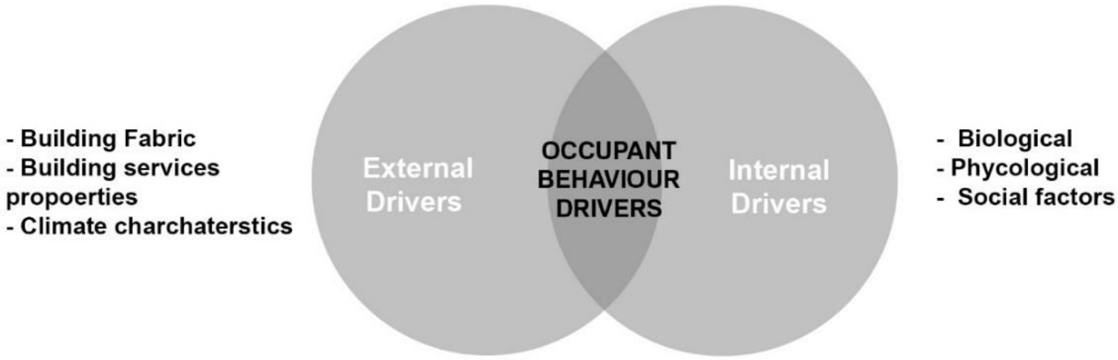


*Figure 6. Occupant behaviour drivers. Adapted from (EIA, 2013:8)*

At this stage, several questions may be suggested in the context of disadvantaged communities, where access to energy services is limited, and the poor conditions of housing are the dominant. How can we define the relationship between the comfort/discomfort and occupant behaviour? Would it be sufficient to look at occupant behaviour models in terms of energy use without taking into consideration the socio-cultural and economic factors? In order to expand on this question, multiple studies that investigated the relationship between the drivers and actions of occupant behaviour in search for comfort have been reviewed in this study.

The occupant behaviour can be triggered by several direct and indirect factors that ultimately have an influence on energy and space use. Many studies investigated these drivers whether it is subjective or objective, external or internal. (EIA, 2013:8) classified the drivers of occupant behaviour based on the interaction scale. Internal drivers include biological, psychological, and social factors while external driving force involve building fabric and building services properties, climate characteristics and time.

Looking at broader perspective, Hong et al. (2015) suggested a DNAS (Drivers, Needs, Actions and Systems) conceptual framework to represent energy-related human behaviour in the building (Figure 7). Drivers act for the environmental factors (which represent the external forces in EIA (2013) study). Needs represent the physical and non-physical requirements of the occupants to ensure the satisfaction of the occupant with their environment (which represents the internal forces of (EIA, 2013) study).

Actions represent the interrelation among systems and occupant's spatial activities to seek comfort. Systems refer to the equipment or mechanisms within the building which an occupant may interact to maintain comfort. By expanding the concept of Hong et al. (2015) on the drivers of occupant behaviour, others assume that dwellings' use is grounded in habits, practices, and norms of the occupant, which results from a combination of social expectations and cultural factors that are not easily redrawn but may shift over time (Shove, 2003; Motuziene & Vilutiene, 2013; Janda, 2011).

*Figure 7. DNAs Conceptual framework to understand the occupant behaviour. Adapted from (Hong et al, 2015)*

However, not all dwellings are designed to provide comfortable indoor environmentthermally. In such situations, occupants are not able to control their environment but have to cope with it. The next section reviews the opposite side of thermal comfort, which is thermal discomfort. Thermal discomfort is strongly related to thisresearch in the context of low- and medium-income groups and social housing in Syria. Therefore, it would be useful to review the factors drivers of discomfort in thedomestic spaces.

### 2.3. Factors affecting discomfort

But what happens when the occupant shows wider range of temperatures, which is below the comfort range and cannot be tolerated? When discussing the concept of discomfort, various fields such as Building Performance Evaluation BPE, Post Occupancy Evaluation POE can be turned to in order to assess the comfort tensions between the occupants and the building. This explained through the concept of the performance gap, which is the difference between anticipated and actual performance (Shi et al, 2019:2). This concept suggests that human behaviour shapes and influences the space they live in and in order to bridge the gap between the building design and performance, architects need to follow consider thermal comfort as a key component in their design. However, the factors affecting the levels of occupant's comfort are diverse. In order to understand the roots of domestic comfort, these factors are reviewed in the following sections.

Although the aim of the dwelling is providing comfort, discomfort is an observed phenomena in multiple studies. Apart from the factors affecting thermal comfort, which were discussed in the previous section, there is further aspects which causeunacceptable indoor environment and result in occupants' discomfort in conditions of thermal environment, daylight, and natural ventilation in the building. These factors are identified in ASHRAE Standard 55 (2004) by causing local discomfort including draught (local air velocity), vertical air temperature difference, warm andcool floors, and radiant temperature asymmetry (ASHRAE, 2004; Parsons, 2003). A study by Efeoma (2016) has reviewed these factors associated with local discomfort. While uncontrollable ventilation may cause uncomfortable air currents inside the building, inefficient floor materials may cause heat or cold stress in the floor due to its high thermal transmissivity. Furthermore, uninsulated envelope and direct sunlight cause non-uniform thermal radiation levels in the room. Finally, displacement ventilation i.e., ventilation that supply air at low level, close to the floor may cause vertical temperature differences between the position of a head and an ankle of a person in the space (Figure 8)

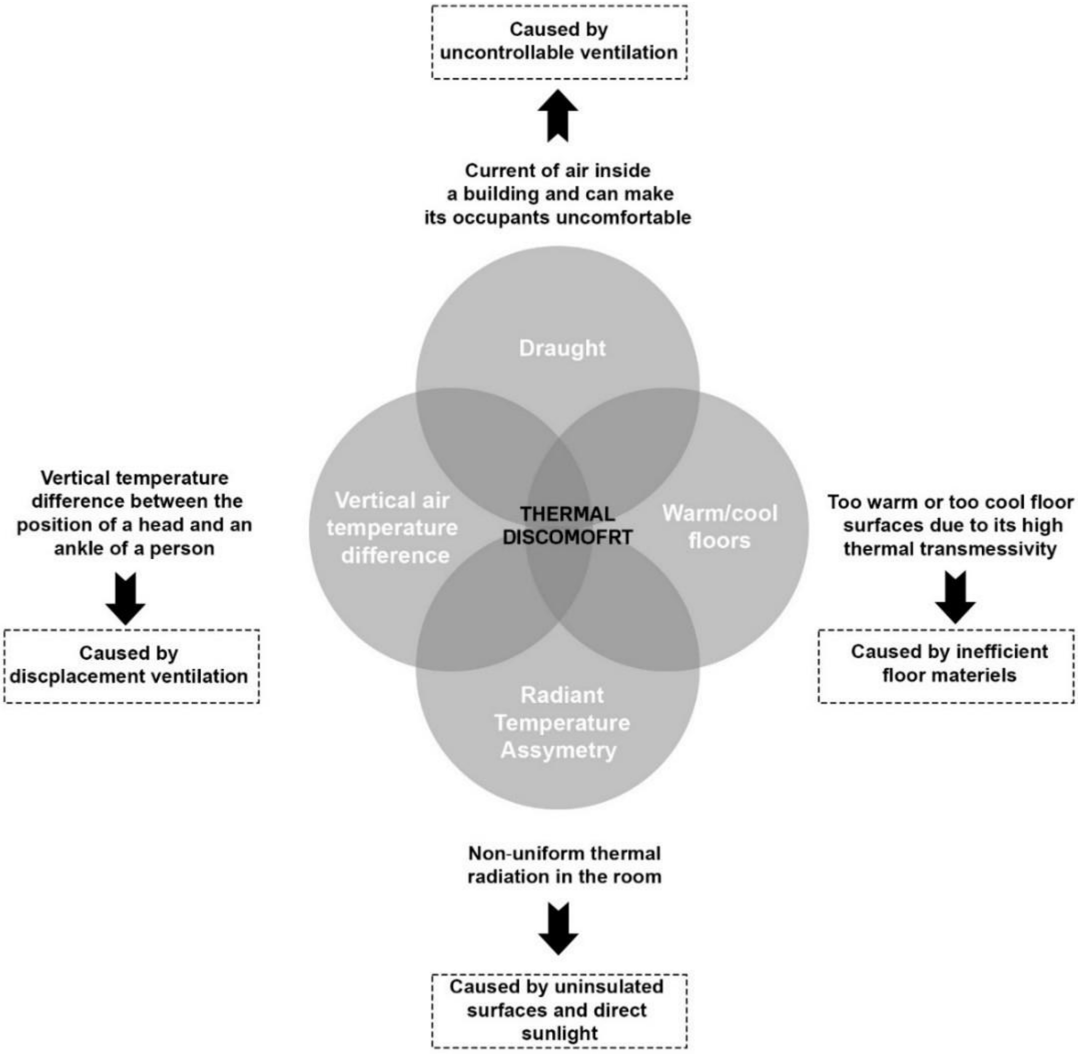


*Figure 8. Factors affecting thermal discomfort. Based on Efeoma (2016).*

However, discomfort is not limited to the discussed factors and can also be a result of further heat-related problems that can be witnessed in the dwellings including overheating. Although there is no universal accepted definition of overheating because it varies with the local climate (Ali & Szalay, 2020; Lomas & Porritt, 2017), it is argued that excess heat occurs when the thermal environment presents conditions exceed the acceptable thermal conditions for humans, that affects the health and wellbeing of occupants. Therefore, the risk of overheating plays a crucial role in causing thermal discomfort. But how occupant respond to the discomfort when there is heat or cold stress? According to Heerwagen et al. (1992: 83), behaviours of coping can be divided into three general classes:

1. Behaviours aimed at changing the situation in some way (environmental coping such as opening/closing windows, use of localized devices, fans or

heaters, spatial arrangements, furniture adjustments).

2. Changes in one's own behaviour (behavioural coping such as adjust clothes, moving to another room).
3. Attempts to adjust to a situation by managing emotions or thoughts about the situation (emotional/psychological coping such as ignoring the problem) when no environmental manipulations are possible, or the "cost" of appropriate action is too high, which meets the concept of fuel poverty.

While environmental stress distinguished between controllable and uncontrollable environments, the environment where occupant have no control to adjust is usually associated with drastic consequences on the occupants themselves including negative moods and social behaviours, decreased motivation, and a sense of hopelessness (Heerwagen et al., 1992: 84). As a result, a “more adaptive” indoor environment in dwellings is crucial for the occupant’ health and wellbeing. (Figure 9) summarised the actions of occupant’s actions in relation to responding to discomfort.

*Figure 9. Categories of response to thermal stress based on Heerwagen et al. (1984).*

## 2.4. Theoretical framework- Conclusion

By reviewing the available literature studies about the context of thermal performance of dwellings. This section discussed the concepts of thermal comfort and discomfort and factors affecting the in order to understand the occupant behaviour in the domestic space. Starting from the occupant as a central factor based on the new hierarchy of low energy design by (Kimpian, J et al., 2020), which needs to consider human behaviour to bridge the performance gap, it was argued that their social, biological, and psychological needs affect their behaviour. This is reflected by internal drivers.

Climate also affects the perceived thermal comfort including air temperature, radiant temperature, air velocity and humidity. Moreover, building characteristics and properties include the mode of ventilation, insulation levels and passive design principles. On the This is reflected by external drivers when the physical environment including the climate characteristics and building components and the building systems also affect the occupant behaviour.

Although the aim of the dwelling is to provide comfort, discomfort is an observed phenomena in multiple studies while discussing domestic comfort in more disadvantaged communities, where access to energy is not always guaranteed. Therefore, apart from the factors affecting thermal comfort, this study has discussed further aspects, which cause unacceptable indoor environment and result in occupant's discomfort. Although discomfort can be a result of multiple factors as discussed, the interaction between the internal and external drivers results in the actions of the occupants in order to adapt to their environment or cope with it including changing environment, behaviours, or managing emotions if there are no choices that can make to secure a comfortable environment.

As a result, this study argued based on the literature review that understanding the interrelation between occupant drivers and behaviors and the physical properties of the climate and the buildings is essential to understand the results comfort/discomfort. In conclusion the theoretical framework was developed to inform the methodology of this study by considering external and internal drivers of the occupant in securing thermal comfort (figure 10).

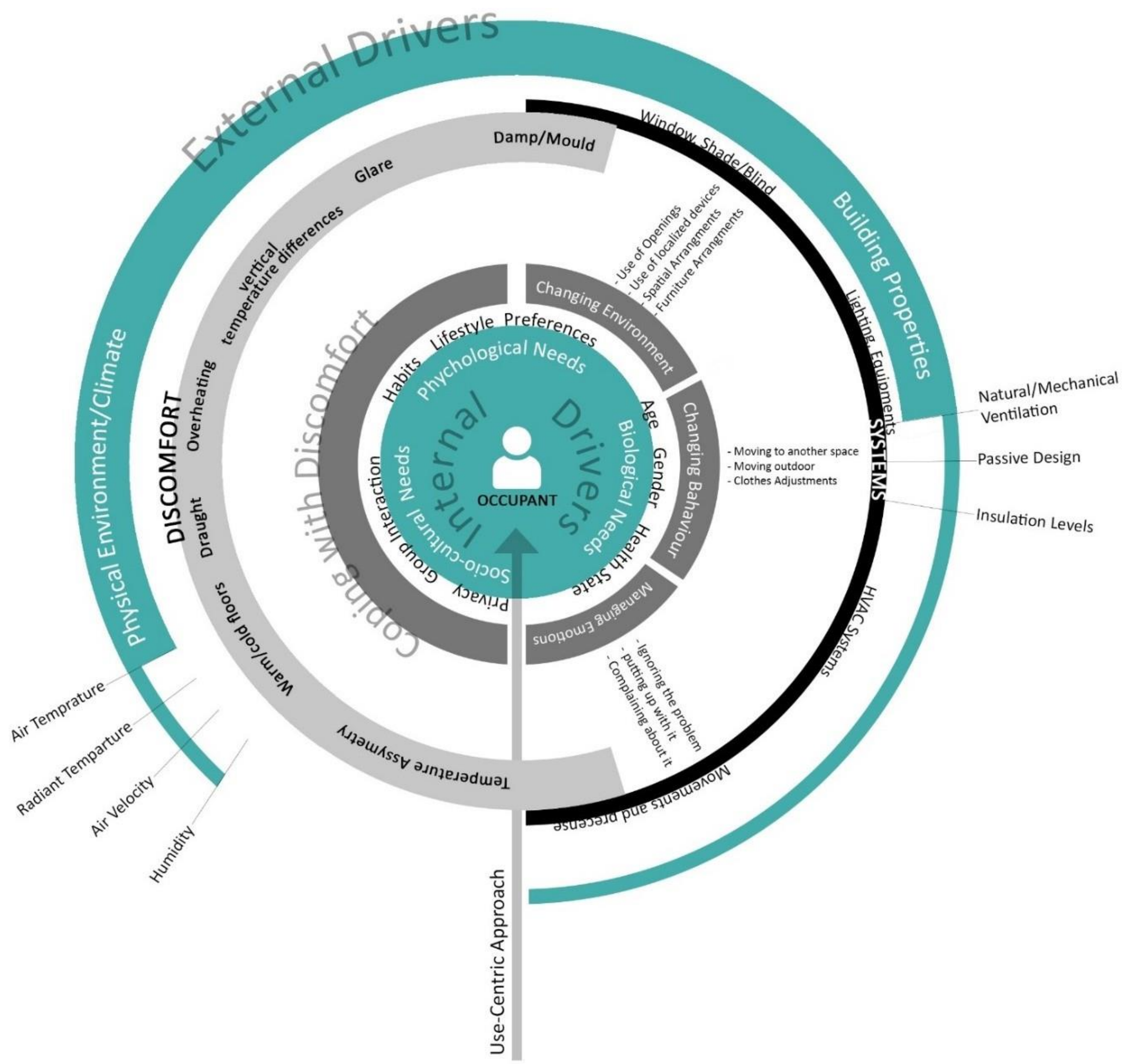


*Figure 10. The proposed theoretical Framework.*

## 2.5. Thermal comfort in the Middle East-a Literature Review

In order to discuss the studies associated with thermal comfort standards in the region of the Middle East, studies about domestic energy and low energy dwellings can assist this study since prior studies about thermal comfort in the middle east is limited. By reviewing the efficiency implementations in housing in the Middle East, it can be argued that the building industry is most sector which lacks any energy efficiency implementations in the multiple middle eastern countries including Syria although these countries have adopted energy efficiency regulations for buildings (RCREEE Regional Centre for Renewable Energy and Energy Efficiency, 2013).

*Table 4. EE building codes in RCREEE member states including Syria (RCREEE, 2013).*

| | New Buildings Built Every Year | Number of Buildings Built According to EE Building Code | Number of Demonstration Projects |
|---|---|---|---|
| Algeria | 80,000[5] | None/nearly none | 600 housing units are currently under construction under ECO-BAT program |
| Bahrain | 6,000[6] | 81 | - |
| Egypt | 69,030[7] | None/nearly none | None |
| Iraq | 22,000 | None/nearly none | None |
| Jordan | 20,000 | None/nearly none | 11 |
| Lebanon | n/a | None/ nearly none | 5 real estate projects |
| Libya | 50,000 | No EE code | None |
| Morocco | 170,000 | None/nearly none | 9 buildings are currently under construction in six climatic zones of Morocco |
| Sudan | n/a | No EE code | None |
| Syria | 30,000 | None/nearly none | 4 |
| Tunisia | 60,000 | 4,681 (administrative) 14,724 (residential) | 43 pilot projects have been constructed under RTEBNT program |
| Palestine | n/a | None/nearly none | 1 |
| Yemen | n/a | No EE code | None |

(Table 4) shows that the number of buildings built in compliance with energy efficiency codes is negligible comparing to the conventional buildings built every year. The table also reveals the massive gap in Syria with regards to the energy efficiency. Although there is a Syrian code for energy efficiency, the buildings are uncompliant to the regulations, which indicates the obstacles in implementing energy efficiency standards in Syrian dwellings.

Another study by Elnaklah et al. (2021) investigated the current thermal comfort standards in the Middle East. It argued that maintaining thermal comfort in an extremely hot climate is the main driver to increasing cooling energy demand in the Middle East (ME) over the last 30-years. The relatively high cooling demand is alsosupported by multiple factors including rising incomes, decline of air-conditioning costs and continuously increasing of the number of buildings. The study presenteda meta-analysis of data from existing studies associated with thermal comfort and showed that only 40% of occupants find their indoor conditions acceptable and 39% occupants expressing cold discomfort, which need to be considered in order to develop localised thermal comfort standards without compromising occupant thermal comfort. However, although cooling demand is a main concern in most Arabcountries, the study lacked consideration of cold stress in winter, which can be considered a huge challenge to seek thermal comfort in multiple countries in the middle East including Lebanon and Syria.

An equally significant aspect of comfort is its level in the natural ventilated dwellings, where active heating or cooling is provided. Various studies have emphasized the strength of the climate characteristics in the middle east. For example, a study supported by the World Bank (2017) shows the very high levels of horizontal irradiation levels which indicates the high potential of solar energy generation in theregion. However, the current implementation of renewable energy is not sufficient for attaining energy security (Figure 11).

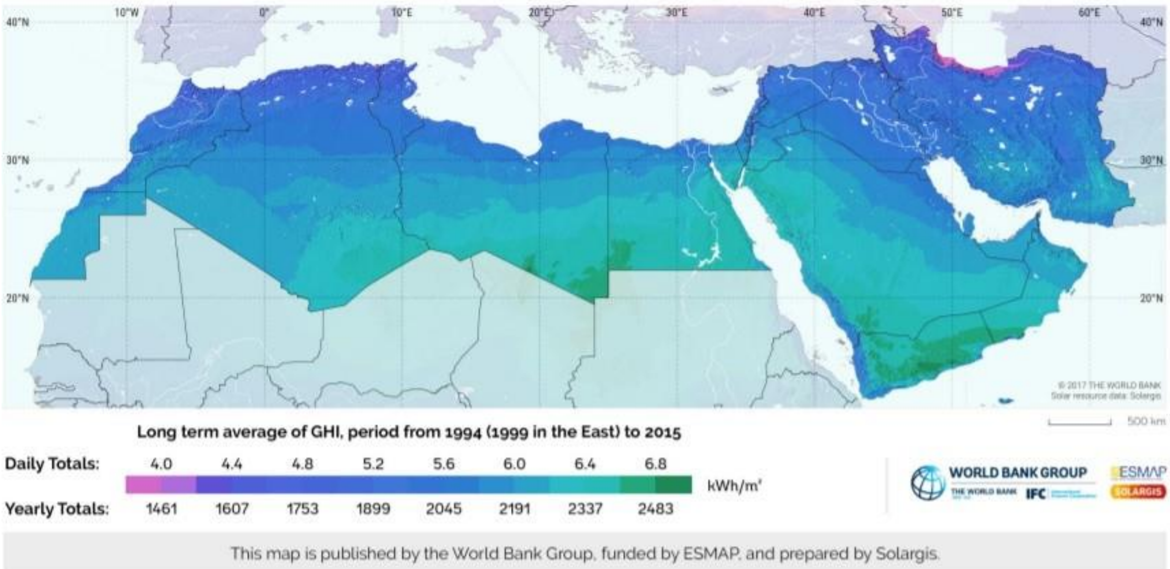


*Figure 11. Global Horizontal Irradiation in Middle East and North Africa region (World Bank, 2017)*

### 2.5.1. Passive design strategies in the Middle East

By reviewing the potential for climate benefit as mentioned before, this study argues bioclimatic design strategies, which takes into account the analysis of the climate and environmental characteristics to achieve comfort conditions and reduce energy consumption, provide another important approach for building morecomfortable dwellings in the Middle East (Nuno et al., 2011). Middle Eastern vernacular architecture can be an important instance of this. According to (Saadatian et al., 2012; Mohamed, 2010) wind towers have been utilised in MiddleEast as ventilation devices to provide natural ventilation and catch the fresh air within passive systems. They have been in various forms as wind-catchers in SaudiArabia or Malqaf in Egypt and Syria. Solar gains also play a major factor in design strategies in the vernacular architecture due to the hight solar irradiation levels in the region. However, the solar gains assist mainly in winter to maintain comfort and reduce cold stress, therefore choosing the appropriate orientation is essential in order to minimize the penetration of the sun radiation in the summer and maximizeit in the winter (Mohamed, 2010).

Furthermore, in the context of Lebanon which suffers from a chronic shortage in electricity supply and summer internal comfort relies heavily on air-conditioning, the implementation of bio-climatic design demonstrates its importance in searching forthermal comfort. Saleh (2018) study contributes investigating the environmental performance of heavyweight construction in Lebanon in order to achieve NetZero dwellings. The study shows that uninsulated double masonry walls can provide thebest indoor environmental and decrease the summer overheating the most. However, implementing the NetZero buildings in Lebanon require not only improving the envelope performance but also understanding other factors associated with producing sustainable buildings. Omar (2020:1) proposed that there is a quantifiable relationship between three pillars—material properties, energy systems, and the culture and social behaviour of occupants—that work together towards a new concept of near zero-energy buildings in Lebanon.

Therefore, creating more socially and environmentally aware dwelling can have a double positive effect on maintaining comfort indoor temperature and reducing energy uses. This synergy applies the best in the case of design of naturally ventilated buildings. While it is argued that natural ventilation can assist as an efficient method for maintaining a comfortable indoor environment, this method canbe reliable in moderate climates (for instance. the Mediterranean climate in many cities in Syria, Lebanon, and Egypt) where climate variables offer the benefit from the solar gains and prevailing wind. A study done by Annan et al. (2016) examinedthe effectiveness of natural ventilation by conducting a survey in the typical dwellings in the capital city of Lebanon, Beirut. The study found that Beirut occupants' behaviour in regulating the opening and closing of the windows is indicative of considerable potential for saving energy by using natural ventilation instead of air conditioning specifically for the two moderate seasons of fall and spring. Understanding the cultural and social practices is essential for producing more comfortable spaces.

In conclusion, the studies highlight the challenges and opportunities related to thermal comfort and energy efficiency in the Middle East. It can be concluded that energy efficiency implementation in the building industry is limited, and compliance with energy efficiency codes is still low. This emphasizes the need to develop localized thermal comfort standards that address both cooling and heating needs in the region. While, passive design strategies, such as bioclimatic design, show potential for creating comfortable and energy-efficient dwellings, understanding material properties, energy systems, and social behavior is crucial for achieving comfortable dwellings in the Middle East.

Overall, there is a need to prioritize thermal comfort and energy efficiency in the Middle East by adopting passive design strategies and considering local climate conditions and cultural practices.

### 2.6. Thermal comfort in Syrian Social Housing

Based on the pervious literature review, it can be concluded that thermal comfort is a critical aspect of housing design and occupant well-being, especially in regions like Syria with varying climatic conditions. Syria experiences hot summers and cold winters, making it essential to assess the current state of thermal comfort in Syrian social housing, considering the challenges faced by the social housing sector.

The review encompassed an examination of housing sector, particularly social housing schemes and typologies implemented in Syria. Additionally, the thermal properties of Syrian housing and existing thermal standards were discussed to gain a comprehensive understanding of the contextual factors influencing thermal comfort.

Furthermore, the review acknowledged the impact of the ongoing hostilities on Syria's energy sector, particularly the domestic energy supply. Understanding the energy supply situation is crucial for informing the methodology of the study and identifying potential constraints or opportunities for enhancing thermal comfort in social housing.

By considering these factors, the research aims to contribute to the existing knowledge on thermal comfort in Syrian social housing. The findings will inform future reconstruction efforts and provide insights for improving the thermal performance of social housing, promoting energy efficiency, and creating more comfortable living environments for occupants.

#### 2.6.1. Housing sector in Syria

The housing sector in Syria has been suffering from both a shortage and affordability crisis that has been increasing significantly since 1970s in conjunction with rural- urban migration in most Syrian cities % (Haddad, 2018:2). Prior to the conflict, over half of Syria's population lived in urban and peri-urban areas (Cunial, 2016:5). The high property prices (land prices, prices of housing buying and renting) and the shortage of housing supply have caused a significant imbalance between supply and demand in the Syrian housing market.

The Syrian Centre for Statistics identified a housing need of 1.5 million dwellings in 2007, while the housing market only supplied 10% of that demand (Haddad, 2018:10). This challenge has put pressure on residents, especially in larger cities like Damascus and Aleppo. As a result, residents have sought affordable housing options such as moving to the outskirts and increasing informal housing sprawl. According to statistics from UN-HABITAT (2007), it was estimated that slums[1] in Syria housed around 10% of the urban population in 2005 (Goulden, 2011:190). However, the influx of Gulf investments into services and real estate after 2005, which was limited to building new tourist villages and resorts, has negatively impacted housing prices in Syria (Haddad, 2018).

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[1] S*lum household according to UN-HABITAT is one that meets one or more of the following conditions: overcrowding, low building quality, poor water supply, poor sanitation facilities, and insecure tenure*

Moreover, the few constructed public housing projects in that period were often badly managed and limited for well-connected individuals. As a result, World Bank (2015) has stated that the informal housing increased from 10% in 2005 to 19.3% and 22.5 % in 2007 and 2014 respectively. However, the official statistics have different estimation. It was estimated by the Syrian centre for statistics (2011) thatthe percentage of people who have been living in informal settlement in 2011 is 35-50%. The reason behind the conflicting statistics was clarified by (Goulden,2011:188) that the housing stock classified as informal would, in large part, not regarded as slums based on the UN habitat definition of slums.[1] However, many houses have infrastructure services including water and electricity but lack official registration. Although it is the government policy of considering these areas as illegal and should be destroyed, it is only legal to carry out such demolitions if alternative housing is provided.

In order to adress the housing need and provide affordable housing alternatives, various strategies and programs have been implemented. Social housing schemes in Syria have emerged since the 1960s, in conjunction with the emergence of the housing cooperative sector. Social housing in Syria refers to subsidized housing that is fully or partially supported by public institutions for low-income and middle-income groups who cannot afford accommodation without subsidies (Ministry of Housing, 2009).

In the upcoming section, an in-depth examination of social housing in Syria will be undertaken to gain a comprehensive understanding of the different typologies and schemes implemented in the country.

### 2.6.2. Social housing schemes in Syria

Several social housing programs have been set for implementation in successive five-year development plans (Ministry of Housing, 2009). Different schemes of social housing cover two main categories of housing supply. First, housing built by the General Establishment of Housing, which has several programs to provide subsidized housing projects. These housing units are built and delivered partially or fully by the General Establishment for Housing and its construction companies. Second, housing built by housing associations, which are private, non-profit organizations that provide low-cost new housing for sell. There are multiple schemes to provide housing including:

1) Low-cost housing, which has many programs including Labour Housing for State employees and social workers, youth housing and housing for university professors.
2) Housing supplied under the home ownership saving scheme, based on the Saving for Home Ownership Act No. 38 of 1978. The scheme has been designed to accommodate families subscribing to the scheme within no morethan 5 years.
3) Housing for military employees and the families of martyrs, which is providedby the martial housing cooperation that was established based on LegislativeDecree No. 12 of 1975.
4) Housing corporations (social landlords): based on Legislative Decree No. 94of 1953, the cities councils have the right to establish housing for public employees and workers.

The General Establishment of Housing[2] in its five-year plan for housing sector (2011- 2015) estimated the housing needs by around million housing unit (Ministry of Housing, 2020). although the response for this need had been mainly through market-led sector (78%) and the public sector (10%), and 12% of cooperatives "Social landlords"), it is argued that the actual implementation was only 10% of theestimated needs (Haddad, 2018:10), which reveals the major barrier in social housing delivery of the delay in construction process.

Despite the policies and programs made by the public sector to meet the housing needs, the practical operation of these programs has been insufficient (Haddad, 2018). The main obstacle is related to the administrative operation of these programs. The gap between housing supply and demand is related to the mismatchbetween the allocated numbers of affordable units to be implemented during the future plans and the actual numbers of affordable units that are provided on the open market during the same period of time. For instance, the number of affordableunits to be provided by the General Housing Establishment in the tenth five-year development plan (2005-2010) was 4810 for Young

[2] *The General Establishment for Housing was created by the government in 1982 to provide affordable housing for low- and middle-income groups in the Syrian cities.*

Housing Programme, and the actual number of affordable units that were implemented in that plan was 3700 units (Al Khalaf, 2014:52).

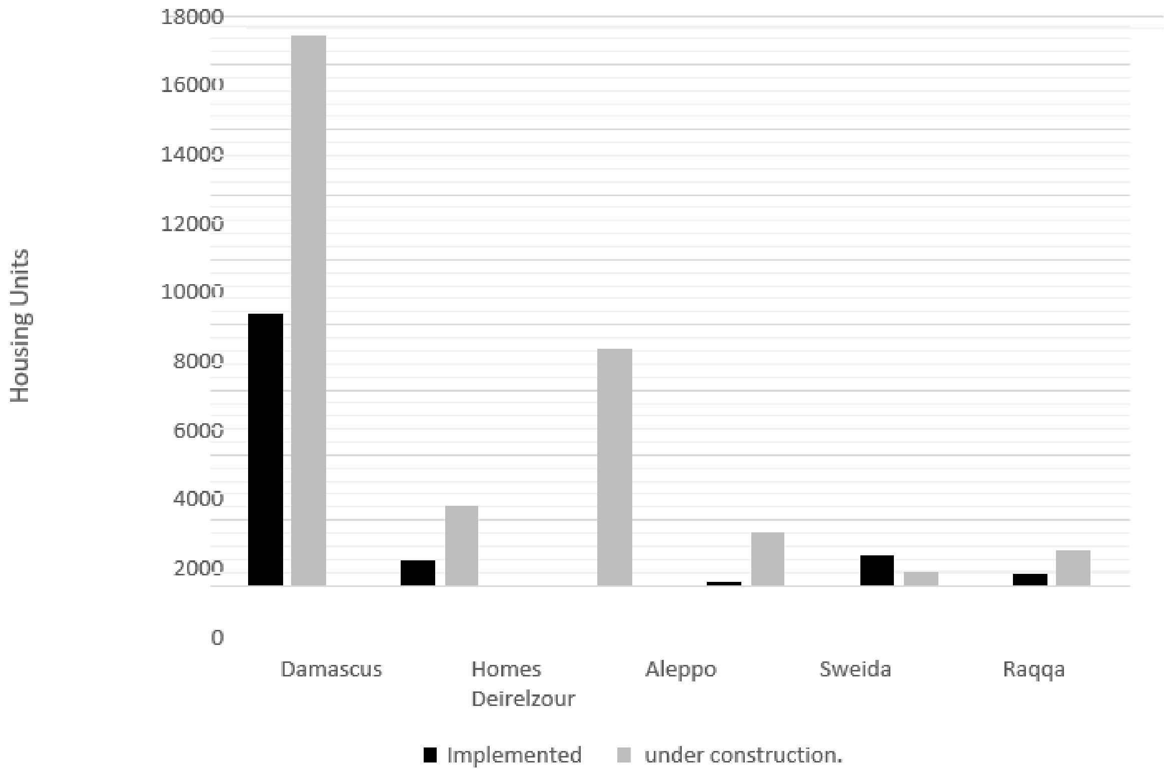


*Figure 12. the Housing units provided through the General Establishment for housing (2000-2010) (The General Establishment for Housing Report, 2011:16)*

(Figure 12) shows the numbers of constructed and under construction housing units in different Syria cites for the period 2000-2010. According to the General Establishment for Housing report (2011:16), the overall constructed housing units over the entire country is 11, 481 units, while the under-construction units and under planning are estimated to be respectively 40,850 and 31,114 units, which overall means that it meets 10% of the estimated housing needs for this period.

Moreover, social landlords suffer from bureaucratic management with having more than one supervisor from the general establishment for housing without any of them making the final decision. There are 2,500 housing association, with more than one million members. However, like the housing provided by the General Establishment For Housing, it takes more than 20 years to deliver houses to the members (GEH Report, 2011). The failure to meeting the members' needs as well as corruption during the construction phase resulted in mistrust in the effectiveness of this sector (GEH Report, 2011) Instead of restructuring the systems of housing associations in Syria, the Syrian government has issued law 3; 2019 for the housing cooperative housing union dissolution. Currently, drastic physical damage to Syrian housing has resulted because of the ongoing war in Syria. Housing is by far the most affected sector comparing to agriculture, health, education, energy, and transport with 65% of the estimated damage (Kostial and Gobat, 2016:21).

However, it is important to state that not all buildings are completely damaged but are partially damaged. Many have sustained only partial damage, where some building structures remain. (Figure 12) shows the percentage of housing units damaged or destroyed in Syria up to 2017, by city. It is estimated that around 760,000 housing units in Syrian cities were damaged by 2017 (Reach, 2019:2), which counts to around 20% of the existing dwellings in Syria before 2011. This acute shortage of housing, and dramaticdamage have led to spiraling rents and house prices across the country, even for houses that lack adequate standards (Reach, 2019). As a result, most young familieswho are considered as low-to-middle income families are not able to rent or buy a home.

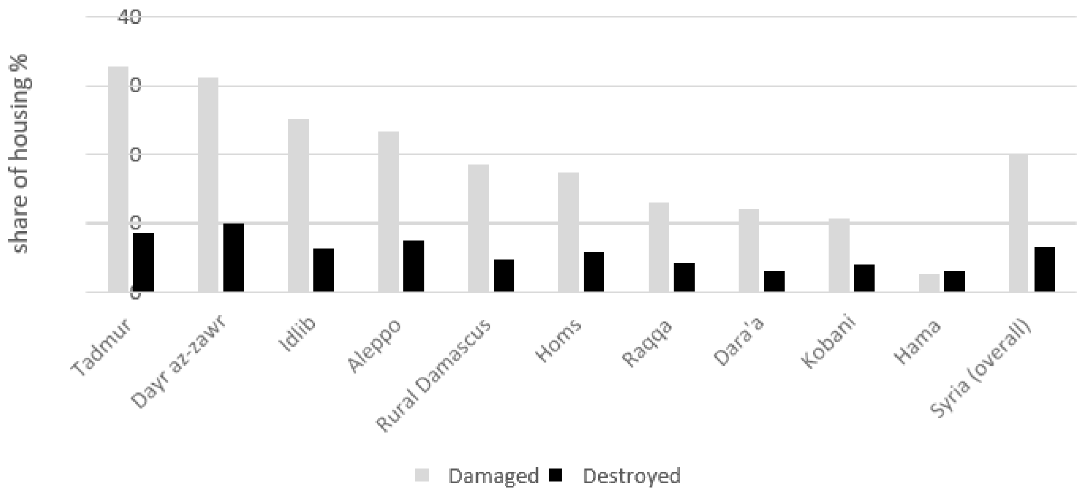


*Figure 13. Percentage of housing units damaged or destroyed in Syria as of 2017, by city (Reach, 2019:3).*

Overall, the social housing sector in Syria has encountered significant obstacles, including failed management, market monopolies, and extensive housing and infrastructure damage caused by the Syrian war. These challenges, both pre-existing and post-war, have resulted in serious issues with housing supply. (Figure 13) provides a comprehensive overview of the discussed challenges.

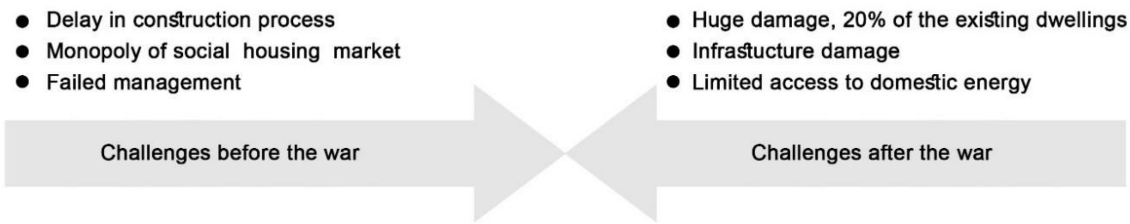


*Figure 14. Challenges in the social housing supply in Syria*

In this context, several questions arise regarding the quality of Syrian social housing. Firstly, it is essential to evaluate the current state of Syrian social housing in terms of its quality. Furthermore, the reconstruction of domestic dwellings in Syria needs to be considered from both environmental and social perspectives, particularly in relation to pre-war models.

Additionally, it is necessary to examine the available evidence on the environmental and social performance of social housing in Syria. This assessment should address whether the current social housing model meets local needs and contributes positively to regional efforts in combating climate change.

The next section explores the performance of social housing in Syria, with a specific focus on assessing thermal comfort levels within the existing model. This analysis aims to provide insights into the quality of social housing and its alignment with environmental and social requirements in Syria.

### 2.6.3. Thermal Performance of social housing in Syria

Several studies have investigated the domestic energy supply in Syria. For example, a study by (Othman, 2018) argued that the household sector is considered as the greatest energy-consuming sector which consumes around half of the total energy in Syria, followed by the Industrial and commercial sectors. The significant consumption of energy in Syria is related to the increasing urbanization taking place and the ever-growing use of household appliances and air conditioners. While domestic sector accounts for the significant energy use, it can be noticed that electrical devices, lighting account for the most energy use (Figure 15).

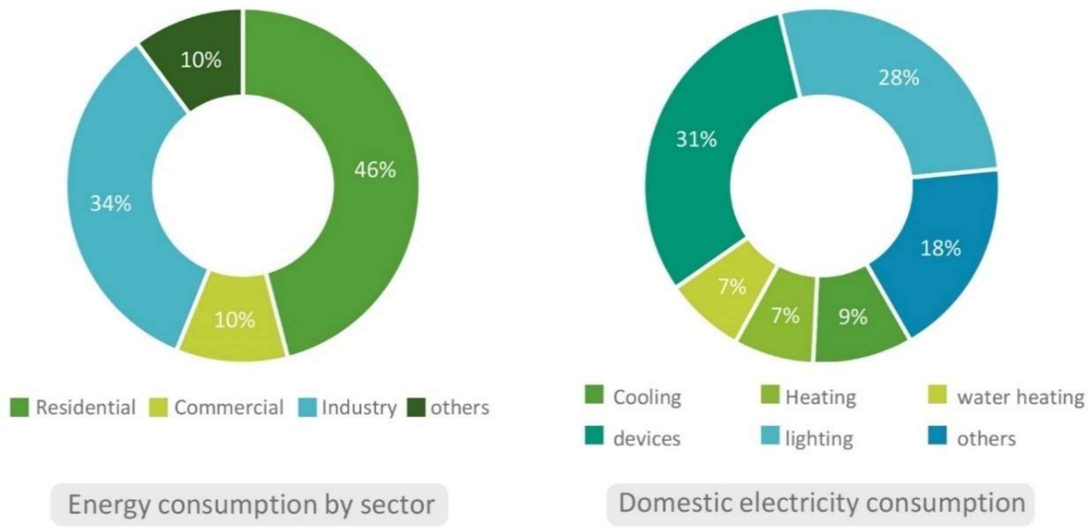


*Figure 15. Energy consumption in Syria (Othman, 2018).*

However, multiple policies have been promoted to improve energy efficiency and increase the thermal quality of Syrian dwellings. There are two policies, which relatedirectly to the thermal performance of the dwelling. Firstly, the thermal insulation code for buildings in 2008, which set the optimum internal conditions for residential buildings and the required thermal properties of the envelope (Table 5). Second, the Syrian Law No. 18 in 2009 which set a general criteria of energy efficient home applications in order to reduce the consumption of electricity (Khaddour, 2021:1).

*Table 5. Environmental targets in residential buildings (Syria building code. Thermal insulation Appendix, 2008).*

| Syrian Code | | | | | |
|---|---|---|---|---|---|
| **Space Use** | **Dry Bulb temperature (C°)** | | **Relative humidity (%)** | **Components** | **(U value) W/(m²K).** |
| | **Summer** | **Winter** | | | |
| **Livingroom, Bedroom and dining room** | 22 | 24.25 | 40-50 | **External walls** | 1.5 |
| **Corridor** | 18 | 26-28 | - | **Internal walls** | Not given |
| **Baths** | 26 | 26-28 | - | **Intermediate floors** | 1 |
| **Kitchen** | 20 | 24-25 | 40-50 | **Glazing** | 3.5 |

Although the energy efficiency measures (building insulation, thermal solar systems) are required for building permits plans, there measures are not implemented in most domestic buildings during construction.

On contrary, another project funded by the EU called the Energy Efficiency in the Construction Sector in the Mediterranean has provided a review about the status of Energy Efficiency Building Code in the Mediterranean partner countries including

Syria (Lihidheb, 2014). It states that the thermal standards related to the building envelope are mandatory while Energy Efficiency Building Codes related to "active systems" including HVAC, Lighting are voluntary. This conflicting literature can be explained in reviewing the real case scenario of the construction industry in Syria, where no energy efficiency measures are implemented in reality. As result, the current housing in Syria is characterised with absence of insulation or energy efficiency measures.

Moreover, according to (Khaddour, 2021), the poor housing energy efficiency in Damascus is a result of the absence of assessment frameworkof operational energy performance improvement potential, which resulted in low- performance envelopes and greater negative effects of air leakage and low thermalresistance.

#### 2.5.4. Thermal Standards for thermal Comfort in Syria

The thermal standards for residential buildings in Syria are provided in the Syrian Code for Buildings (Syrian Code, 2008). However, the standards are given only for active heating and cooling while no standards were given for naturally ventilated dwellings. in comparison with CIBSE comfort criteria (CIBSE, 2015), it may be argued that CIBSE standards are more flexible with bigger comfort range for summer and winter, which is beneficial for adapting passive strategies to reduce heating and cooling loads. Therefore, this study combines the approach to adaptive comfort in the thermal standards with comfort criteria to the Syrian case.

*Table 6. Internal temperatures in residential buildings (Syria building code. Thermal insulation Appendix, 2008).*

| | Syrian Code | | CIBSE | | |
|---|---|---|---|---|---|
| Space Use | **Dry Bulb temperature (C°)** | | **Dry Bulb temperature (C°)** | | **Relative humidity (%)** |
| | **Summer** | **Winter** | **summer** | **winter** | |
| **Livingroom, Bedroom and dining room** | 22 | 24.25 | 22-25 | 22-23 | 40-50% |
| **Corridor** | 18 | 26-28 | 21-25 | 19-24 | - |
| **Baths** | 26 | 26-28 | 23-25 | 20-22 | - |
| **Kitchen** | 20 | 24-25 | 21-25 | 17-19 | 40-50 |

While considering naturally ventilated dwelling, occupants seem to adapt to the internal environment according to the outdoor temperature. (CIBSE, 2015) allows for a±3K from the comfort temperature for the adaptive approach. Hence, the values given by the Syrian code is adopted with adding a range of ±3K.

*Table 7. Adaptive comfort ranges combined with Syrian code comfort criteria.*

| **Space use** | Dry bulb temperature (C°) | | Relative humidity (%) |
|---|---|---|---|
| | Winter | Summer | |
| Livingroom, bedroom, and dining room | 19-25 | 21-28 | 40-50 |
| Corridor, W.C | 15-21 | 23-31 | - |
| Baths | 23-29 | 23-31 | - |
| Kitchen | 17-23 | 21-28 | 40-50 |

### 2.6.4. Domestic Energy Supply in Syrian Housing

Syria's energy sector has been heavily affected by the ongoing hostilities. Prior to the conflict, Syria was a natural gas and oil producer in the MENA region as the energy sector accounted for a fourth of government income (RCREEE, 2013:16). The domestic sector in Syria is mainly dependent on non-renewable energy resources. 94% of generated electricity comes from conventional thermal power plants based on oil and gas, whereas 6% come from hydropower (RCREEE, 2013:17). The energy consumption of typical dwelling in Syria can be illustrated in (Figure 15).

While the cooling and heating systems rely on electricity through air conditioning units, a lot of families in Syria still use diesel for heating through woodfires during winter and ceiling fans for cooling during the summer. As for cooking, typical households in Syria uses gas- ringed hobs for cooking.

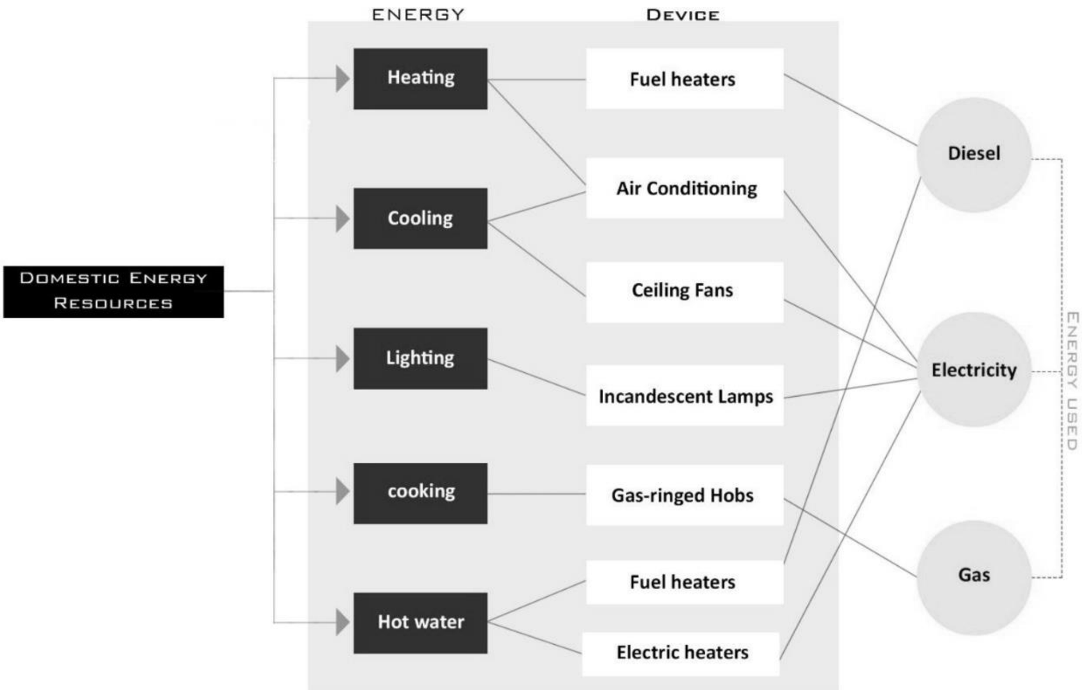


*Figure 16. Domestic energy resources in Syria.*

As a consequence of the Syrian war, drastic damage has occurred to the energy infrastructure including oil, natural gas pipelines and electricity networks. This made supply of fuel is very challenging. Syria energy statistics shows a massive gap between energy demand and energy supply (Butter, 2015:10). Electricity infrastructure has been attacked.

As a result, energy deprivation in Syrian homes has been a significant systemic problem, that can be measured in the expenditure on domestic energy. While the typical expenditure threshold of measuring fuel poverty is 10% of household income (Boardman, 2012:143), households in Syria need to spend more than 42.5% of average income to maintain an adequate level of warmth and provide energy for cooking (Haddad, 2019:23).

While the current conflict has exacted a heavy toll on Syrian economy, the domestic crises can be observed back in 2008 when the government has removed subsidies on fossil fuels and replaced it by cash transfers for lower income groups. According to International Monetary Fund (2009:14), "the replacement of the diesel coupons with cash transfers is likely to enhance the targeting of assistance and consolidate efficiency and fiscal gains". However, the implementation of this strategy was chaotic, and most people were unable to receive the assistance. As a result, the price of diesel jumped from 7 SYP/litre to 25 SYP/litre, which had a strong negative effect on people who were just above the poverty line (Haddad, 2019:22).

A study by Haddad (2019), revealed that the typical Syrian family spends 600-800 litres of fuel oil for heating per year. While the heating season extends for four months in Syria, the introduced measure had put more pressure on the Syrian familyto compensate heating with other household needs. The Syrian conflict hasdramatically affected Syrians, particularly low and middle-class groups. With inflation not being matched by wage increases, Syrians are facing a five-fold reduction in purchasing power (Bolton, 2020:3).

As a result, most families have been left unable to cover the heating expenses for the heating season. In 2015, the government offered cash transfer for 400 litres ofthe supported fuel oil, which costs 180 SYP/litre in accordance with the introducedsmart card in 2018, while the unsupported oil could reach 300-350 SYP/litre. The delay in transferring cash and corruption in Syria have left Syrians compensating the expenditure on energy for other expenses like food. (Figure 17) shows the significant increase of fuel prices in Syria.

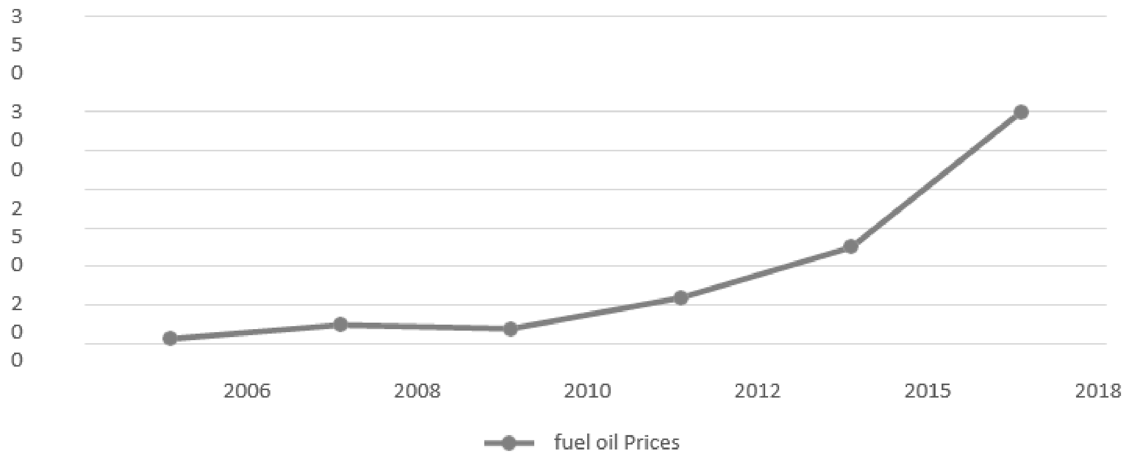


*Figure 17. Fuel oil prices in Syria (The researcher based on data provided in Haddad (2019) study).*

At the same time, the cost of gas, which is mainly used for cooking, has increased dramatically, while the price of the gas tank was relatively affordable. The figure hascompletely changed after 2011. Households have also opted for gas substitution (mostly electricity in case of availability or using firewood in the rural areas under the recurrent electricity cuts). Based on the previous studies, it is proven that most Syrian families may experience cold conditions due to the poor performance of housing, which add greater difficulties to the low and middle-income groups in Syriato secure a comfortable domestic space.

### 2.6.5. Low energy social housing in Syria

According to literature studies, several projects have been undertaken to improve energy efficiency and promote the adoption of renewable energy in the MENA region. One notable initiative is the development of a Sustainable Energy Action Plan by the EU in 2010. This plan aims to enhance energy efficiency and implement climate change mitigation measures at the local level, including in countries like Syria.

Another project, commissioned by MEDA-program, supported the design, construction, and monitoring of 10 low- energy demonstration buildings (Pilot Projects) in 10 southern and eastern Mediterranean countries including Syria from 2006 to 2010 (Wenzel, 2009:3).

These projects reflect the increasing recognition of the importance of energy efficiency and renewable energy in the MENA region, including Syria. They demonstrate a collective effort to address climate change concerns and foster sustainable development by integrating energy-efficient technologies and renewable energy sources.

The pilot project in Syria was a low-income residential building in the social housing neighborhood of Qudssia in Damascus. The approach of low energy inventions was "smart technology mix" which consider the relation of energy savings to additional cost, limit the use of available technologies in choosing the feasible technology according to the type of building, the climate zone, national energy prices and the availability of technologies. In the case of Syria, the technology used are thermal insulation, traditional shading, solar chimney, evaporative cooling, solar floorheating & hot water.

On average, the low energy dwelling in Syria showed 64% of primary energy saving compared to a conventional building of the same size and comfort (concerning heating and cooling). This needed incremental investments of about 37% and showed a pay-back (Wenzel, 2009:10). This present a high protentional of technical feasibility of low- and even zero-energy houses and green buildings in the region. However, professionals have very limited qualification for identifying the appropriate technologies and no experience in implementing. For instance, insulation material had to be imported as no production facilities exist in Syria due to inexistent demand.

Moreover, the study argues that the poor economic performance indicatorsof the Pilot Project in Syria are mainly the result of highly subsidized energy tariffs.The lessons learned of the MED-ENEC project seem to be evidently an appropriatepolicy mix of energy efficient products and strategies with emphasis on reducing non-targeted energy subsidies and at the same time protecting the vulnerable part of the population. An integrated package of regulation and standards, financial support and incentives, information, training has to come along with improved economic framework conditions in order to successfully improve energy use in Syria.

#### 2.6.6. Conclusion

In conclusion, the literature review highlights the importance of thermal comfort in

Syrian social housing and the challenges faced by the housing sector in meeting the demand for affordable and quality housing. The shortage and affordability crisis, as well as the extensive housing and infrastructure damage caused by the Syrian war, have significantly impacted the housing supply in the country.

The review also reveals the need for further research and evidence regarding the environmental and social performance of social housing in Syria. Addressing the housing needs and improving the thermal performance of social housing in Syria requires a comprehensive approach that takes into account factors such as building design, energy supply, and the social and cultural context. This can contribute to the development of sustainable and comfortable living environments for occupants while also promoting energy efficiency and climate change mitigation.

Overall, the findings underscore the urgency of addressing the multifaceted challenges present in the Syrian social housing sector. This comprehensive approach holds potential for improving housing quality, ensuring optimal thermal comfort for occupants, and bolstering the overall well-being and resilience of Syrian communities. Further research and evidence-based policy interventions are needed to effectively navigate the complexities of the post-war housing model in Syria.

# Chapter Three

## 3. Methodology

This chapter sets out the implemented methodology of investigating the thermal performance of the case study dwelling. This includes building modelling, simulation process and personal diaries. The methodology approach is based on the new zero energy design hierarchy proposed by Kimpian et al. (2021) where understanding occupant needs and their spatial-related activities, significantly influences building performance. In order to close the performance gap, feedback should be considered as a main stage for flexible and adaptable design strategies. This study argues that the human-centric approach can assist not only to design new zero energy dwellings in Damascus but also to understand how our conventional dwellings perform from an occupant perspective, which informs later the future design process.

Therefore, this study intended to look at the building performance evaluation of thecase study with regards to the thermal performance of the envelope and the way the family uses their space on a daily basis. While the environmental simulation hasbeen used to quantify the thermal performance of the envelope, the diary format has been in this research a functional tool to involve the residents in framing the problem of discomfort.

First, the climate of Damascus has been analyzed considering multiple climate variables and their impact on the design decision-making. Then, the case study configurations including geometry, physical properties, constructions, occupancy patterns, ventilation mode, and the modelling assumptions are described in order to model the thermal conditions in the case study building. Furthermore, the non-physical information about the occupants and their relation to their home are described based on the field study of thermal comfort (Figure 18).

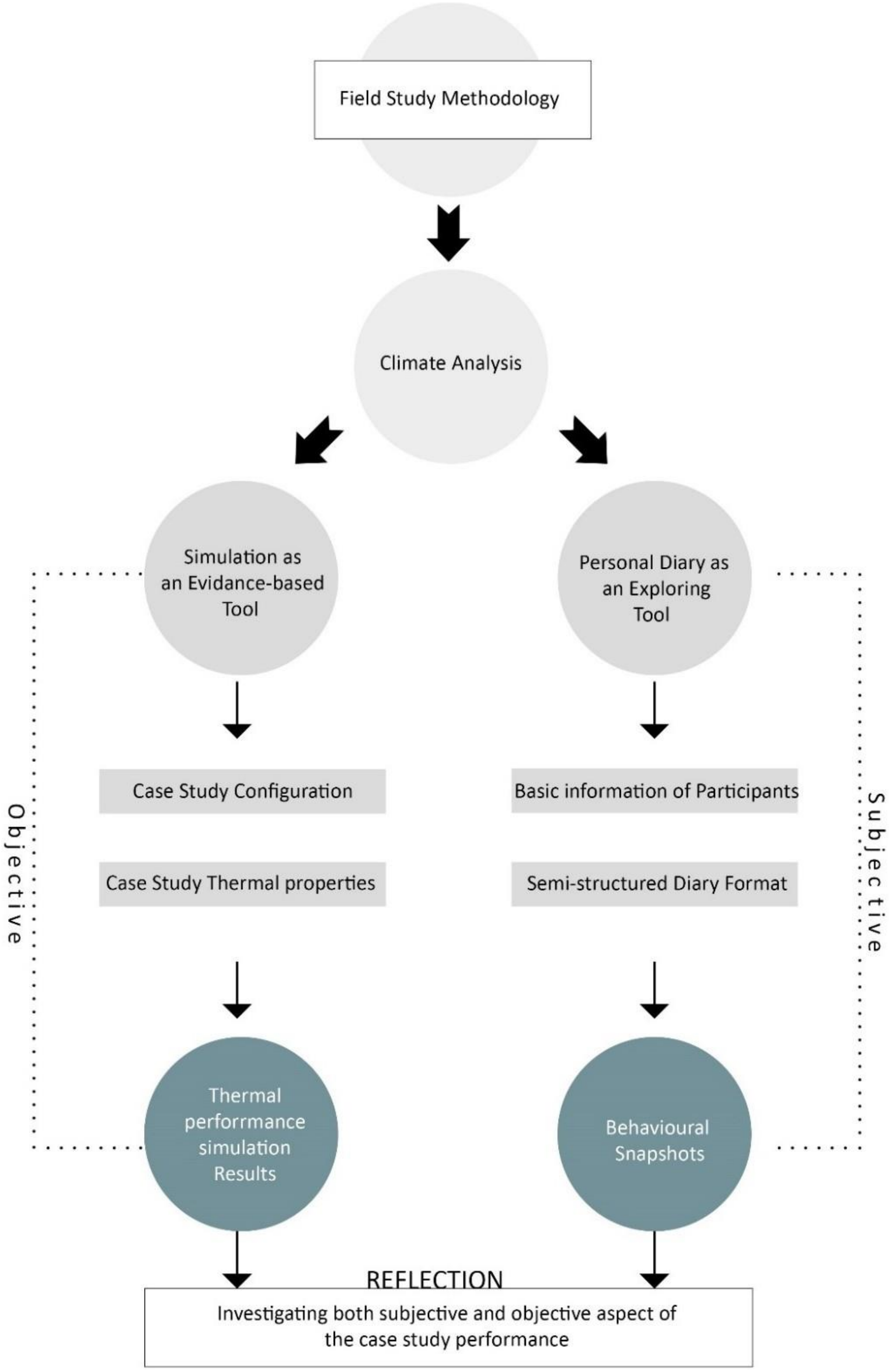


*Figure 18. The methodology of the case study.*

### 3.1. Research Design-study approach

Case studies have been considered in multiple studies as an assisting tool for the preliminary stages of research studies, which investigatse a phenomenon or settingwithin its real-life context (Gillham, 2000; Rowley, 2002; Sarvimäki, 2016). The casestudy approach can be particularly useful for exploratory research when the boundaries between phenomenon and context are not clearly defined (Yin, 2013). Eisenhardt (1989: 548) argued that diaries are:

> *Particularly well suited to new research areas or research areas forwhich existing theory seems inadequate. This type of work is highlycomplementary to incremental theory building from normal scienceresearch. The former is useful in early stages of research on a topicor when a fresh perspective is needed, whilst the latter is useful in later stages of knowledge.*

This statement emphasizes that there is a great strength in considering the case study approach for this research project due to the Lack of previous research studies on the performance of Syrian dwellings that would provide the theoretical foundations for the research questions. The case study according to Gillham (2000) can be a single case such as an individual or a group - such as a family. It can also be a large-scale community such as a town. On the other hand, the case study approach might conclude multiple cases based on the research questions that the researcher tries to answer. The case study types in general is summarized in Haddad (2009) study (Table 8).

*Table 8. Case Study Types. (Haddad, 2009)*

| Type | Definition | Reference |
|---|---|---|
| **Descriptive** | Provides a detailed account of a particular issue,person, or process; | Grix, 2004 |
| **Exploratory** | carried out with the intention of testing initial working hypotheses and assessing the suitability ofthe case for further and more extensive research. | Grix, 2004 |
| **Explanatory** | When researchers seek to generalize the results ofthe single case-study and reflect on other cases. | Yin, 1994; Grix, 2004 |

While case study selection varies between single and multiple case designs, Yin (1994) has argued that the selection criteria of the single case study may also vary based on the purpose of the case inquiry. There are three approaches to select a single case study. The first approach of the single case study is the critical case, which addresses questions related to a formulated theory. The second approach of selecting a single case study is selecting a unique case study in order to document a rare case. Finally, representative case study can be followed as a research method in order to capture the daily conditions of the case study. While some studies select a single case study, other studies can be approached by selecting multiple case studies can in order to create a comparison among the case studies (Table 9).

*Table 9. Selection criteria for single and multiple cases. the researcher based on (Yin, 1994)*

| Single case | | Multiple cases |
|---|---|---|
| **Case study selection** | **The objective of the case study selection** | **The objective of the Case study selection** |
| Critical case | Testing a formulated theory | Literal replication: cases selected to predict similar results |
| Extreme or unique case | Documentation of a rarecase | Theoretical replication: cases selected to predict contrasting results |
| Representative ortypical case | Capture the conditions ona daily basis | |

This research has selected the third approach of the single case study, which is thetypical case in order to develop more contextual understanding of the building performance aspects in an affordable dwelling in Damascus and capture the conditions of the occupant thermal comfort on a daily basis. This in turn can contribute to a comprehensive understanding of the performance of conventional social housing in Syria.

This approach involves collecting data about a typical dwelling in a typical social housing neighborhood in Damascus, using preliminary data analysis to determinethe overall performance of the residential space in order to build an in-depth understanding of domestic conditions of a typical dwelling in Syria.

## 3.2. Case Study selection

After framing the theoretical aspects of thermal comfort and reviewing the factors related to domestic comfort in Syria, in order to answer the question of how the building performance currently affects the occupant behaviour patterns in Syrian dwellings and how occupants respond to the residential space in terms of their thermal-related activities, this study follows more analytical approach on a micro level by analyzing one Syrian typical dwelling. It is important to mention that this study has focused on Damascus, where the data collection can be easier to access than other Syrian cities due to the researcher's current connections. The case study is selected in Dahiya Qudsaya, a social housing neighborhood in Damascus, which was built as a part of a program the Institute for Public Housing launched in 2002 under the name "Youth Housing Project" (Khaddour, 2021).

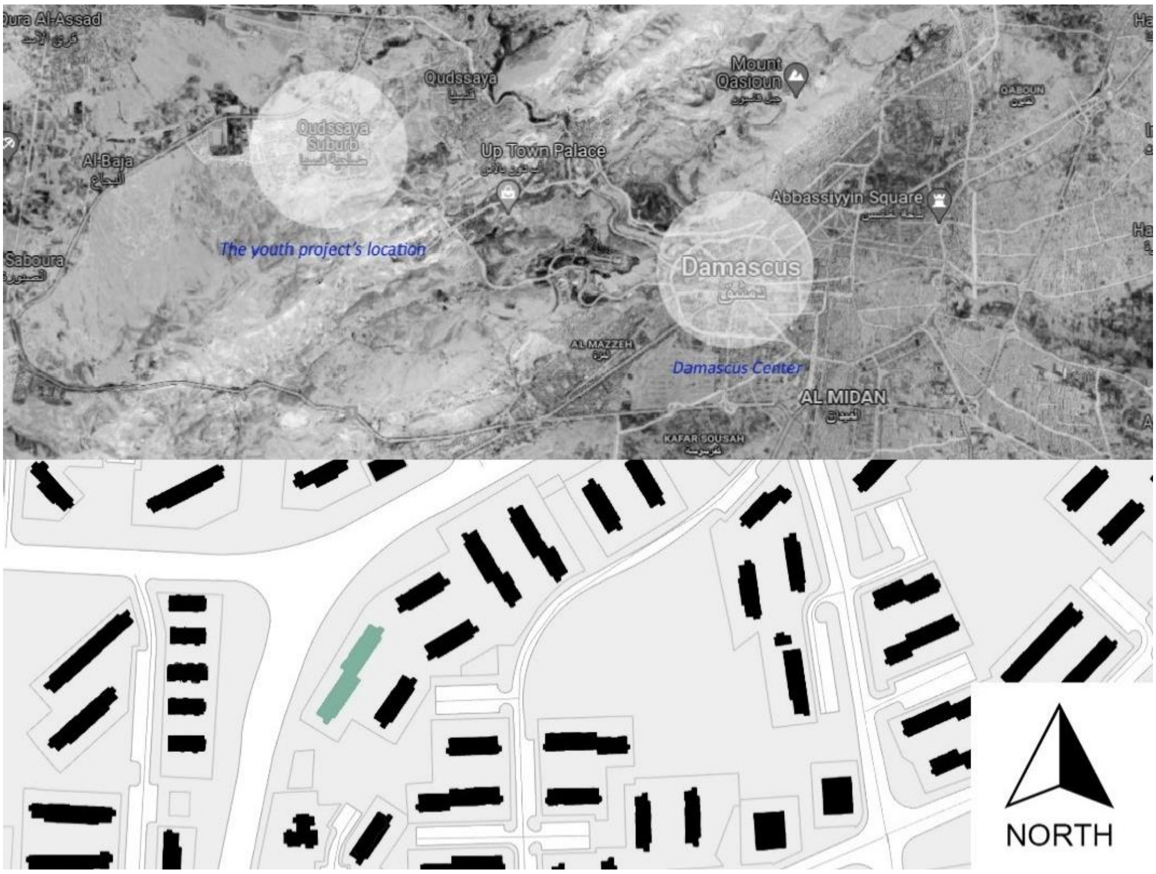


*Figure 19. Location of Qudsaya Neighbourhood in Damascus and the location of the case study building in Qudsaya Neighbourhood.*

One residential building was selected as case study in this research, which is as a representative case study to capture the conditions on a daily basis (Yin, 1994). Block 4 in Dahiya Qudsaya in Damascus is a typical Syrian residential social block. The 3-storey side-attached residential block is located in Qudsaya Neighbourhood. The building is a part of a prefabricated construction scheme, which follows standardized plans and building components as the external walls are composed of 200 mm pre-cast concrete panels. Although the flats layout is standardized in the dwelling, the residents have adapted their flats differently. The building facade shows different adaptations for the same balcony design (Figure 20). Some residentsopted for closing the balcony and adding it to the interior space while some addedseveral components such as canopies or extra balustrades in order to have a more comfortable environment. Further details about the case study flat are provided in Appendix 7.1.

*Figure 20. The selected social dwelling in Qudsaya Neighbourhood.*

### 3.3. Data collection methods

This research attempts to develop an in depth understanding of the performance of the selected case study flat on multiple levels. First step was analyzing the climate and its relation to design strategies. Second, environmental simulation has been conducted to quantify the comfortable temperature levels in the internal environmental. Finally, the relationship between occupants and their used space was investigated through analyzing their personal diaries.

As a result, the case study research method in this study includes mix of quantitative and qualitative approaches in order to holistically address the research question. On the one hand, measuring quantitative data is essential when looking at the physical characteristics of the indoor environment such as calculating air temperature and humidity. On the other hand, qualitative methods enable the researcher to explore complexities that are beyond the scope of more 'controlled' approaches (Rowley, 2002).

This study adopts the concept of the user-centric integrated design which was mentioned in the previous chapter and suggests a new hierarchy of low energy design by Kimpian et al. (2020). This considers the occupant in the design assessment and argues that it is an essential step to build a holistic approach for assessing thermal comfortin the dwelling. This theoretical framework is also supported by the methodology suggested by Roaf and Nicol (2005). The study concluded that field studies of thermal comfort draw attention to the changing nature of the interaction between buildings and their occupant. Therefore, this study argues that analyzing the interaction of occupants and building is crucial to measure the human factor in thermal comfort studies.

As a result, mixed methods of simulation and field studies of thermal comfort contribute to a better understanding of the actual performance of dwelling.

The field study is conducted remotely with the help of an associate[3] who is based in the city of Damascus since the main method of data collection in this research takes place online due to the travel restrictions to Syria. Although Lobe et al (2020) argued that online platforms have increasingly becoming a method among researchers to collect data in response to social distancing requirements during the COVID-19 pandemic, there is multiple challenges facing online research, especiallyqualitative research as stated in Carter et al. (2021) study.

First, barriers to accessing a large sample of participants during the online contact.Not all participants will collaborate in online interaction although it would be part of their daily work or social routine. Second, unlike the traditional research ethics considerations, online data collection raises multiple challenges with regards to ethics including obtaining informed consent. Therefore, Obtaining the consent formshas been conducted with the help of the associate who is based in the city of Damascus.

In addition to the online research challenges, it should be mentioned that this studyfaces another barrier in the Syrian context, this research argues that it is challengingto collect primary data from all flats of the whole case study dwelling since Syria is still a warzone and is not easy to contact large sample of residents

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[3]The associate helper is an architecture student who is based in Damascus, Syria andagreed to help with collecting data.

without an officialpermit from the government. Therefore, it is more facilitated to focus on a smallersample of a residential flat in conducting the field study. After having informal onlinediscussion with some of the households of the dwelling, one residential flat on the second floor is selected since the residents showed interest in participating in the study.

As a result, a mix of methods was used in order to investigate the building performance and comfort-related occupant behaviour in the case study flat based on:

- Phase 1: Climate analysis Considering the lack of research studies about environmental performance of dwellings in Damascus, the researcher argues thata general understanding of climate of the city of Damascus should be considered before being able to assess the building performance. Analysing the climate of the city where the case study flat is located, and setting predesign conditions is an indicator tool that should be considered before being able to assess the building performance.
- Phase 2: Environmental simulation by defining the properties of the dwelling based on the pervious phase as inputs, the case study has been modelled in orderto run an environmental simulation using Ladybug Tools (the use of Ladybug Tools will be explained thoroughly in section: Simulation as an Evidence- based Tool) to investigate the indoor environment conditions during a typical summer week and a typical winter week and assess the thermal conditions of the residential spaces. The primary data about the physical characteristics of the case study flat including construction properties, dwelling layout, and the basic information of the participants including ages, gender, number of households inthe flat, living conditions and space use has been obtained with the help of by the associate helper.
- Phase 3: Diary Format after simulating the objective aspects of the indoor environmental in the case study flat, the subjective aspect of the occupant wasinvestigated through the diary format. The participants (the residents of the flat) were asked to write their diaries about the space use during a typical winter day and a typical summer day in order

- to explore the daily occupant behaviour that relates to the energy use and thermal comfort.
- Phase 4: a reflection, which is typically used in practice-based research in order to assist practitioners to improve practice (Alvesson & Skoldberg, 2000). This study has attempted to reflect on the findings of the case study analysis in terms of passive design and user-centric design in order to speculate about the optimization potential of the dwelling design.

(Figure 21) summarizes the mix of methods used in this study that leads to qualitativeand quantitative results.

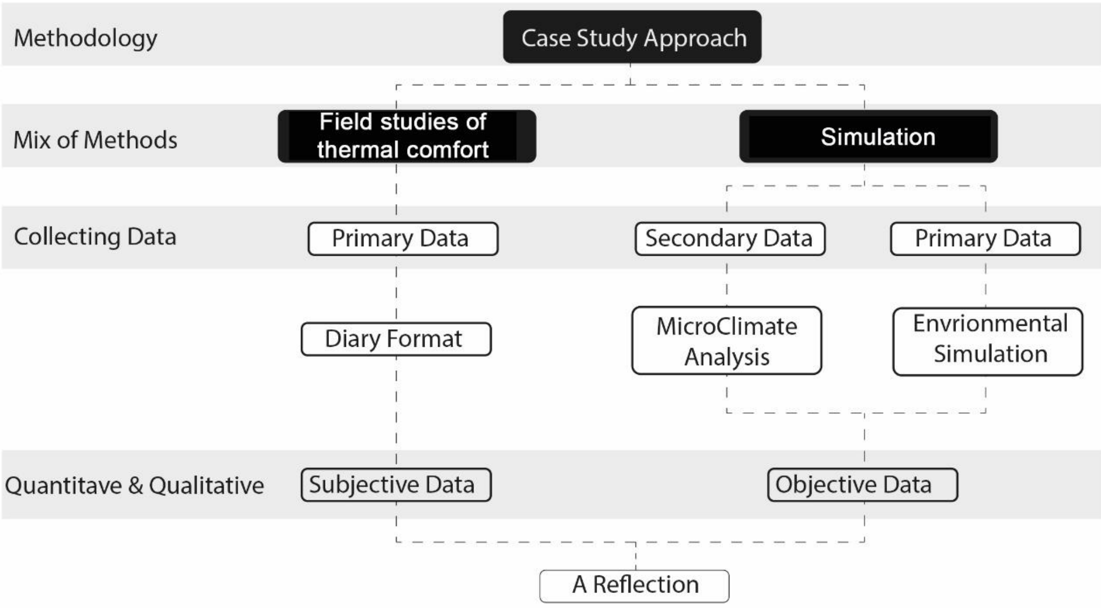



*Figure 21. Research methods.*

### 3.3.1. Climate Analysis as a Prerequisite Tool

The climatic characteristics of the city of Damascus from the viewpoint of human comfort and the thermal performance of buildings have been analyzed using Ladybug Tools. Ladybug Tools is an environmental analysis plugin, which facilitatesthe process of environmental design analysis. The plugin is a free and open-source environmental plugin for Grasshopper, and it is able to calculate the heat and cold stress based on the adaptive thermal comfort model in a parametric environment (Roudsari, 2018). Furthermore, Ladybug tools calculate the indoor and outdoor airtemperature levels in the selected contexts.

The climate characteristics of Damascus were analysed based on the weather file provided from the Typical Meteorological Year weather data (2004-2018) for the city of Damascus according to ISD (US NOAA's Integrated Surface) Database. Thisanalysis involves presentation of the annual patterns of the main climatic variables that has been set in the literature review in Section 2.2.1 including monthly patternsof the sun path, solar radiation, UTCI temperatures, wind speed and cloudiness.

Since prior research studies that are relevant to climate impact on design decision in Syria are very limited, developing a general quantitative understanding of the climate impact of various design strategies was explored in this study using a shoebox model. The aim of this shoebox analysis is to provide a quantitative understanding to the impact of climate on architectural design. According to (Reinhart & Ibarra, 2012), "Shoebox" energy model is an initial, oversimplified energy model of a building in which the actual building (or part of the building) is represented as a rectangular box, which consists of thermal model for the whole zone or the major zones (Dogan & Reinhart, 2013). The shoebox energymodel is particularly valuable to bridge the gap between architecture and other engineering fields by allowing feedback loops in the early stage of design (Dogan &Reinhart, 2013) (Jabi, 2014).

Therefore, this study developed a quantitative analysis by modelling a simple box and testing its performance according to the climate variables of Damascus. The inputs of the shoebox model were limited to the space use, climate data and ventilation mode. Multiple variables including shape, zoning, orientation, window towall ratio and shading were analyzed in the shoebox model.

The geometric form and orientation were analyzed to investigate their influence onboth harmful and helpful solar radiation. Harmful solar radiation was explored during summer months (June-September) while helpful solar radiation was explored duringwinter months (December – February).

In order to investigate the effect of geometric shapes, three basic geometric shapesthat include square and rectangle shapes were established with variations in W/L ratio (Fig. 30). The selection of W/L ratio are based on studies from (Olgyay, 1963;Yeang, 1994) which suggested that building form with W/L ratio 1:1.3 is the optimum ratio for hot arid climate. Another two iterations of different geometric proportion were tested based on the same area including W/L ratio 1:1 and 1:2.

Thirdly, the window to wall ratio was explored based on percentage of times peoplecan be comfortable at indoor environment. While the shoebox model is set to be naturally ventilated, adaptive comfort model is used to quantify the percentage of comfortable conditions when temperature within the selected comfort range.Another design variable was shading devices, which is an essential factor in limitingsolar heat gains during summer months. This study has different horizontal shadingdepths to help assess the effect of external objects on the heating/cooling of interiorspaces. Second, the vertical shading was tested on the four windows orientations to quantify the shade benefit. (Figure 22) summarizes the tested design variables and inputs in the shoebox analysis.

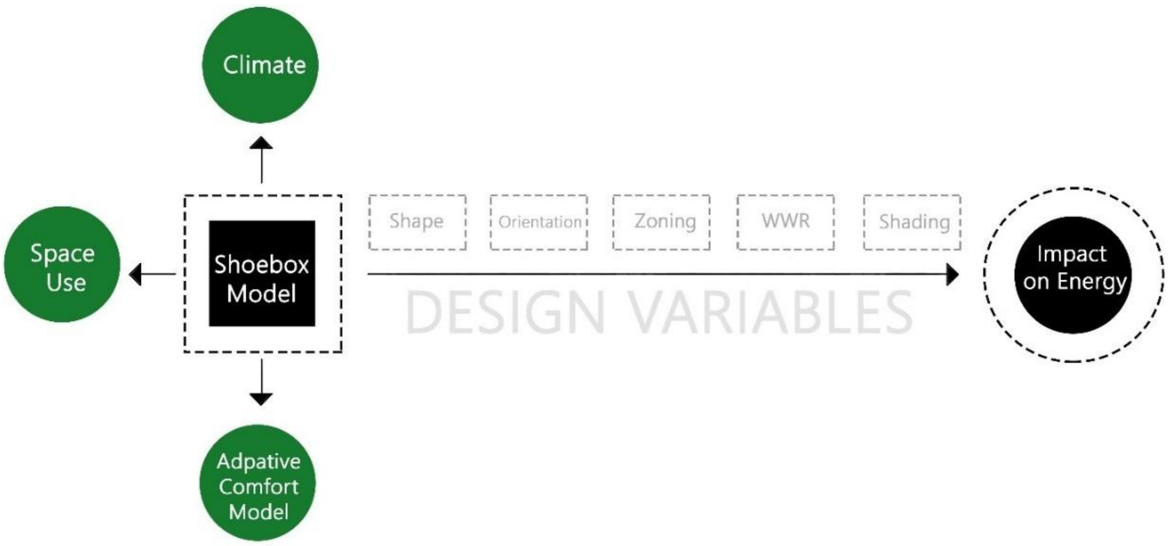



*Figure 22. Shoebox energy analysis inputs.*

### 3.3.2. Simulation as an Evidence- based Tool

This study is aimed at assessing the environmental performance of the case study building by investigating both indoor temperature levels and heat/cold stress in the case study model during winter and summer using the environmental analysis plugin, Ladybug Tools. In order to assess the performance of the case study, thereare multiple methods to collect data for Building Performance Evaluation. According to Sharpe et al. (2013), building performance evaluation methods include gatheringof quantitative and qualitative data. The qualitative data can be gathered through surveys, questionnaires, and diaries while physical monitoring can be conducted togather quantitative data. Multiple studies have combined both qualitative and quantitative research methods to investigate user influence on building performance in terms of expectations, comfort, and interaction with building controls and not only evaluating the building performance itself (Mahdavi et al., 2003; Brown & Cole, 2008).

Looking at building performance evaluation within the context of the Syrian construction industry, it can be argued that the current standard practice lacks anyevaluation for the building's performance or environmental consideration during thedesign phase (Ismail, 2015). Therefore, investigating the performance of the conventional dwellings in use is more challenging, where no clear environmental targets have been set. Although the measures of energy efficient buildings were introduced in the Syrian code for building in 2009 (The Syrian code for thermal insulation, 2008), they are recommended values and not binding regulations. Furthermore, the ongoing conflict presents more pressing challenges toconduct such assessments, where the power dynamics affect the field investigationof comfort in the dwelling. These challenges include difficulties in accessing housingand getting an official permission in Syria to conduct field research. Travel restrictions to Syria also represents another challenge in order to adopt morereliable quantitative method of in-situ monitoring and evaluate the case study performance. Therefore, thefield research is characterized by the improbability of doing physical monitoring.

Building modelling simulation on the other hand offers a helpful tool for providing quantitative data in order to predict the indoor thermal comfort in the case study. Although Building Energy modelling and simulation is mainly used as a research method for increasing housing efficiency at the design stage (Augenbroe, 2002), itcan be argued that it is also applied in the existed buildings, mainly in the retrofit and optimization studies. Since environmental modelling simulation is able to estimate the building's projected performance, water, and energy use, analysing the building performance has been also used in existing building in order to increasethe efficiency of the buildings and improve comfort by exploring multiple optimization parameters. Therefore, this research has adopted building modelling as an evidence-based-tool to investigate the performance of the case study envelope, where doing physical monitoring would encounter multiple difficulties.

Another essential contextual consideration that should be mentioned in selecting the research method is the selection of ventilation mode. Although the case study has a split unit for active heating/cooling in two rooms in the flat, the current continuously electricity cut make it very difficult to have active heating/cooling as areliable source (Hatahet & Shaar, 2021). Therefore, this research has adopted the natural ventilation mode in modelling the case study as a worst-case scenario and a reflection of the real-case scenario that occur on a daily basis in Syria. As a resultof the selection of the ventilation mode, the building performance is investigated through the aspects of indoor temperature. Aiming at the adaptive comfort level, the dwelling has been tested as a naturally ventilated model. Heating and cooling setpoints are required to run adaptive comfort metrics simulation as environmental targets. Combining the environmental targets (the selected heating and cooling setpoints for the thermal comfort in Syrian, which were selected in the previous chapter and summarized in (Figure 23) with modelling inputs, the environmental simulation has been run to calculate the indoor temperature levels and explore the performance of case study.

(Figure 24) explains the followed steps in the simulation process to investigate the performance of the case study.

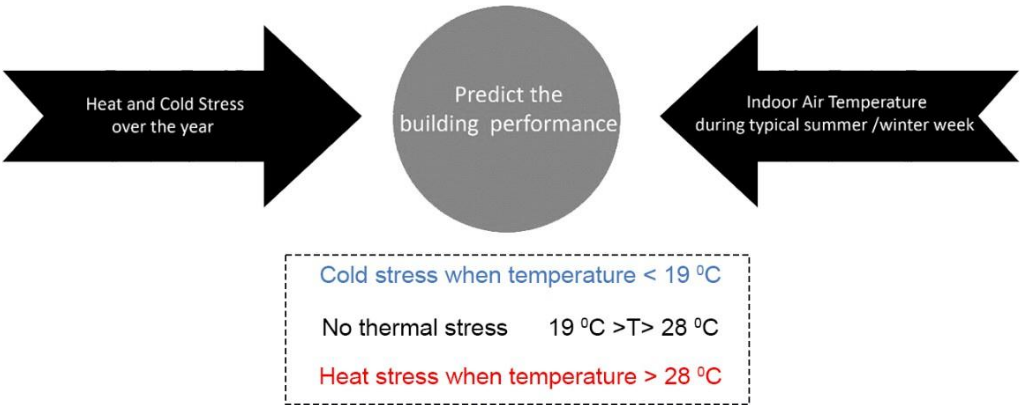



*Figure 23. Quantitative data to be collected in the simulation study.*

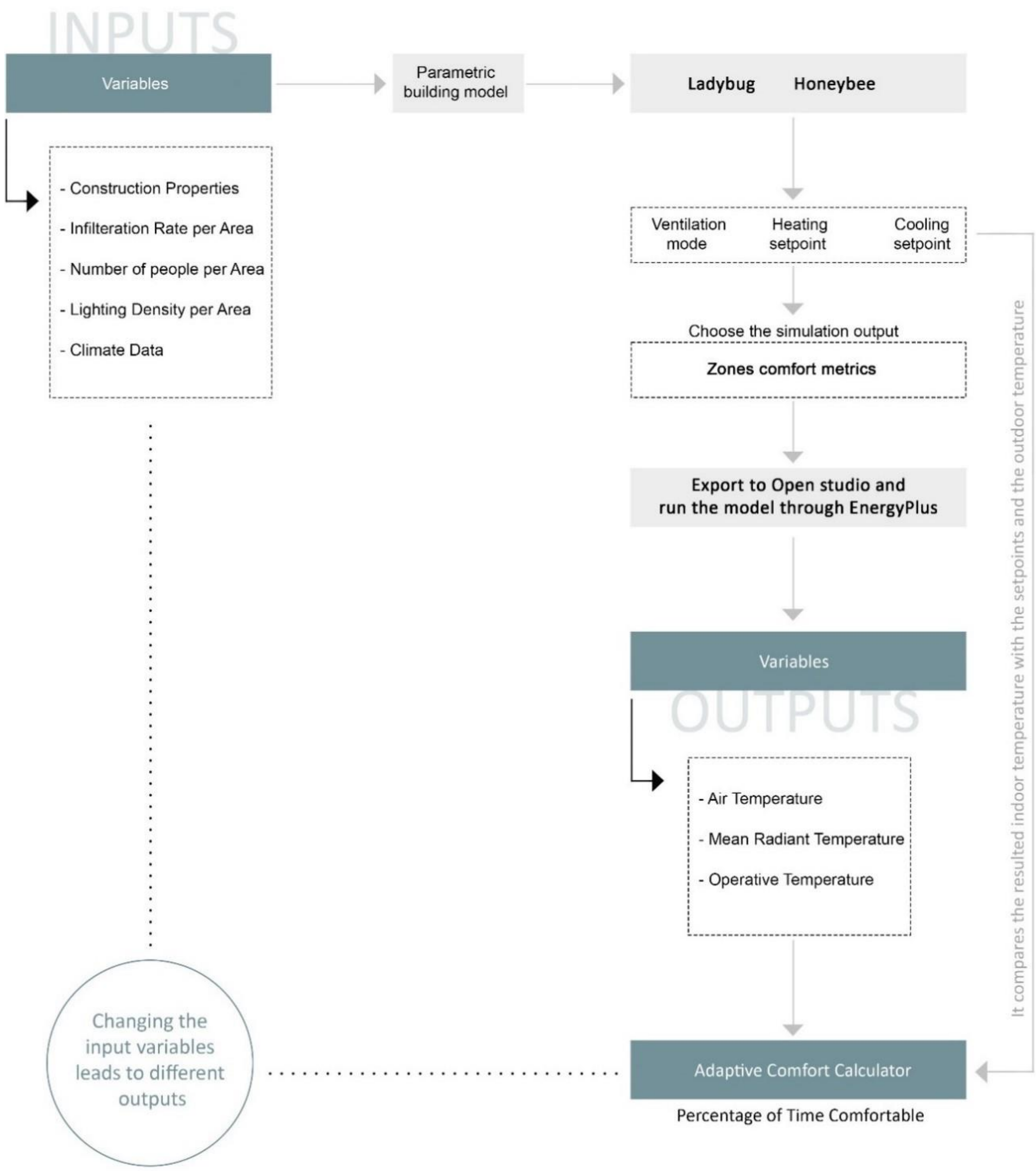



*Figure 24. Thermal comfort simulation Process and tools.*

#### 3.3.2.1. Case Study Configurations

The building envelope is a main contributor to the overall building performance. Since the properly designed building envelope combines moisture management, structural integrity, temperature control, and air pressure boundaries into a cohesivesystem. By looking at the building envelope of the case study dwelling, it is characterized by pre-cast concrete walls of 150 mm and plaster finishes with no thermal insulation whilst internal walls are formed of concrete blocks of 130 mm thickness. Internal floors are composed of 300 mm reinforced concrete slabs. It should also be mentioned that Internal walls and ceilings are plaster finished with no thermal insulation while the windows are single glazed with metallic frame without thermal break. Considering the poor thermal performance of this frame its transmittance was rated equal to 5.88 W/m2K. (Figure 25) shows the case study model with its components layers and surface properties.

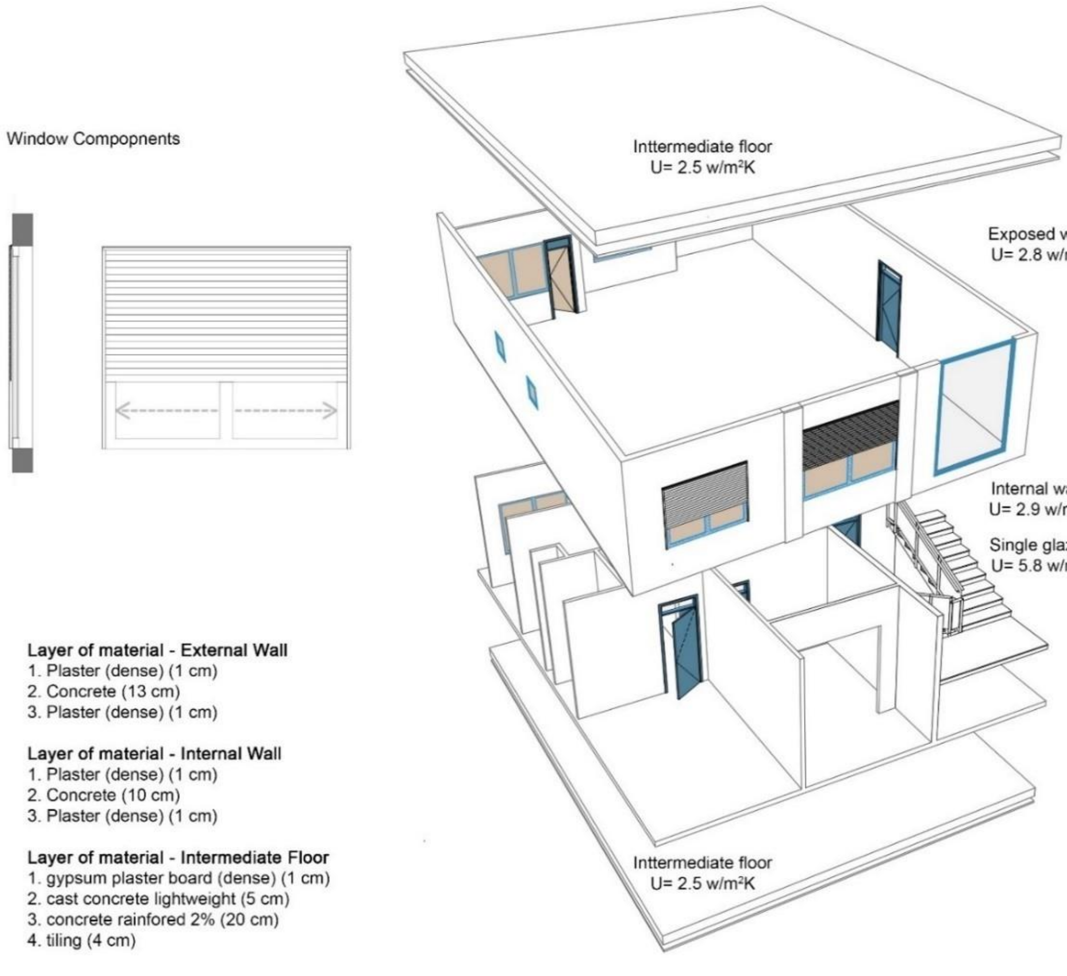



*Figure 25. Surface Properties for the case study*

The thermal characteristics of the building envelope is compared to the minimum required performance requirements in comparison with the Syrian code (The Syrian code for thermal insulation, 2008) (Table 10).

*Table 10. Comparison between the performance requirements and the case study configurations.*

| | Building components performance | |
|---|---|---|
| | **The case study (U value) W/m²K** | **The Syrian Code (U value) W/m²K** |
| **External walls** | 2.8 | 1.5 |
| **Internal walls** | 2.9 | Not given |
| **Intermediate floors** | 2.5 | 1 |
| **Glazing** | 5.8 | 3.5 |

As for occupancy, the base case was modelled with five people, who share the livingroom space. Although the dwelling consists of HVAC systems (a split system is installed in the living room and the master bedroom), the rooms were modelled using natural ventilation mode as explained before. It should be mentioned that theinfiltration rates assumption were based on CIBSE (2013) since no assumptions has been mentioned in the Syrian code for thermal insulation (2008). Overall, the used variables in the energy model including orientation, U-values, ventilation and energy services configuration and temperature setpoint to calculate adaptive comfort modelare showed in Table 13 in the Appendix 7.2.

#### 3.3.2.2. Basic information of the participants

The occupant general information is very essential in energy-related research not only for estimating the occupancy rate but also to inform the building performance evaluation by understanding the occupant's daily patterns. According to Kimipian etal. (2021) in addition to the physical properties of the building envelope, the way the occupant uses their spaces and operates the building has a major impact on their satisfaction and comfort. In pursuit of more inclusive perspective of building performance evaluation, the role of the occupants' activities in the space isconsidered in this study. Therefore, the information about the participants' age group, occupation and gender was collected. Further information about the occupant's number in the rooms whether the participant have a separate room, or they share it with others and the relationship between the room window and occupant's presence has been collected (Figure 26).

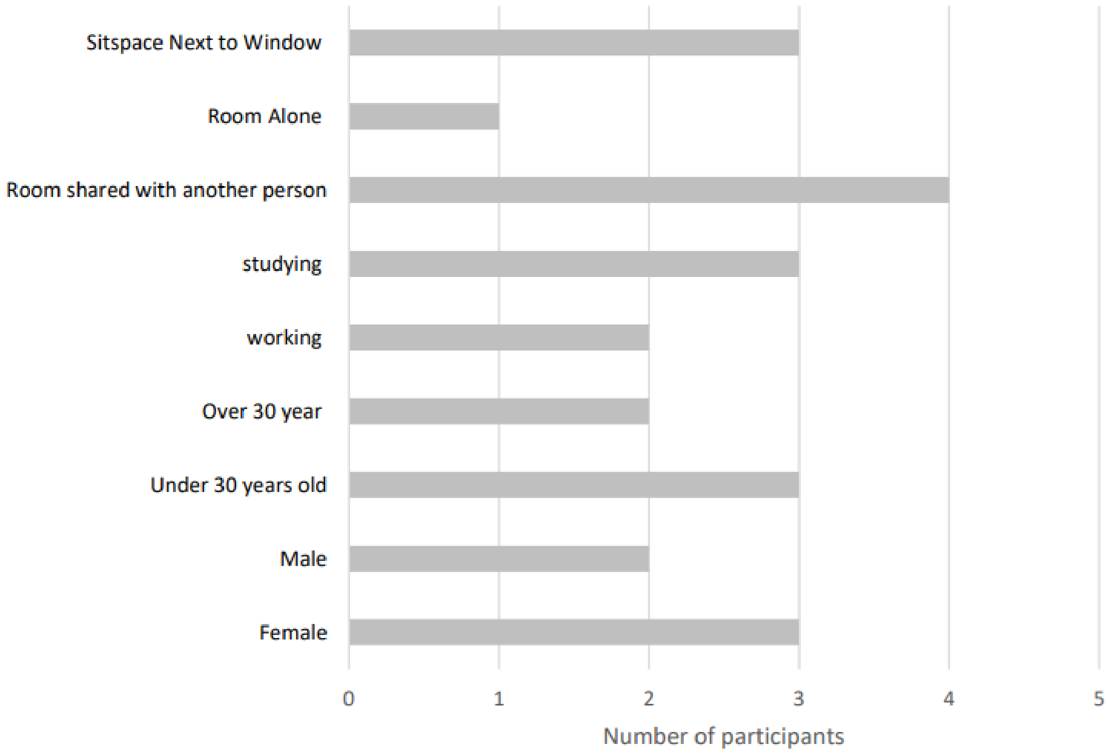



*Figure 26. Collected information of the participants.*

The one family flat consists of five members. The two parents are working. While the mother is a teacher and work five days for 6 hours per day, the father is a pharmacist and works six days a week for 12 hours per day. Therefore, the greater presence is for the mother, who is more affected by the building performance. Twogirls are sharing one room. The youngest girl is a student at school (19 years old) while the second girl is a university student (21 years old). They study mainly in their east-facing room. Their study space is directly close to the window. The fifthmember of the family is the son, who has his own room and is currently a student (23 years old) and has a part-time job. Therefore, he spends most of his time outside.

As a result, it can be said that three out of five family members spend a lot of timeindoor, and the dwelling's performance would affect their activities and performance.

### 2.3.1. Diary Research Method as a Discovering Tool

> "The function of a diary is… to build a memory out of paper, to create archives from lived experience, to accumulate traces, prevent forgetting." (Lee, 2015:12)

Diary studies can assist as a functional informational tool in order to capture the occupants' energy-related actions in dwellings. Furthermore, it can be relevant to researchers looking for evidence in their research in a range of contexts. As June et al. (2015) suggested, the diary is an instrument for coping with the unknown. Thiscan be strongly related to the Syrian context, where the current literature lack studies about the domestic behaviour of occupants and subjective aspect of domestic comfort.

The diary according to Lejeune (2009) can be also defined as a document that "sculpts life as it happens and takes up the challenge of time". Moreover, diary research methods offer another advantage in involving the occupant in the role of the building performance. They become more aware of the building impact on theircomfort when people write about their daily activities (Carlander et al., 2019). Thirdly, collecting data based on the diary's studies are able to give insights into habits, behaviours and situational decisions over time (Bolger et al., 2003). The advantages of diary method as a result can assist with understanding the comfort- related occupant activities and their drivers in this study.

Diary studies are widely used in various disciplines, in history, as a form of autobiographical record, and in user experience as a form of behavioural record. However, it is also applied in the field of energy research, where it allows to get a contextual understanding of occupant's behaviour in the residential space over time(Lavinia, 2017). Diaries have been used and analysed particularly in projects relatedto people's everyday behaviour. One example is using diaries to collect time use forenergy-related behaviour in Swedish homes. Hiller (2015) used a structured diary to write down everyday activities in 57 homes. On a smaller scale, Ahmed & Islam (2021) have used unstructured diaries to investigate the relationship between the occupant's living pattern and the indoor thermal environment within a traditional timber house in Bangladesh.

Therefore, the diary research method can assist this research by not only exploring the subjective side of the thermal comfort in the case study and understand how theresidents conceive their domestic comfort but also involve the occupants in this investigation, which can validate the simulation results. Diaries may have various functions, three functions have been outlined by Lejeune (2009), which they directly relate to the research context. First, to express oneself, which allows to thoughts and communicate. Second, to reflect, which has an analytical effect. Finally, to freeze time and build a memory out of paper.

In terms of methods of logging the data, diary studies have also been classified intothree categories according to Wheeler & Reis (1991): interval diaries, signal diaries, and event-contingent diaries. While the interval-contingent design requires participants to report on their experiences at predetermined intervals, Signal-diariesrely on some signalling device to provide diary reports at fixed intervals. Lastly, event-contingent diaries require participants to provide a self-report each time the event in question occurs (Eckles, 2008)

In relation to this study, the aim of the diary is to draw representative behavioural scenarios of the occupants at home during typical summer and winter days by tracking the energy- related building use including space, energy services, and building components in order to draw snapshots of their behaviours. Therefore, in order to investigate the three functions of diary format within the selected case study, the diary was designed as a semi-structured (to explore the participant thoughts and feelings about their thermal comfort) and interval contingent (to trackthe occupants' behaviour in the spaces over time).
The five occupants of the case study flat were asked to record their presence and space-related activities during three main time periods (morning, afternoon, evening). Each participant wrote the paper-based diary in two different days (13 December 2020, and 13 July 2020). The dates were selected in typical summer and winter weeks for the weather of Damascus based on the weather data. These dates also reflect the critical time of the year that causes indoor discomfort in the case study flat based on the environmental simulation results. The aim is to discover how
the participants respond when they cannot only rely on acceptable outdoor temperature range and require active cooling/heating to seek comfort.

(Table 11) shows the diary inputs for the field study. Each diary includes required information about the participant's activities during the day (what I am doing) and which space they are in (where I am) and the energy devices they use in the residential space for lighting, heating, and cooling (use of equipment) and their perception of their thermal comfort (Do I feel hot/cold/OK). In each time period, a field was left blank for the participant's comments to express their comfort- related thoughts and feelings during the day.

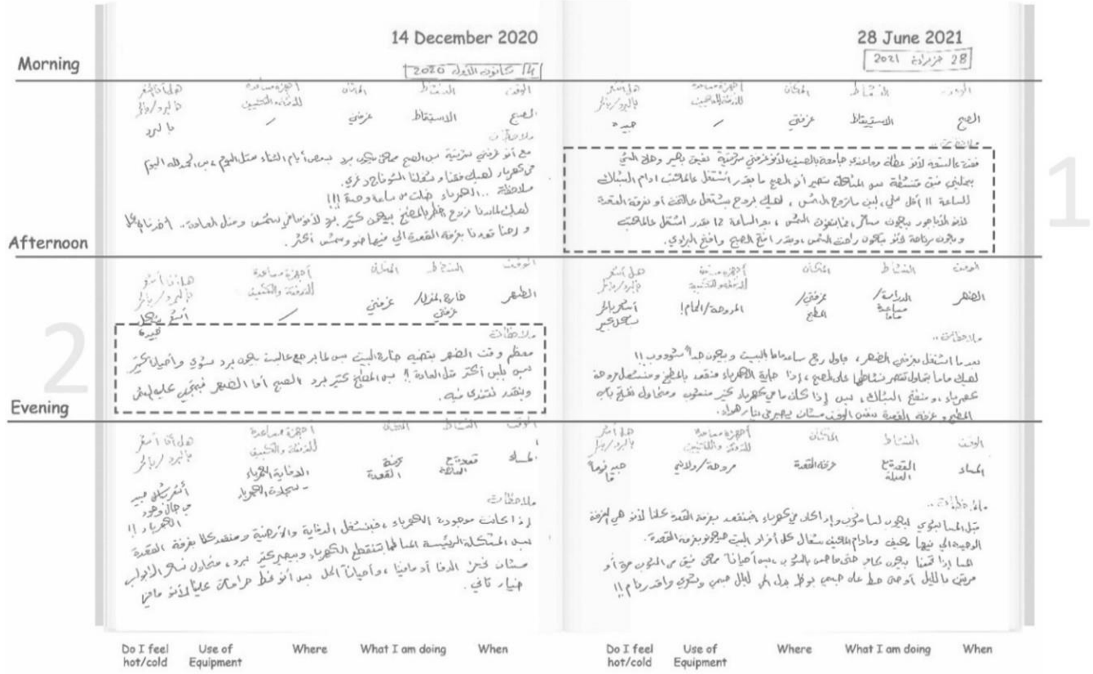
*Table 11. Diary Inputs.*

| | What I am doing | Where I am | Use of equipment | Do I feel hot/cold? |
|---|---|---|---|---|
| | | Which room in the house | Lamps, heaters, fans, hot water usage | |
| **Morning** | | | | |
| Comments | | | | |
| **Afternoon** | | | | |
| Comments | | | | |
| **Evening** | | | | |
| Comments | | | | |

By recording the activities of the family members by themselves, this diary format acts a way to communication between the researcher and the residents. Although diary writing is a common and popular form of writing "to release and communicate", June et al. (2015) argued that diaries can be a repository for self-reflection "to analyze oneself and to deliberate", which corresponds to Lejune (2009) suggestion "To reflect". Later, the researcher situates herself as a mediator between the residents and the reader by analyzing the residents' diaries and trace their interrelated behaviours.

(Figure 27) shows an example of original draft of the collected diaries in Arabic with some selected text samples translated into English. The Arabic version of all diaries the is provided in the appendix.

1 “It’s morning in the summer and we have a summer vecation at summer. however, I woke up ealy at 9.00 am becuase my room is east-facing and this makes more active in the morning but the probem comes when I want to work on my table. it is diractly near the window and the sun rays becomes very strong so I study at my bed or in the livingroom because it has shuters and we can block the sun. after 12 pm I feel comfortable working on my desk because the sun because the sun is gone.”




2 “Most afternoons I spend most winter afternoons outdoors. however, when I return home I always feel a bit of cold and sometimes a lot of cold and therfore I weare more clothes but the most stressing problem is in the kitchen, it is two cold in the morning and but the sun’s afternoon enter the kitchen and it becomes more acceptable.”

*Figure 27. One example of the collected dairies; the diary of the twenty-four-year-old girl in summer and winter, which shows her activities in the domestic space over three main periods, morning, afternoon, evening and also her feelings whether she is comfortabl*

By communicating and reflecting, the third function of the diary format, to freeze time, was used to expose the reader to discover the domestic Syrian space by themselves during frozen moments of discomfort, when the residents wrote in their diaries that they are uncomfortable. The research has combined the participants’ diaries during selected frozen moments and presented it as behavioural snapshots.Therefore, these moments act as behavioural snapshots that share a story of diaries of discomfort of middle-class family house in Damascus.

While the case study flat consists of five rooms, three snapshots in three rooms were chosen to present the diary’s results as a way order to visualise the occupantcomfort-related patterns in the space. The rooms and time-periods were selected to represent the following criteria:

1. understand current space use pattern in the living space where all family members are directly affected by indoor environment.
2. aid in conducting a follow-up evaluation for the rooms that showed the most discomfort ranges in the simulation results. Third, to include a diverse selection of rooms; both living and sleeping spaces.
3. include the rooms that most family members' diaries have complaints about.

Therefore, in order to present the occupant comfort-related patterns in the case study flat, a visual narrative of the combined diaries of the family members has been discussed for three rooms at different times during the winter/summer typical days as behavioural snapshots. The selected snapshots were as following (Figure 28). First, the winter day in the evening in the living room when the temperature ranges can drop to less than 5 C0 (based on the air temperature simulation results). Second, the winter day in the morning in the kitchen when the sunlight and daylightlevels are low (west-facing room) and temperature ranges are also low.

Another snapshot was presented for the kitchen when it is afternoon in the summeras most family members complained about when it is extremely hot due to the highpercentage of solar gains. Third, the summer day in the girls' bedroom in the morning when there is direct solar gains (due to the east-facing room orientation).


*Figure 28. The selected behavioural snapshots to be discussed in the results.*

# Chapter Four

## 4. Searching for comfort: Results and Discussion

This chapter presents the results of the applied methods in order to investigate theperformance of case study dwelling. Firstly, the results of climate analysis have beenpresented in this chapter in order to have an in-depth understanding of the climate conditions of Damascus. Then, the results of thermal simulation have been discussed in order to assess the performance of the dwelling as awhole. Later, the thermal simulation results were combined with the finding from the family members' diaries and discussed through three main behavioural snapshots.

The behavioural snapshots are presented in visual snapshots associated with the various members' diaries in the residential space as a whole Building. Three main spaces were highlighted including the kitchen, living room andthe one bedroom (the daughters' bedroom). A reflective analysis of the researcher is integrated in the last section which consists of a detailed reflection of the building performance considering both objective and subjective aspects of domestic thermal comfort and the mechanisms of occupant responses to thermal discomfort.

### 4.1. Results of Climate analysis

The analysis of Damascus climate using the weather data file based on ISD (US NOAA's Integrated Surface) Database shows a significant potential for sufficient sunlight and daylighting levels. However, solar gains may be undesired in the peak summer months. (Figure 29) summarizes the climate analysis' finding using Ladybug and Honeybee Tools.

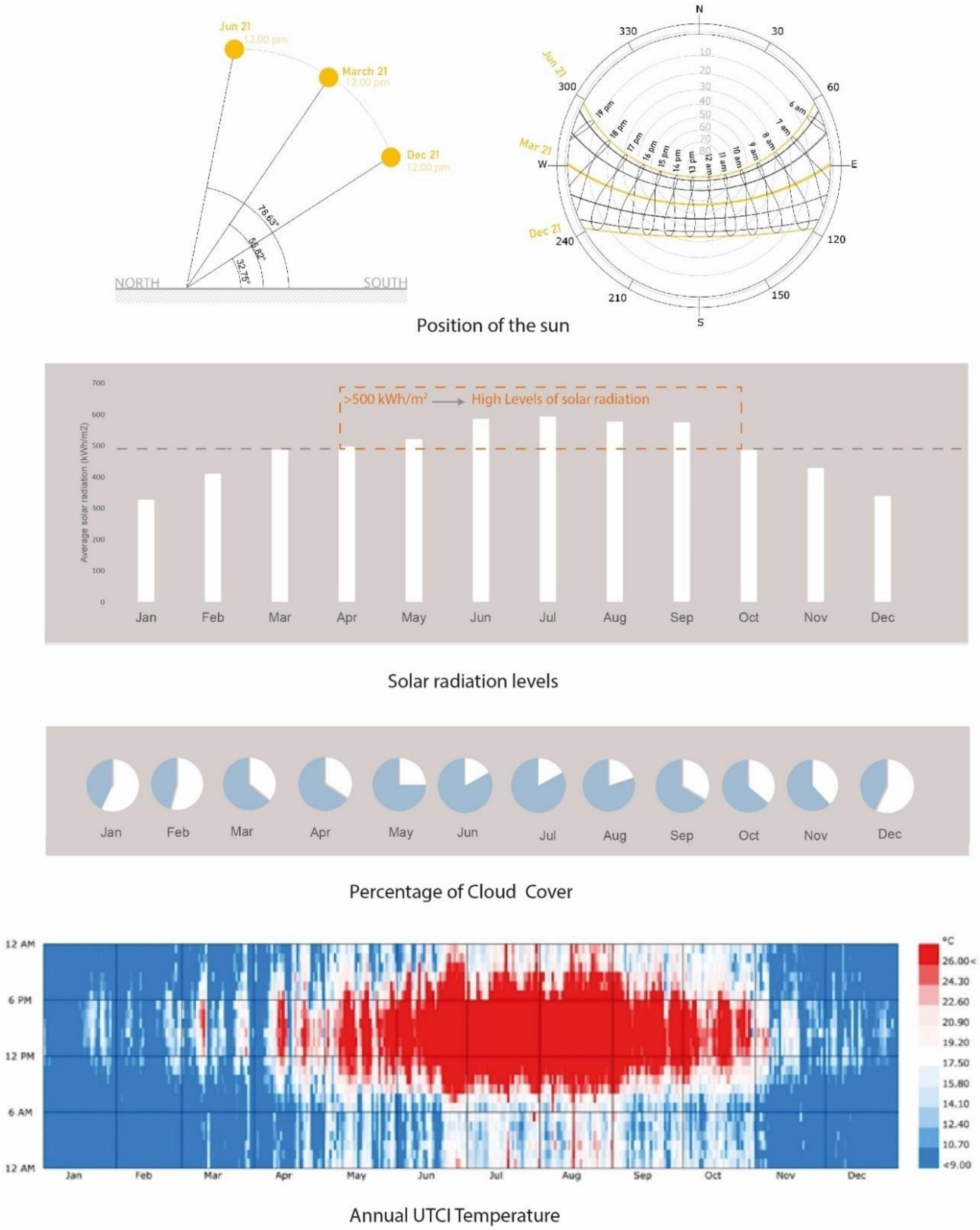



*Figure 29. Results of analysing the climate variables in Damascus (based on the weather file)*

In details, the analysis of the sun path shows high potential for solar gains. During summer months, the sun rises around 60° from northeast. The maximum sun angle at noon during summer solstice is very high with angle of 78.63° above the horizon. On the other hand, the sun at winter rises from southeast. At its highest point at winter solstice noon, the altitude is around 32.75° above the horizon. The only time of year when the sun rises directly from east is in spring and autumn. As a result, designing the right depth of solar shading is crucial at summer to prevent the unwanted solar gains. For winter, when the sunlight is preferred, the optimal windows orientation can be achieved based on the time of the day including southeast at morning, south at noon, and southwest at afternoon.

Solar gains are not only affected by the sun angle during the day but also the intensity of the solar energy that reaches the building. While looking at Damascus, the months of July and August have the highest solar radiation amount compared to other months with radiation levels reaching 750 $Wh/m^2$. This may lead to higher heat gains through the external envelope. A solar radiation table is provided in the appendix. It shows various radiation levels of incident solar radiation in Damascus during the day throughout the year in order to identify hours of low levels of solar radiation.

As for total sky cover analysis of Damascus, the results show a great opportunity of daylight benefit with around 24.2% of the total year. While sky partly cloudy days increase in January and November, June and July are the clearest months with less than 5% cloudy times. This indicates a sufficient amount of daylight.

Overall, the climate is characterized by a significant availability of natural light. It is sunny around 83% of daylight hours while the remaining 17% of daylight hours are likely cloudy or with low sun intensity.

Thirdly, the results for annual UTCI analysis for Damascus (2004-2018) show that indoor environment can be passively comfortable around 49% of time with no heat stress while the rest 51% of the time of the year witnesses a thermal stress. In Summer, temperature could cause a heat stress of 11.26% with temperature above 26 $^0$C, while in winter the temperature causes a cold thermal stress especially at night with cold stress of 13.53% of the year. A detailed analysis of the temperature difference throughout the year is provided in the appendix. In general, it can be concluded that there is a remarkable difference in temperature of summer and winter. The average maximum temperature in the hottest month (July) is about 29°C while the average minimum temperature of the coldest month (January) is 6°C.

The psychrometric chart shows the selected comfort range for summer and winter combined with the climate data of Damascus (Figure 30). The climate of Syria shows a significant risk for high solar gains at summer, when humidity has low levels.  Passive strategies including natural ventilation, evaporative cooling, and thermal mass are recommended to achieve the thermal comfort. Other the other hand, there is a high demand for heating in winter, while sunlight and daylight levels are respectively high.

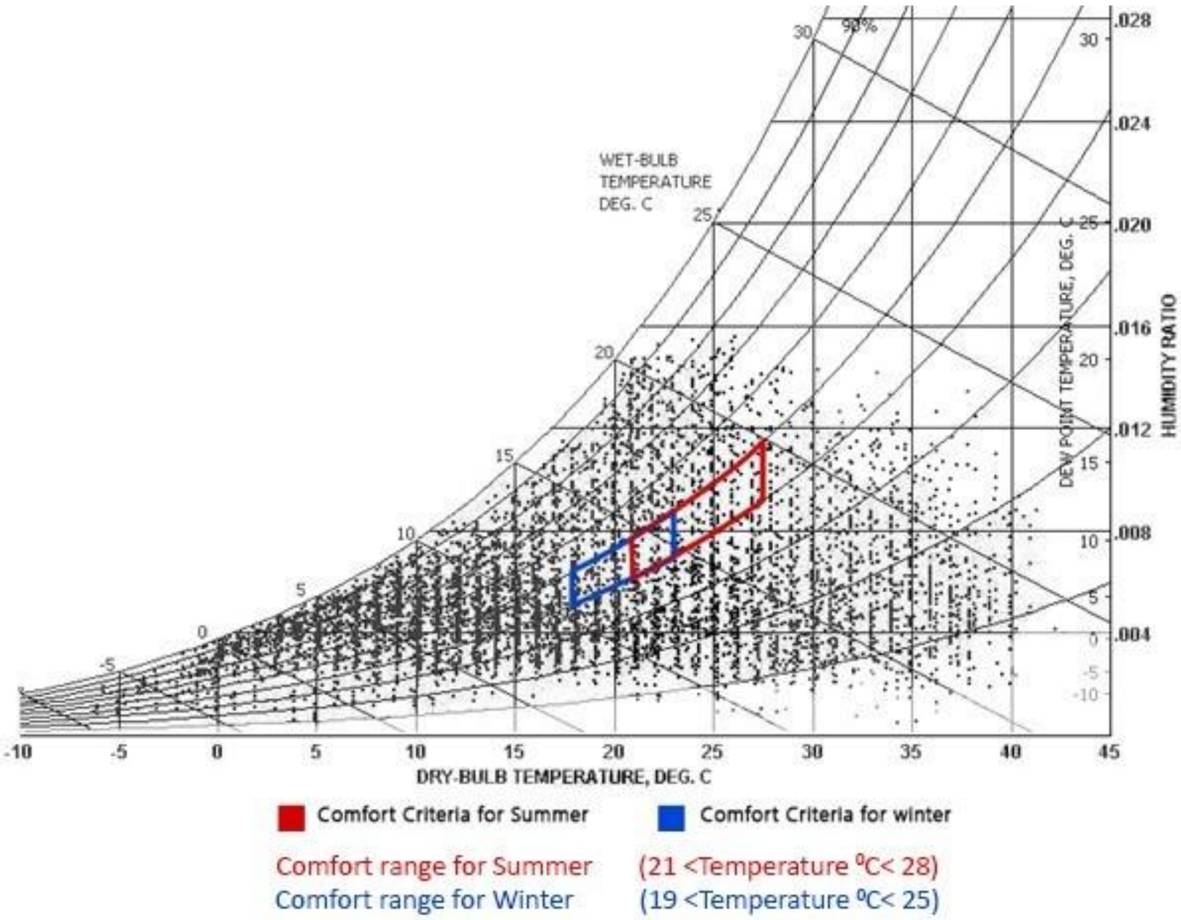



*Figure 30. Psychrometric chart for the selected comfort criteria.*

Overall, considering the adaptive model and the selected comfort criteria, people can experience comfort around 56.7% of the overall time throughout the year. This can be observed during spring and autumn months (Mar-May, Sep-Nov). (Figure 31) shows times of the year when people can rely on passive thermal conditions. In summer, the critical time is from 11 am to 4 pm, which requires active cooling. People can rely on or passive strategies at summer night to reduce heat stress. In winter, people may feel the highest cold stress in December and January, when active heating is required. It should be mentioned that all results of climate analysis of Damascus are presented in the Appendix 7.3.

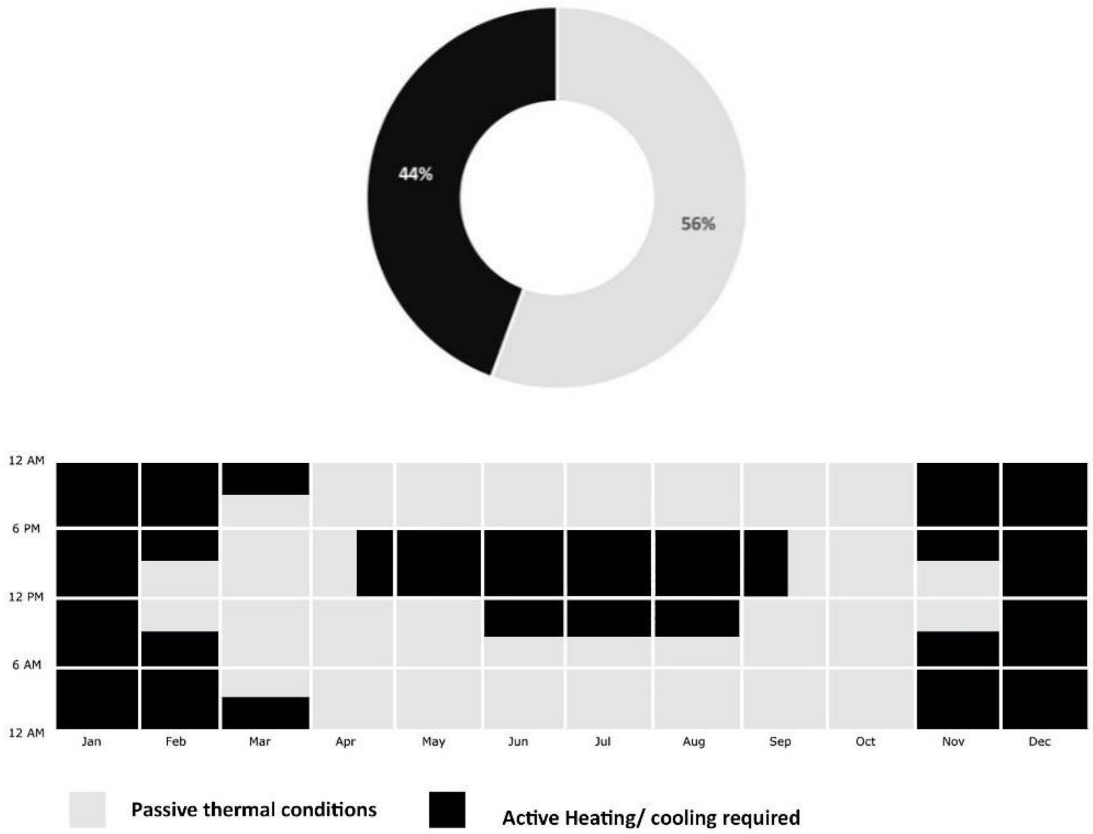



*Figure 31. Times of the year when people can rely on passive thermal conditions.*

### 4.1.1. Bio-climatic Design recommendations

The results of the shoebox analysis show that building design in Damascus should follow multiple design criteria in order to benefit from passively the climate. First, the results of analyzing the optimal shape showed that orthogonal shape with W/L ratio 1:1.3 with the longest side facing North-south axis is the most appropriate shape for Damascus. On the other hand, limiting exposed surfaces on eastern and western facades lead to less heating gains in the summer months.

As for orientation, the shoebox analysis showed that the optimum orientation was selected to be 0 at East-west axis, as it maximizes heat gains at winter and minimize heat gains at summer. On the other hand, the North-South axis with 90° would be the worst option with maximum heat gains at summer months.

Thirdly, the results of the window to wall ratio showed that the opening on the eastern and northern façade results in higher levels in comfort due to the reduced heat gains while WWR has the greater impact on the southern façade as undesired solar gains mainly come from south facades in Damascus. The results of shoebox analysis showed that WWR of the western façade should not exceed 40%.

Finally, the results of shade benefits analysis show that there is no benefit of shading devices on the northern façade. However, the shading has the greatest impact on the western façade. A thickness of 25 cm of horizontal shading could save up to 250 kWh of required energy loads. The shading benefit has also a greater impact on the southern façade as 25 cm thickness of horizontal shading could save up to 150 kWh of required energy loads.

(Figure 32) summarizes the findings of the shoebox analysis according to the various design variables. More detailed results are showed in Appendix 7.4.

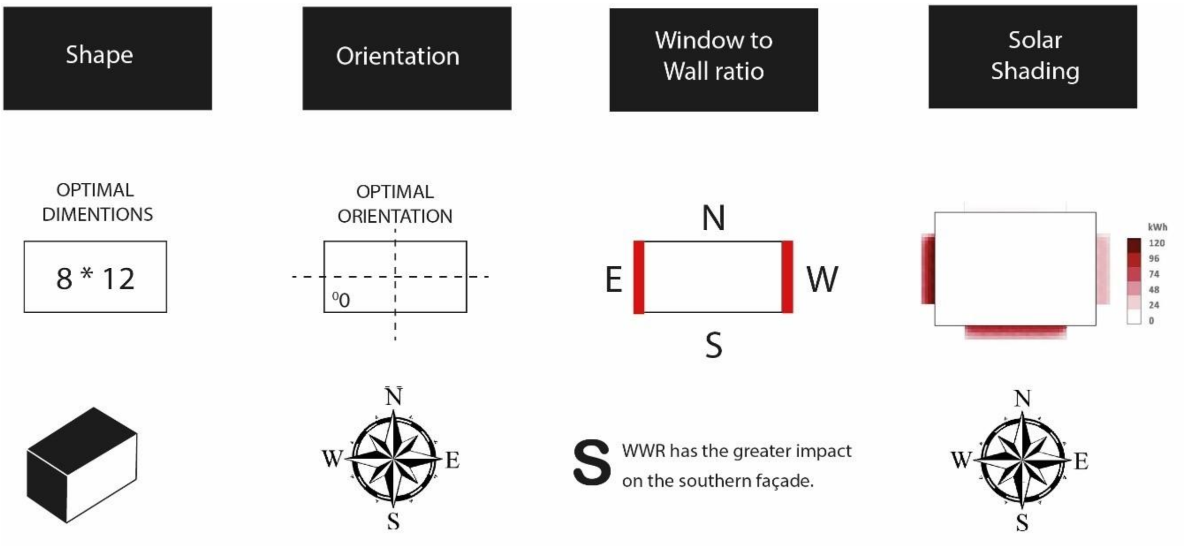



*Figure 32. The results of shoebox analysis based on the simulation.*

### 4.2. Case Study Thermal Performance

The comfort indicators were illustrated based on the heating and cooling setpoints for providing thermal comfort in Syrian. The Syrian comfort temperature levels were adopted from the Syrian thermal standards. However, the temperature levels were only provided for mechanical ventilation. While the case study building is mainly naturally ventilated, a range of ±3K was adapted as an indicator of adaptive comfort. More details about the selected standards for thermal comfort in Syria are explained in the previous chapter (pp. 50).

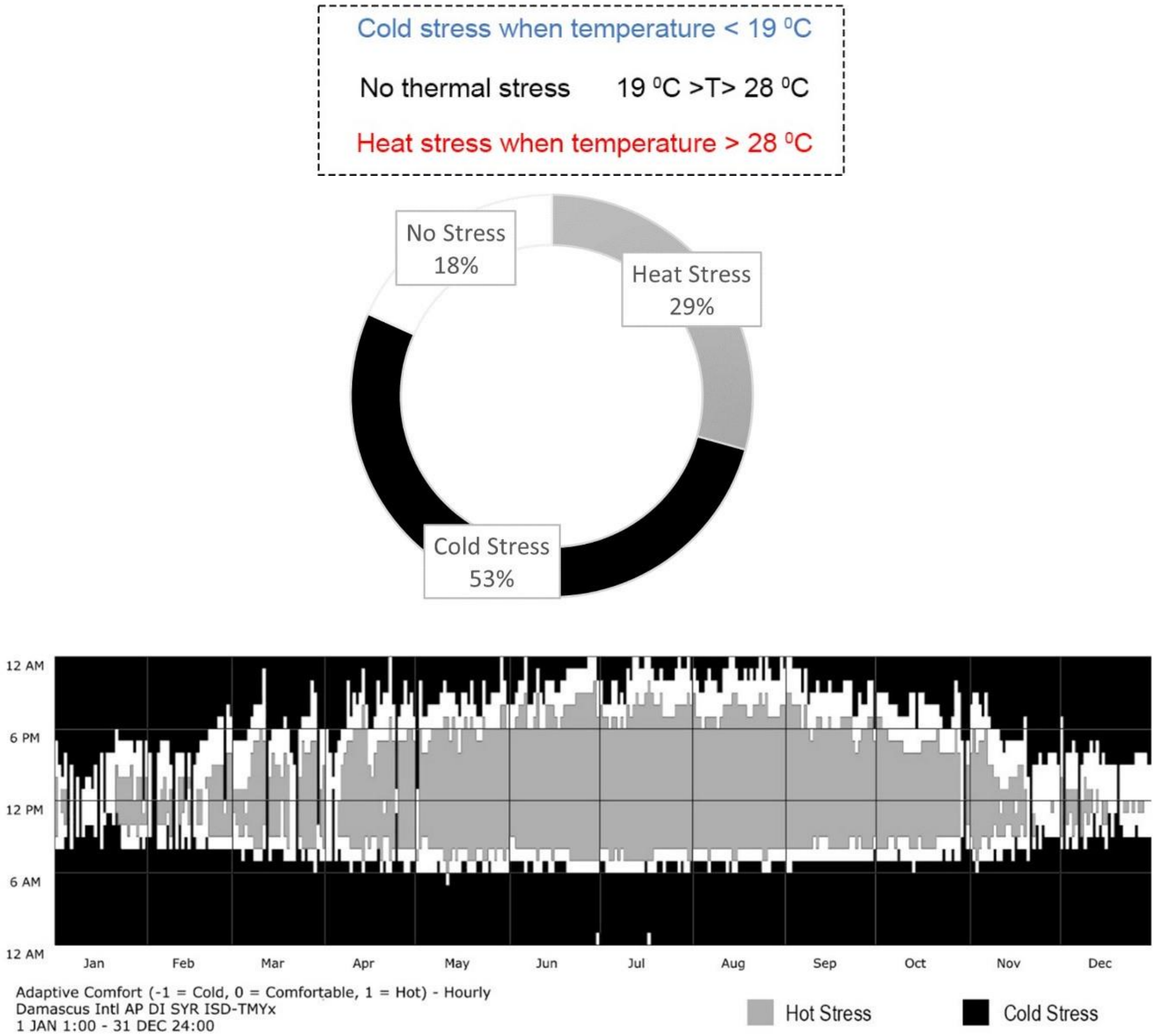



*Figure 33. Adaptive comfort results for the case study during the whole year.*

The initial results of the adaptive comfort analysis show that the dwelling indicates significant levels of discomfort most of the time as a result of the low thermal properties of the building envelope. (Figure 33) shows the percentage of the comfort levels within/below/above the comfort range during the whole year. whereas the winter months are the most critical months for the occupant comfort with approximately 53% cold stress of the year (when temperature is below 19$^0$C), the hot stress is also significant during summer months with more than 29% of the year (when temperature is above 28$^0$C). Therefore, the residents feel uncomfortable for the majority of the year while they have comfortable indoor environment only 18% of times of the whole year according to the simulation results. However, comfort ranges are varied not only based on the heating and cooling seasons, but they are also varied during the various periods of the day. By looking at the adaptive comfort results for each month in (Figure 33) within the whole period of the day, the heat stress may be a main concern for the resident between 12 pm and 6 pm for summer season from May to September. On the other hand, the winter season shows cold stress, which occurs specifically during night while temperature during the day falls mostly within the comfort range. However, most nights in winter shows cold stress as temperature drops in the dwelling below the comfort range, which needs to be considered in order to provide the occupant with adequate indoor environment.

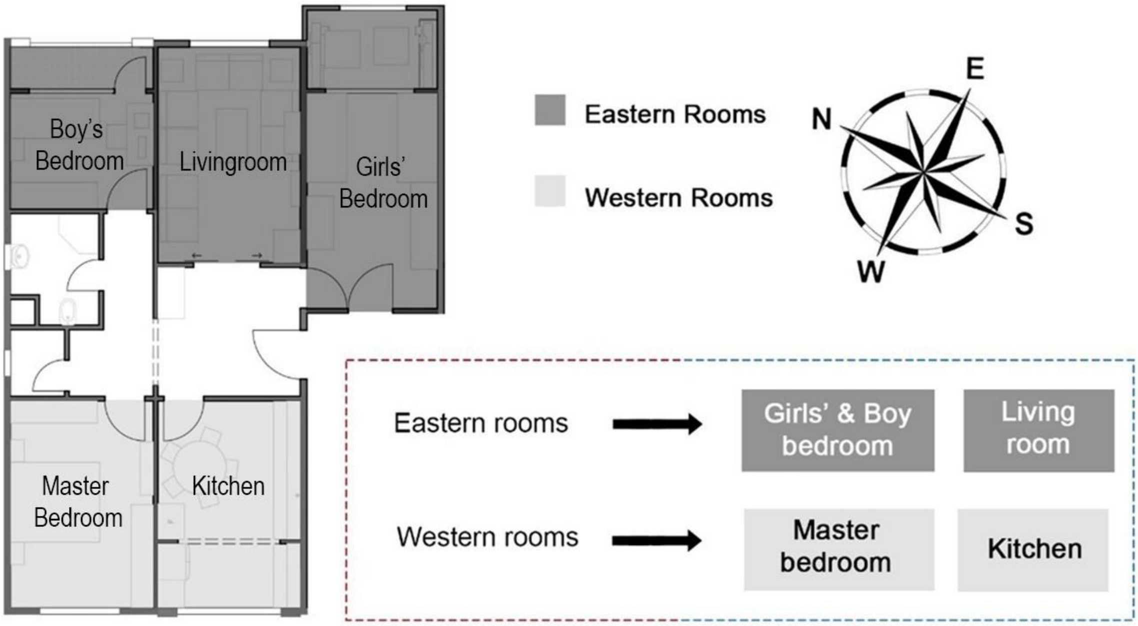
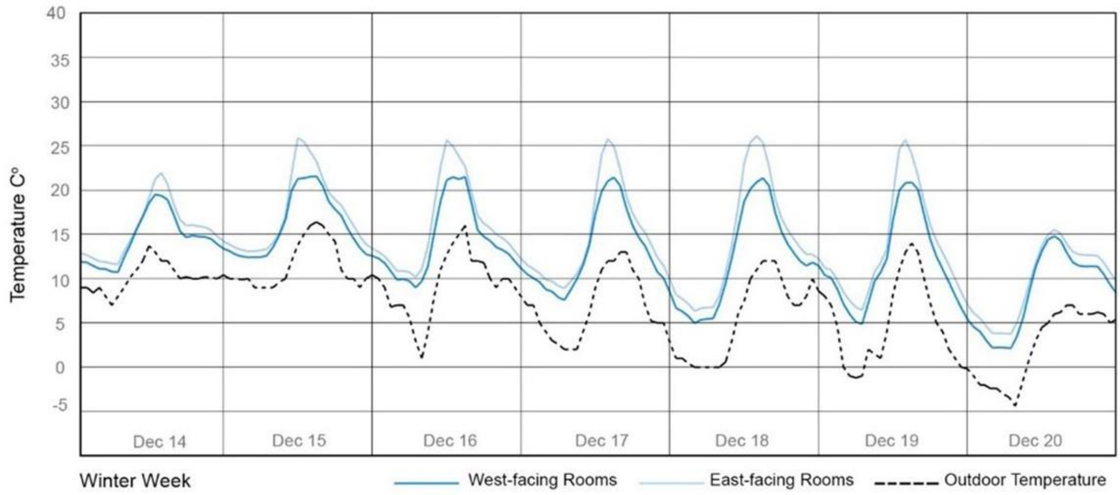



*Figure 34. Tested zones*

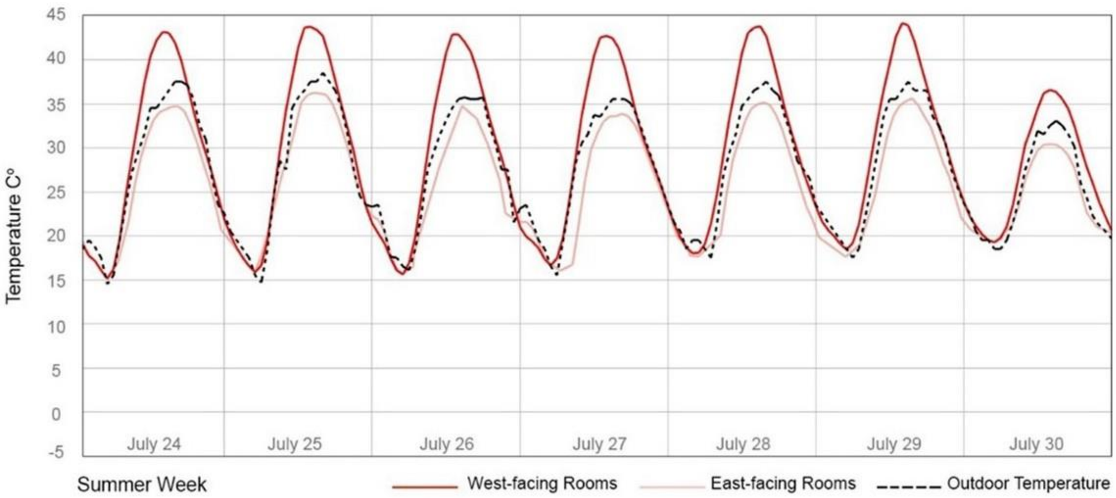
Since all rooms in the dwelling are mainly oriented towards whether east or west, the impact of orientation was investigated in this study by diving the rooms into two zones including west-facing zones and east-facing zones (Figure 34). While the east-oriented rooms include living room and the two bedrooms, the kitchen and the master bedroom are west-oriented. In order to understand the levels of discomfort levels varies in winter and summer, multiple studies identify air temperature as the most important factor that influences indoor thermal comfort (Maarof et al., 2009; Hailu et al., 2021).

Therefore, the impact of orientation on the measures of air temperature was tested in the two zones for two typical weeks during the whole year based on the climate analysis. The first week was a typical cold winter week (the average typical outdoor temperature of January is 6°C) while the second week is selected as a typical summer week (the average typical outdoor temperature of July is 35°C).

(Figure 35) shows that temperature in winter in the eastern rooms can be tolerated




The resulted temperature ranges in the dwelling in a typical winter week.




The resulted temperature ranges in the dwelling in a typical summer week.

*Figure 35. temperature ranges in the dwelling during typical summer and winter weeks*

during the day as it ranges between 18-25 0C while evening hours show critical indoor temperature levels to human comfort as temperature ranges start to drop below 120C, which is critical for occupants to maintain adequate indoor conditions. However, west facing room shows lower ranges, which can drop below 10 0C in the evenings. The resultant temperature ranges can be explained also through infiltration, when air enters/leaves the structure through gaps in the unsealed building envelope. The resultant temperature ranges are an expected result of the low performance envelope. However, this can be seriously critical in the absence of active heating and may, in its turn, affect the occupant’s health and wellbeing and compel them to cope with this discomfort. Moreover, the low performance of the building envelope in winter allows moisture to infiltrate the envelope during occupancy, which result in consequent problems related to the indoor environment. On the other hand, the summer week results show significant heat gains in the whole dwelling. While the average outdoor temperature can reach 42 0C, the indoor temperature during the day in the west-facing rooms are even higher than the outdoor temperature. As a result, the building envelope does not protect the interior of dwelling from the outdoor temperature. A lower temperature pattern can be observed in the east-facing rooms during midday hours since temperature ranges are below the outdoor temperature ranges. Combined with active cooling, windows are needed to be regularly opened by the occupants in order to reduce the discomfort indoor temperature levels. The results of temperature levels at night in both east and west-facing rooms in summer are acceptable to some extent and can be more tolerated.

Overall, the low comfort levels results are indicators for low thermal performance of the building fabric, which significantly reduces the occupant's comfort and wellbeing. The indoor air temperature results showed in detail how temperature fluctuates throughout the rooms based on their orientation. However, this range is clearly varied due to the orientation. In order to meet the minimum comfort requirements, active heating/cooling is required. Therefore, there is several consequences of the building design on the indoor environment. As there is a significant temperature stress in the case study, thermal discomfort can be an expected result of the resulted indoor temperature. It can be argued that case study design including the envelope specifications and the rooms layout is a main contributor to the occupant discomfort causes. In order to understand the special impact of the temperature levels on the occupant's comfort in the various spaces of the case study, the results of the collected diaries will be presented combined with the simulation results.

### 4.3. Searching for Comfort: Behavioural Snapshots

Besides modelling thermal comfort levels in the case study dwelling, this study is aimed at calibrating the simulation results with real case scenario through the resulted of the collected diaries in order to verify the simulation and understand how people respond to the expected indoor environment.

The five members of the family wrote their diaries about their daily activities in theirhome including their use of equipment to seek domestic comfort for two days: onein a typical summer week and one a typical winter week as mentioned before in themethods chapter. The combination of the occupant's diaries during the selected days with the simulation results of indoor air temperature is more reliable to understand the occupants' environmental drivers and their spatial behaviour. The results of this combination are presented as visual snapshots for three spaces in thecase study dwellings. The three rooms include the kitchen, living room and one bedroom (girls' bedroom), where the people felt not comfortable at summer or winter as explained in the previous chapter. (Figure 36) summarizes the results that is presented in the behavioural scenarios for each space in the next section.

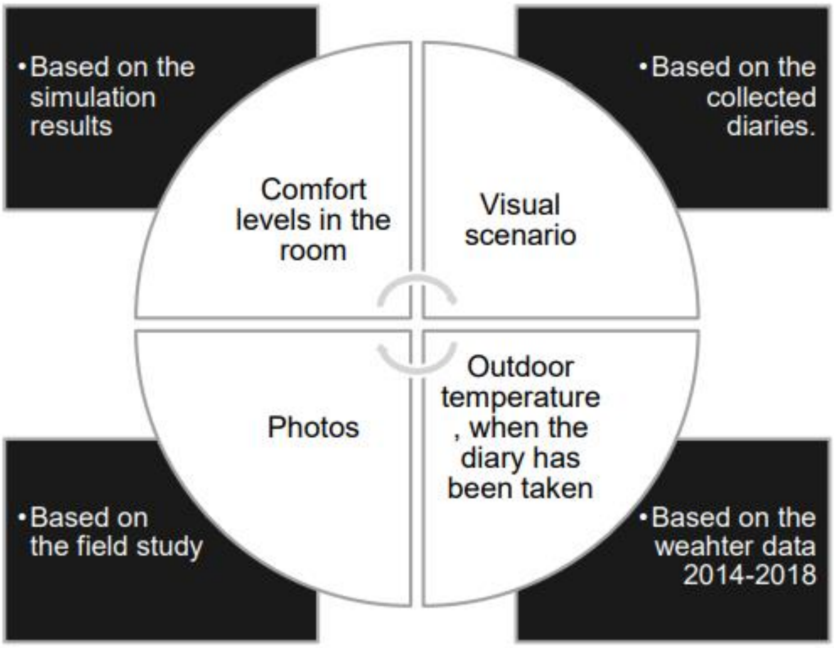
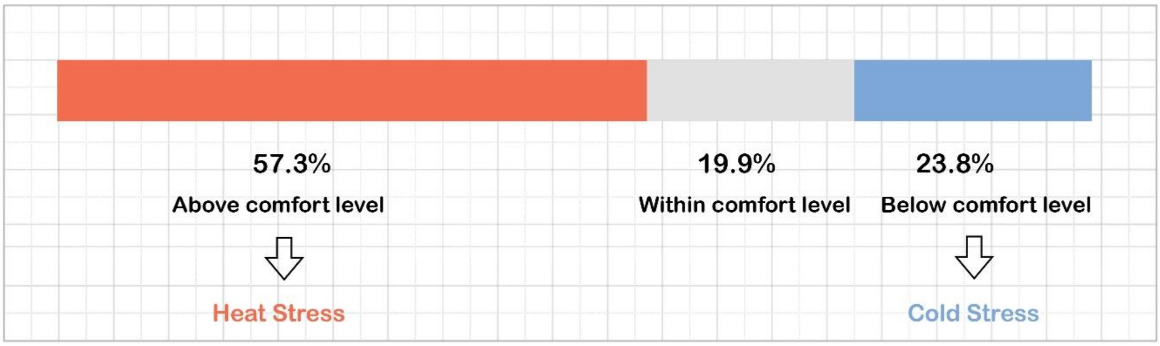


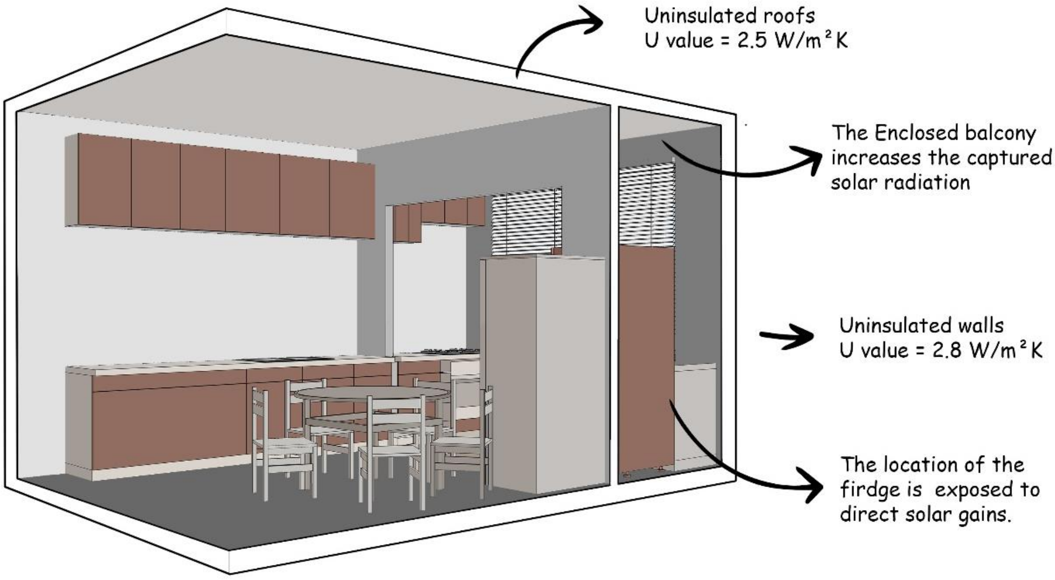

*Figure 36. Behavioural scenarios based on the combined results.*

## 4.3.1. Kitchen

**a. Comfort levels in the kitchen during the year (based on the simulation results)**




**b. Section Perspective of the Kitchen space**




**C. Photos of the Kitchen - April 2020**

The location of the oven close to the window.

The fridge is also located close to the window.

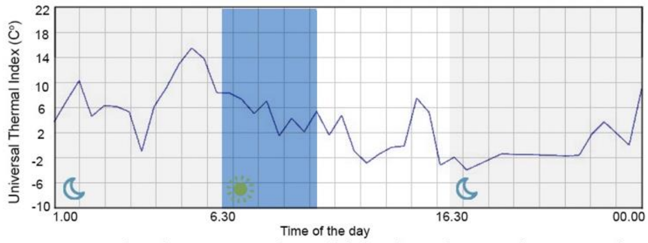
The interior space of the Kitchen, which shows the compact space that led family to add the balcony to the kitchen.

*Figure 37. A visual representation of the comfort simulation results including drawing and photos of the kitchen.*

## Winter

*13 December 2020 , Morning*

Outdoor Temperature: Around 2 C⁰



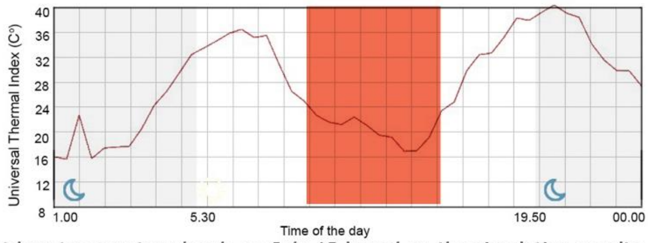

*a. Outdoor temperature levels on December 13 based on the simulation results.*


*b. Visual representation of the occupant behaviour in the livingroom on December 13 based on the collected diaries.*

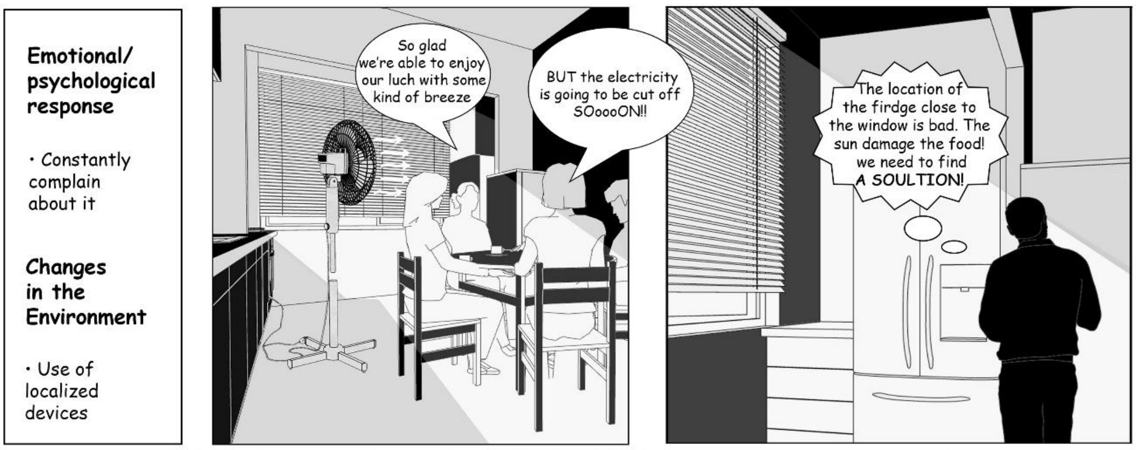
## Summer

*13 July 2020, Afternoon*

Outdoor T emperature: Around 35 C⁰




*a. Outdoor temperature levels on July 13 based on the simulation results.*




*b. Visual representation of the occupant behaviour in the daughters' bedroom on July 13 based on the collected diaries*

*Figure 38. Occupant behaviour during the morning of December 13 and afternoon of July 13 in the kitchen based on the outdoor temperature and collected diaries.*

The simulation results of comfort levels show that kitchen witnessed the largest cold stress (23.8%) during the whole year. Similarly, the indoor environment in summer is also uncomfortable over 55% of the times of the years (Figure 37). The results of high temperature stress indicate discomfort, in which the family may witness in the kitchen. By looking at the kitchen space, three main factors should be taken into consideration in order to understand the critical simulation results. The west-north orientation of the kitchen, the addition of the balcony to the kitchen space, and the low envelope performance. These three factors contribute significantly to the heat gains and heat losses, which are also observed in the collected diaries of spending time in the kitchen.

> *"Oh no! The electricity went out again! It is so cold for the children to eat here without the electric heater"* says the 44-year-old mother while she is preparing breakfast for her family in the kitchen when the daylight dims on one of the cold mornings in December 2020 and outdoor temperature drops to less than 6 0C.

In addition to the low performance of the dwelling, the problem of electricity rationing has become a daily issue for Syrian families to deal with. However, the domestic electricity cuts increase dramatically in the extreme coldest/hottest months, which can reach up to 18 hours of blackouts citywide. In case of not being able to rely on active heating, here comes the importance of passive strategies to reduce cold stress. However, the domestic electricity cuts increase dramatically in the extreme coldest/hottest months. Despite the availability of sunshine hours in winter in Damascus, the family is not able to benefit from the sunheat in the morning due to the west orientation of the kitchen. Moving to another space is one of the discomfort responses to cold stress in the absence of electricity. The family usually moves to the east-oriented living room which has plenty of sun to eat breakfast. Temperature asymmetry is another problem in the kitchen. Due to the low performance of the building envelope, the spaces adjacent to the exterior walls are colder than the rest of the space. Therefore, the family members usually avoid sitting near the windows as a behavioural response to discomfort.

Another problem is faced in the kitchen is the temperature asymmetry. Due to thelow performance of the building envelope, the adjacent spaces to the exterior walls are colder than the rest of space. Therefore, the family members usually avoidsetting near the windows as a behavioural adjustment, which limit their comfort inthe kitchen space.

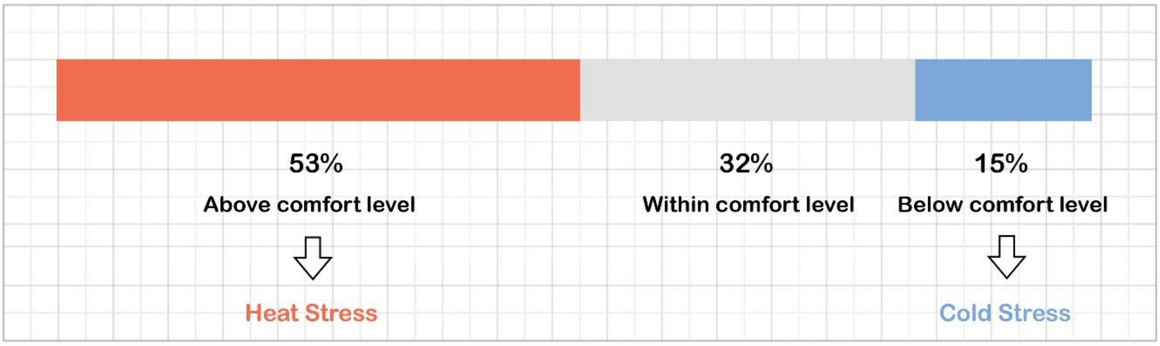
On the contrary, the kitchen witnesses a high risk of heat stress in the summer. A clear expression of overheating is reflected in the afternoon period during lunchtime in summer. On Wednesday July 13, 2021, all the family members complained in their diaries about the high temperatures while they were having lunch in the kitchen. The overheating has been particularly notable in the collected diaries during power blackouts when the family opens the window to cool the space. However, due to the high-speed wind in the west, the inadequate cross ventilation forces the family to close the window. The diaries also revealed the emotional responses to discomfort in the kitchen due to the unavoidable direct solar gains on the refrigerator, as the family members can do nothing about it other than complaining. Whereas the kitchen's original design consisted of a 2-meter-wide balcony, the family has opted to close the balcony and add the extra space to the kitchen due to aforementioned privacy reasons. Therefore, every electric device located in the enclosed balcony is subject to harmful direct sunlight in the afternoon period in summer. This is reflected in the family diaries by the complaints about the location of the refrigerator.

> *"This is just like a sauna here […] I am not satisfied with the location of the fridge here! We have to move it somewhere else,"* complains the father.
>
> *"Most food spoils so quickly, but we don't have enough space in the kitchen. The freezer should have the priority to be in the shaded space!"* writes the mother.

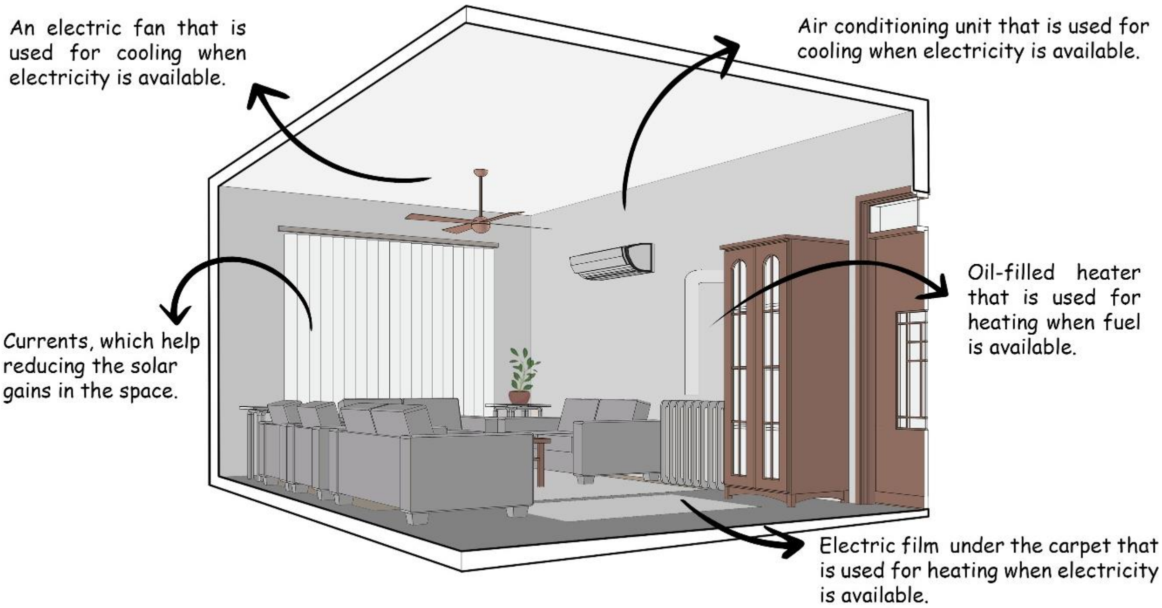
In conclusion, both diaries and simulation results showed that the residents do not feel comfortable in the kitchen due to heat and cold stress. Although the kitchen showed the highest level of discomfort, living room has also witnessed local discomfort, which is discussed next.

### 4.3.2. Living Room

**a. Comfort levels in the living room during the year (based on the simulation results)**




**b. Section Perspective of the living room space**




**C. Photos of the living room - April 2020**


*Figure 39. A visual representation of the comfort simulation results including drawing and photos of the living room.*

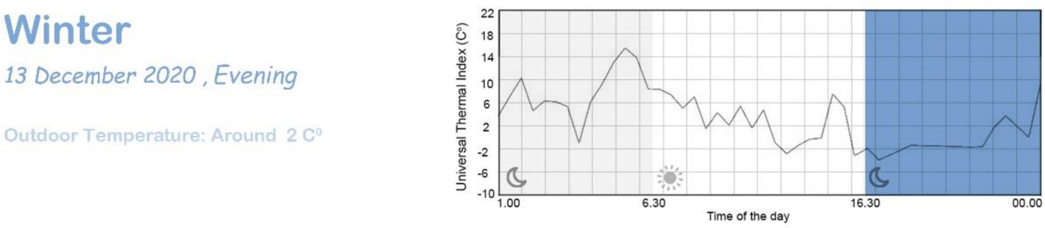
It is winter in Damascus by the time the family is gathering in the living room in the afternoon. Due to the characteristics of the climate in Damascus, the temperature decreases at night and reaches its lowest level during December and January. The comfort simulation results showed that while outdoor temperature may drop to less than 5 $^{0}$C, cold stress in the case study dwelling occur 15% of times during the year. At this time of the day, people may experience greater cold stress, which requires active heating. When the electricity is available, the family uses an electric heater, as a behaviour to change the environment, in addition to an electric film on the floor under the carpet.

The heating films are a new heating method and are manufactured locally as an alternative because they use less electricity than the air conditioning. Although there is air conditioning in the living room, the family does not use it in order to reduce the electricity costs.

> *"This air conditioning is for prestige! We only turn it on when we have guests".*
> Says the twenty-one-year-old daughter.

However, considering the frequent blackouts, the family spends most winter evenings without any heating utility. The clothing factor acts as one of the 87 main behavioural responses to discomfort to actively control the environment (Brager/de Dear 1998). The only way to get warm is using more blankets and thick carpets in order to increase the heat gains. Psychological/ emotional response is sometimes the only mechanism to face the discomfort unpleasantly. (Figure 40) summarizes the behaviours of coping with discomfort in a visual narrative, that reflects the collected diaries.

To further explore the aspects of comfort within the case study, the east-oriented girls' room is an interesting instance of how environmental conditions affects the occupant's performance.




*a. Outdoor temperature levels on December 13 based on the simulation results.*


*b. Visual representation of the occupant behaviour in the livingroom on December 13 based on the collected diaries.*

*Figure 40. Occupant behaviour during the evening of December 13, 2020 in the living room based on the outdoor temperature and collected diaries.*

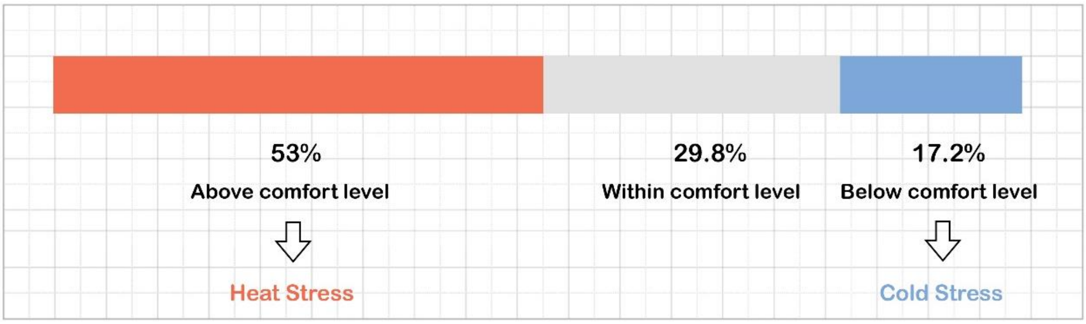
### 4.3.3. Girls' Bedroom

*"My room gets uncomfortable in summer especially in the morning, when I cannot use my desk because of the sunlight"* writes the twenty-one-year daughter.

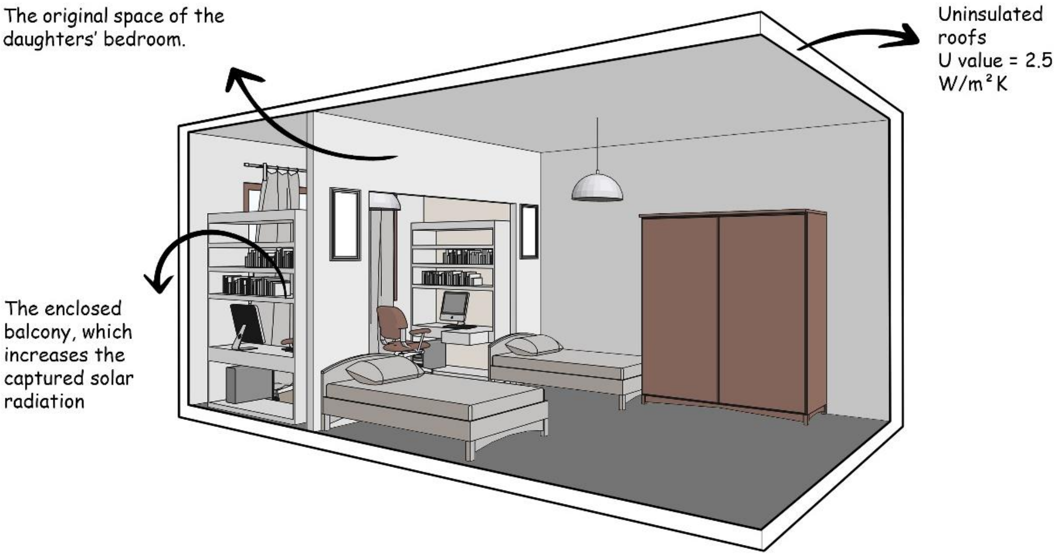
The simulation results of comfort levels in the girls' bedroom show critical heat stress in summer with around 53% of times of the year while the room show cold stress for around 17% of year (Figure 41). The heat stress can be an indicator to the high solar gains that the room may witness, which is a result of the enclosed added balcony to the interior space. While adding the balcony to the internal space, the room has lost the potential of shading that can be provided by the balcony.

## 3. Daughters’ Bedroom

**a. Comfort levels in the girls’ bedroom during the year (based on the simulation results)**




**b. Section Perspective of the daughters’ bedroom**




**C. Photos of the daughters’ bedroom - April 2020**

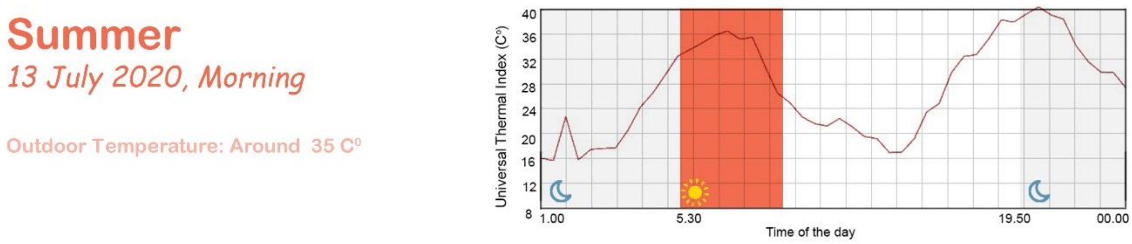

A localised electric heater


The working space on bed.

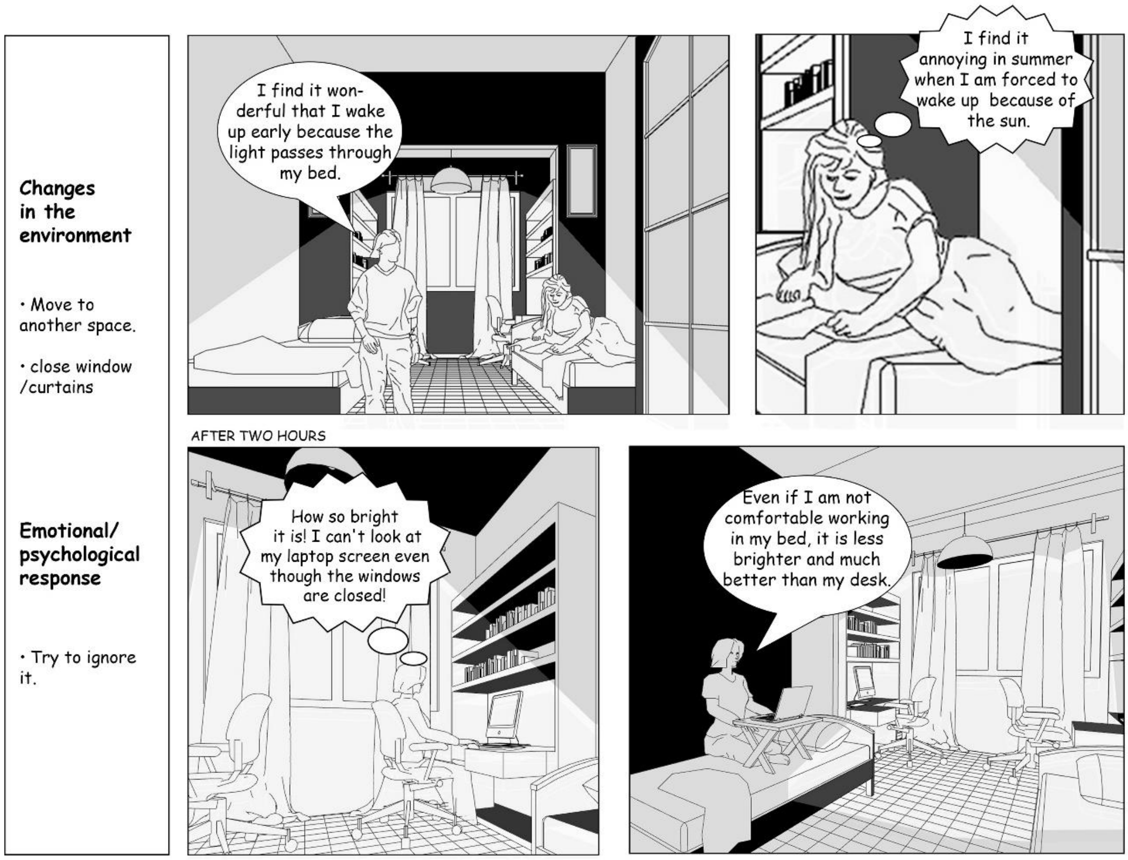

The added balcony to the room space.

*Figure 41. A visual representation of the comfort simulation results including drawing and photos of the daughters’ bedroom.*

The daughters’ room is like most dwellings in Syria, where overheating and sun glare in south- and east-oriented rooms is a common problem in domestic spaces (Figure 42). While people usually adapt by getting rid of furniture that adds more heat, such as carpets or fabric canopies outside the window (changes in the environment), they sometimes adapt by avoiding the sunny spots in the room (changes in behaviour). Similar to the kitchen, the balcony in the daughters' room has been glazed and added to the room because of the lack of space and it is used as a space for the desks. However, since the room has east orientation and no other intervention has been considered, such as adding a shading device, this created overheating in summer due to the direct unwanted solar gains. The problem of intensive solar gains could be observed especially in the morning, when one of the daughters wrote in her diary that she was not able to work because of the sun glare and ultimately had to move to another space (changes in behaviour).




*a. Outdoor temperature levels on July 13 based on the simulation results.*




*b. Visual representation of the occupant behaviour in the daughters' bedroom on July 13 based on the collected diaries*

*Figure 42. Occupant behaviour during the morning of July 13, 2020 in the daughters' bedroom based on the outdoor temperature and collected diaries.*

By analyzing the written diaries of the participants, several problems associated with the overall thermal performance of the flat can be discussed. First, the dominant problem of thermal comfort is temperature stress as a result of the low performance envelope and the inappropriate orientation. Second, the leaky envelope resulted in high level of humidity, which can be witnessed in the cracks and mould on the wall. This significantly increases heat losses and gains. Third, while the results of both diaries and environmental simulation found that heat stress is a major problem in summer months, the inconsideration of shading contributes to creating the problem of sun glare, which in its turn reduce the indoor thermal comfort.

### 4.4. Gap Analysis: A discussion

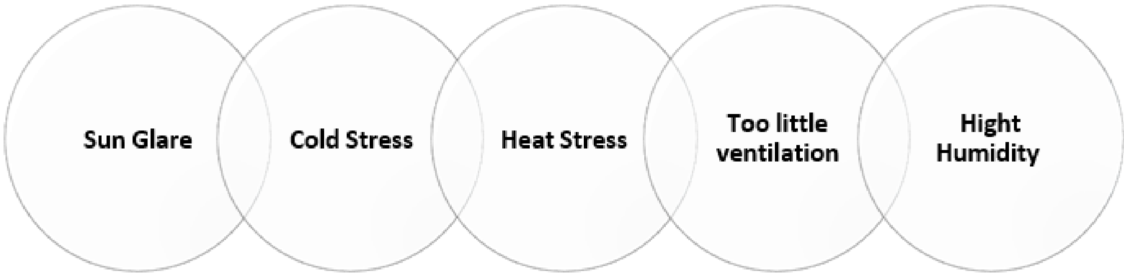



*Figure 43. Thermal problems in the case study dwelling.*

The results of analyzing the case study show four discomfort problems including sun glare, cold and heat stress, little ventilation, and high humidity (Figure 43). Byreflecting on the theoretical framework, coping with discomfort includes three main processes: environmental alterations, changes in behaviour, and psychological processes. In winter, the three responses has been part of coping with cold stress in the case study flat. The residents used an electric heater in the bedrooms while an underfloor electric film was used in the living room in order to store heat. It canbe said that this method is an interesting mechanism of environmental alterations for coping with the chronic electricity blackout during cold winter days. While electricity is available, the residents can turn the underfloor film on, which stores heat for a long time while the electricity is down. This method can help residents keeping the living room warmer than other rooms in the dwellings. However, the effect of electric films is limited due to the unequal heat distribution in the space. The cost of the electric films is also not affordable for all families. Changes in behaviour include using more clothes or even using the blankets in the evening, when temperature levels are very low but do such behaviours always satisfy the resident to maintain a minimum comfort level when no power is available to use localised devices? The diaries show the opposite. While the residents most times do not have the choice to keep warm, they face the situation of electricity blackouts unpleasantly and constantly complain about it as the only available psychological response to thermal discomfort.

Furthermore, the location of the kitchen caused multiple problems, particularly overheating and sun glare during summer. The occupants' responses ranged from opening windows and doors trying to provide a cross ventilation by opening the eastand western sides of the dwelling. Sometimes, the residents responded by moving to the living room or just getting a shower. The psychological response for overheating is unpleasant and there is always discussion to change the environment and furniture to seek more comfortable space. Sun glare discomfort has been also witnessed in the girls' living room as their study desk were located in the glazed balcony which have hight number of solar gains in the morning. While ventilation also shows another contributor to the levels of thermal comfort in the case study, the participants complained about the air quality in winter. It can be argued that while residents try to close the windows and keep the space warm with the help ofelectric heaters with limited capacity, the moisture would be trapped in the space, developing condensation on windows and constantly damp and moisture on Surfaces.

As a result, the experience of various discomfort problems in the case study dwellings has caused multiple several adjustments in the residents' behaviour and psychological mechanisms in order to restore their comfort, that can be summarised in (Table 12). However, due to the low performance envelope and lack of energy services, it is very challenging to keep thermally comfortable home. Although, the five family members have said they are not satisfied with the building performance in summer, their complaints about the winter discomfort was larger especially in theliving spaces. During cold winter days, and while the electricity is on, higher thermallevels can be achieved. However, the residents had no flexibility to stay in their spaces since the electric heaters have limited flexibility. Therefore, the family members gather in one space although it is not an optimal choice when the children want to study, but their psychological response involve prioritising their thermal comfort over their spatial comfort.

While the residents have to compensate their comfort where no energy devices is available, what is the role of the design of the envelope performance? This study argues that root causes of occupant’s discomfort lie in the poor design that causes,in its turn, the low thermal performance of the dwelling.

*Table 12. Mechanisms of coping with thermal discomfort in the case study.*

| **Changes in the Environment** |
|---|
| • Use of localized devices<br>• Open window/door |
| **Changes in Behaviour** |
| • Adjust clothes<br>• Move to another space<br>• Use blankets<br>• Getting a shower |
| **Emotional/psychological response** |
| • To face it unpleasantly- nothing we can do about it.<br>• Try to ignore it.<br>• Constantly complain about it. |

In conclusion, the poor design of the case study can be analysed within the frame of the building performance gap, which is divided in this study into three main aspects. First, the lack of a site-specific design; while the prevailing wind in Damascus is west-south direction, the wind speed can reach more than 15 m/s based on the weather file, which can create strong wind current if the wind is perpendicular. As the dwelling overlooks the main road on the north-western facade, it can be noticed from the photographs that the case study building standsat the crossroads of multiple roads which creates a traffic island just overlooking the west-northern façade. As a result of the open space facing the dwelling entrance, there is no physical obstruction to reduce the wind speed when using natural ventilation in winter.

On contrary, it has two negative consequences. First, the high-speed winds increase air circulation and results in un-controlled ventilation in case of opening window and have reverse effects on natural ventilation. Second, the effect of the accelerated airflow in winter have a negative impact on the dwelling’s envelope as streams of air that flows in through the leaky dwelling’s envelope increases the humidity entering the building and encourage mould and damp.

(Figure 44) Summarizes the site-related characteristics of the case study that shouldhave been considered in the original design.

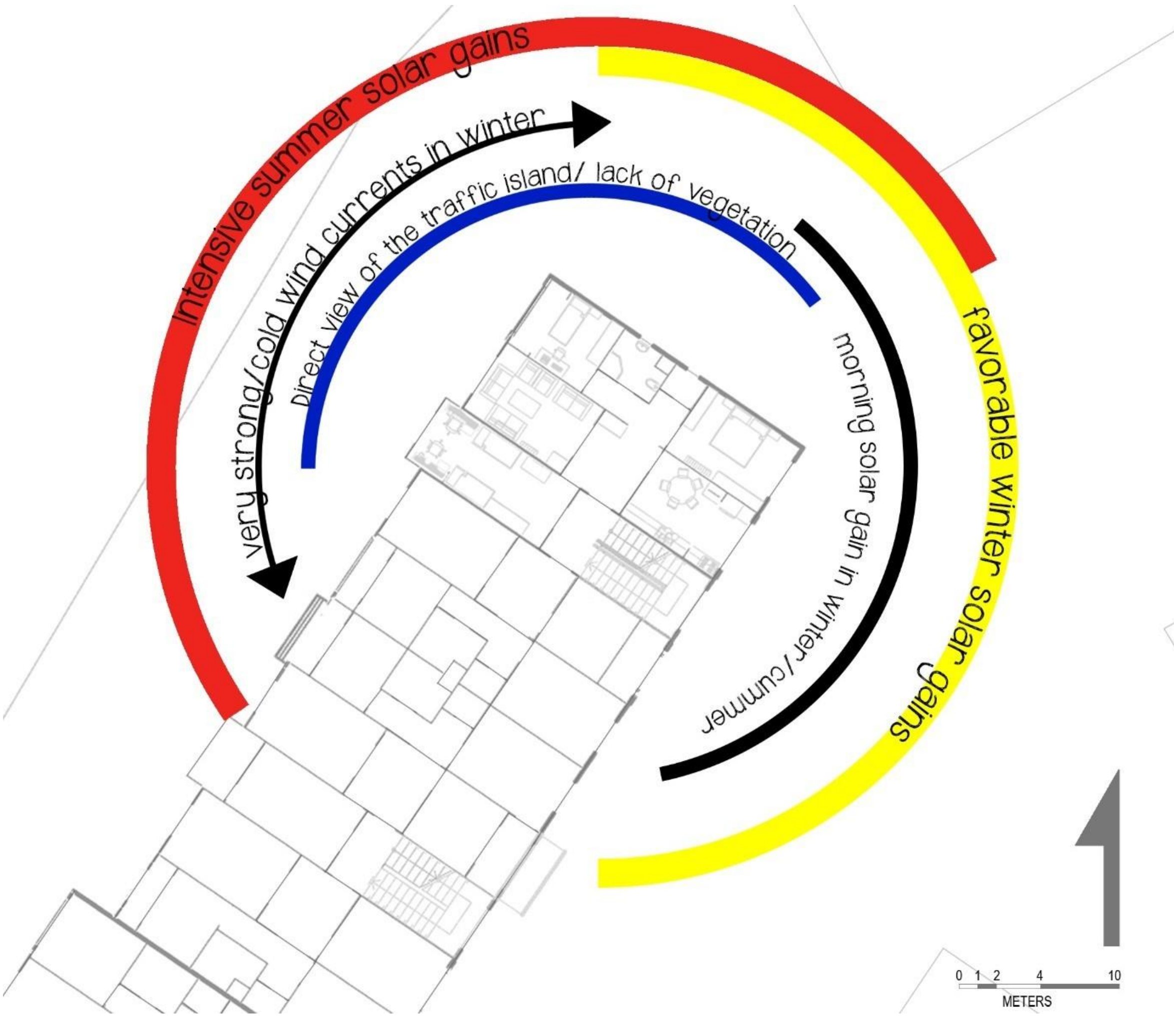



*Figure 44. Thermal performance gap of the case study dwelling.*

Second, the occupant behaviour; although the design plays an essential role in creating low levels of thermal comfort in the dwelling, the occupant's intervention in the space should also be discussed in order to highlight its impact on the low thermal comfort. Although the original design has to balconies, the residents opt for adding them to the space as enclosed balcony. This intervention resulted in wasted opportunity of using the balconies as buffer spaces in order to increase the shading and reduce the heat gains in the Interior space. However, social drivers behind such actions should also be understood including privacy and lack of space.

As a result, the inconsideration of environmental and social aspects in the design of the case study dwelling has results in a performance gap, which is in its turn, led to low level of thermal comfort in the space.

# Chapter Five

## 5. Conclusion

> When do you think people die? When they are hit by a bullet? No! When they suffer from a disease? No! When they eat a soup madeout of a poisonous mushroom? No! People die when they are forgotten” (Oda, 2001)

This chapter summarises the main findings of this research including findings of the theoretical framework and the selected methods in order to emphasize the strategic importance of this study and its results. Then, it states how the selected approach in this study contributes to knowledge. This study has multiple limitations, which affected the decision making of the methodology. These limitations were highlighted in this chapter. Finally, recommendations for further research have been thoroughly discussed in this research.

## 5.1. Summary of the main findings of the research

As this study aims to investigate factors associated with thermal comfort in a social housing building within the Syrian context, the main question was how the social housing case study environmentally performs to secure occupant's thermal comfort. Based on a quantitative and qualitative analysis of the performance of the case study, this question was attempted to be answered by following a user-centric approach in exploring both subjective and objective aspects of domesticcomfort in the case study. However, before analysing the performance of the case study, this research went through two main stages.

First, a review of the current literature studies about comfort and discomfort and the previous studies in the Middle East was conducted in chapter 2. Based on the discussed literature, a theoretical framework was concluded in order to understandthe occupant behaviour in the domestic space. Starting from the occupant as a central factor, it was argued that their social, biological, and psychological needs affect their behaviour (internal drivers). On the other hand, the physical environment including the climate characteristics and building components and the building systems also affect their behaviour (external drivers). The interaction between the internal and external drivers led this study to understanding the drivers of the occupants' actions in adapting to their environment or coping with it. The occupant responses include changing the environment, changing behaviours, or managing emotions if thermal discomfort is presented in the indoor environment.

Second, the study went through a detailed analysis about the current supply of social housing in Syria and the climate characteristics of the city of Damascus from an architectural perspective since the current literature lacks any architectural-related studies for Damascus climate. The climate analysis results of Damascus showed a large demand for heating and cooling. The months of August and January showed that the most critical results. The percentage of the cold stress during the year with less than 9 °C is around 14%. However, the lowest mean value in January was -2.0 °C at night, which is equivalent to a moderate cold stress. Later, by analysing the indoor environment of a case study flat in a social housing dwelling in the city of Damascus and the thermal experience of the residents of this flat, this thesis showed how the residents in Syria are significantly affected by their indoor conditions, which directly and indirectly shape their spatial decision-making. On the other hand, this study investigated how the social drivers can also directly affect the resident's spatial decision-making, which indirectly shapes the thermal indoor environment.

While the analysis of one case study limits the generalizability of the results, this approach provides new insights into the performance of Syrian dwellings, where no field studies have been conducted within this context. This study highlights the importance of investigating the occupant behaviour while looking at the domestic thermal comfort in order to provide a wider perspective of domestic comfort and understand the direct and indirect drivers of the occupant's actions. Multiple findings can be concluded from the implemented methodology:

- The results of the shoebox analysis showed that the optimum orientation was selected to be 00 at East-west axis, where it maximizes heat gains at winter and minimizes heat gains at summer. Furthermore, the horizontal shading benefit has a greater impact on the southern façade of 25 cm. Thirdly, the results of the window to wall ratio showed that the opening on the eastern and northern façade results in higher levels in comfort due to the reduced heat gains while WWR has the greater impact on the southern façade as undesired solar gains mainly come from south facades in Damascus. The results of shoebox analysis showed that WWR of the western façade should not exceed 40%.

- In applying the fundamental principles of passive architecture in the climate of Damascus including a minimum level of thermal insulation and an optimal orientation and window to wall ratio. The simulation results showed that people can experience being comfortable around 57% of the overall time through the year with range of temperature levels of 19 to 28$^0$C. However, the simulation results of the case study showed that the people experienced being comfortable level of indoor temperature (19 to 28$^0$C) only around 19% of the overall time through the year, which indicates the significant performance gap in the case study.

- Given the lack of energy supply in Damascus over the past ten years, it can be argued that this has significantly reduced comfort levels in the case study dwelling. Nevertheless, this study found that building properties and the design decisions has a major contributing factor to the discomfort problem, which could have been addressed by following passive design to ensure minimum levels of comfort in the residential space.

While the diary form is not often encountered in the context of thermal comfort studies, diaries method showed a strong potential as an instrument for coping with the unknown context of Syrian housing. Based on combining the results of simulation and the collected diaries, multiple findings have been concluded:

- It is concluded that the resulted indoor discomfort in the case study dwelling was an outcome of three main factors. First, the low thermal performance of the dwelling was a result of the absence of passive architectural strategies. This referred to the inappropriate orientation of the rooms, the absence of insulation and shading devices. Second, the lack of access to energy services was an essential challenge in the current situation of Damascus. The chronic electricity blackout, particularly during cold winter days, significantly limited the occupants' comfort and lowered their expected level of comfort. finally, the occupant's interventions. i.e., the enclosed balconies created several problems associated with comfort as it increased the exposed area to the external environment. This sequentially increased the heat gains and losses and eventually increased the temperature stress.
- The occupants responded to discomfort within three main processes including: environmental alterations, changes in behaviour, and psychological processes. The varied coping processes have acted as the occupant's mechanisms to adapt their indoor environment during cold or hot stress and seek comfort. The environmental alterations included changes in the indoor environment of the occupant such as using localised devices, changing the state of openings, or even moving to another space where heat asymmetry can be avoidable. The behavioural responses attempted to adjust the own's behaviour to seek comfort such as changing clothing level. Finally, when the occupants were unable to alleviate their discomfort, they just responded emotionally or complained as a response of being incapable to alter their indoor comfort.
- Social and functional drivers were essential elements in the decision-making process of the occupant's actions. While privacy was considered as a main driver for the occupant's intervention, this factor had not been considered in the

original design which led to more negative consequences on the comfort levels. It has also been concluded that the occupant's lack of awareness was a contributing factor for the resulted discomfort. For example, while the residents were driven by lack of space, they opted for enclosed balconies and expanding the room's space. This led to negative consequences associated with thermal comfort and made the whole room's space uncomfortable.

This research acknowledged that the abnormal circumstances in providing the domestic energy services posed additional challenges in securing domestic comfort. However, it clearly highlighted the low performance of Syrian dwellings and investigated how residents were trying to adapt to the daily discomfort. This also raises the question of the potential of providing more comfortable domestic space in the existing Syrian social housing, where energy services are limited.

But are there ways to address the failure of the existing social housing and improve their environmental performance? This challenge may be tried to be answered with the potential of implementing low energy social housing retrofit in Syria. Although housing retrofit was not a discussed topic several years ago, the on-going Syrian conflict and the mass partially destructed housing in all Syrian cities raises the opportunity to consider low energy housing retrofit in the ongoing debates of reconstruction in Syria.

Several changes that remain unanswered are the limits of costs and the availability of Syrian technical craft with regards to energy efficient housing retrofit. However, such interventions need to be encountered on a national scale to prioritise the social and environmental needs in rebuilding the future of housing design model in Syria. Therefore, this research is considered as a motivation for research studies that focus on shifting the current model of social housing within the Syrian context. Multiple open questions about the efficiency of the current model of affordable housing in Syria when speaking of Syrian reconstruction need to be further investigated. Is producing the same models of domestic building the answer for the Syrian reconstruction, environmentally and socially? And can we set standards to build energy efficient homes in Syria, that consider meeting the social and cultural needs?

### 5.2. Contribution to Knowledge

This study aimed to contribute to the architectural research in relation to the Syrian context by developing an analytical framework to investigate thermal comfort levels in a typical Syrian dwelling.

The first contribution of this thesis is contextual. Considering the lack of research about the performance of Syrian dwellings, this study has focused on one family flat in a 4-storey domestic block in Damascus and analysed its thermal performance in order to understand its thermal performance. However, this study argues that the understanding of building performance should not only be focused on the objective aspects of the dwelling but also the occupants themselves and how they respond thermally to the space they live in. The second contribution is the use of the diary format as a tool to capture the comfort-related occupant behaviour in architectural research. Diary research methods are not common methods, which are encountered in the building energy research. Therefore, this study has contributed to exploring the diary method, which provides wider perspective to understand all factors associated with the subjective aspects of building performance.

This thesis is submitted for an MPhil degree. Therefore, the field study was limited to analysing the comfort levels within one case study in the city of Damascus without proposing strategies for the physical design for low energy housing.

### 5.3. Research Limitations

It is essential to clarify the limitations for this study in order to better understand the context and the conditions of this study that affected the results. First, considering the ongoing conflict in Syria, it has been recommended not to travel to Syria to conduct the field study. However, it was authorised to be conducted online. This limitation has significantly affected the research methods and the results of data collection. First, due to difficulties in recruiting participants, the sample size was limited to one case study dwelling. Second, the method of thermal simulation has been chosen due to the limitation of conducting monitoring and on-site environmental measurements while doing this research online. This has affected the validation of the results. Third, while analysing the microclimate of a case study building at a neighborhood scale is essential to understand the interaction of climatic factors with surrounding buildings and outdoor spaces, this study encountered an additional barrier in limited access to primary data of neighboring buildings, which limited the scope of analysis to the case study with consideration of neighboring buildings.

Another strong limitation that should be mentioned is the constraints of time and resources. This study is submitted for an MPhil degree, which has a limited research period. This affected the period of data collection and limited it to focusing on one case study. Furthermore, there is very limited studies about the social housing and energy performance of dwelling in Syria. Therefore, all data was collected as primary data, which represent a further limitation to the results within the study's time.

A final limitation related to the fact that this research was conducted during a period in which Syria is still experiencing a transition period. The city where this research is conducted is Damascus, which is currently out of conflict areas. However, there are still multiple difficulties to conduct research studies. Therefore, the field study was conducted remotely with the help of an associate who is based in the city of Damascus and is one of the residents of the dwelling. This has facilitated the process of data collection due to her informal connection with the participants.

### 5.4. Moving Forward: Recommendation for Further Research

This study has investigated the domestic comfort in Syrian social housing and used both environmental simulation and diary research methods as a trigger for exploring the user centric approach in thermal comfort research. Due to the limitation of research studies and resources about the performance of social housing, the intention of this research was to understand the Syrian domestic space by focusing on one family flat in a typical dwelling in Damascus due to time and workplan constraints. However, this study is considered only a starting point for further study on thermal comfort in Syrian dwellings on a wider scale.

If the work is to gain a broader impact, this project has the opportunity to expand on multiple levels. One way is to expand on the diary methods. While the diary format has been used in this research as a functional tool to involve the residents in framing the problem and track their relation to the building performance in two days, diaries for the family can be tracked closer over a whole year in order to better understand the impact of climate on the domestic comfort. Another way is needed to be considered is to include more families in the diary study in order to compare the different interventions for inhabitants in searching for domestic comfort within the same standardized plan.

Furthermore, diary studies ,as functional informational tools for researchers who looks for evidence, seems to be very limited in energy and thermal comofrt studies in the built environment. This study showed the impact of using the diary format to capture the occupants' energy-related actions in dwellings in an unknown context such as Syria, which can be an assistant tool in different countries and cities while investigating the environmental performance of the dwelling not only from the objective aspects but also understand the objective aspects of domestic comfort and the spatial related activities.

The current knowledge about the domestic comfort and performance of social housing in Syria is narrow. Therefore, the research findings emphasise the role of lack of domestic energy services in producing domestic comfort. Further studies about energy poverty in Syria are essential to spectate domestic comfort from a wider perspective and understand the political and economic related factors, that directly impact the occupant's spatial behaviour. More studies about energy poverty and environmental performance of dwellings are also needed in different cities in Syria to enable more comparative studies.

Not only economic factors affect the resulted discomfort, but also socio-cultural factors have an impact on the decision-making process of domestic comfort as it was concluded in this study. However, there is limited number of studies which have investigated the relationship between the socio-cultural factors and the architectural production, which is recommended in this study to be a further research focus.

The research findings support a positive attitude towards reactivating the role of social housing in the housing production in Syria. While Haddad & Ezzi (2021) concluded that the current gap in Syria between housing supply and demand is over 2 million housing units. This significant need cannot be bridged only by providing new stocks of housing but also considering low energy housing retrofit in order to turn the mass destruction of Syrian housing to an opportunity that benefit from the existing materials and structure and provide cheaper housing solution.

With the urgent need for rebuilding in Syria, it should be mentioned that major international donors still refuse to fund reconstruction within the current political conditions (Lund, 2018). This can be reflected by the lack of research about Syrian housing redevelopment.

Nevertheless, the need for sustainable methods of domestic energy production and consumption and avoiding reliance on active heating and cooling including air conditioning and oil heaters should be a priority in the Syrian housing retrofit due to its economic and environmental benefits. Therefore, low energy retrofit is recommended to be one of the most considered priorities in renovating Syrian housing. The potential of focusing the further research on proposing an environmental-aware model of retrofitting Syrian housing is recommended in this research in order to ensure that housing fulfills the needs of middle-income and low-income groups in Syria including the socio-cultural, environmental, and economic needs.

# 6. References


Al Khalaf, Aseel. (2014) The Production of New Affordable Housing in the Syrian Cities: The Possible Role of Procurement Processes in Improving Construction Efficiency. PhD thesis Heriot Watt University.

Ali, Suha and Szalay, Zsuzsa. (2020) Overview and Analysis of the Overheating Effect in Modern Sudanese Buildings. Pollack Periodica. 15. pp. 208-219.

Al-Mohamad H and Karmeh. (2003) Wind energy potential in Syria. Renewable Energy Journal, Volume 28, Issue 7, pp. 1039-1046.

Alvesson, M., and Skoldberg, K. (2000) Reflexive Methodology: New Vistas for Qualitative Research. London, Thousand Oaks, CA and New Delhi: SAGE Publications Ltd

Amer, En & Hamed, Fareed. (2012) Reality and Prospects of Wind Power in Syria. Energy Procedia. Volume 19, pp. 55–62.

ASHRAE, Standard 55. (2013) Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta.

ASHRAE. (2009) handbook: Fundamentals. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

Asseburg, Muriel. (2020) Reconstruction in Syria Challenges and Policy Options for the EU and its Member States. German Institute for International and Security Affairs. Berlin, Germany.

Augenbroe, Godfried. (2002) Trends in building simulation. Building and Environment, Volume 37, pp 891-902.

Baaghideh, M. M., Fatemeh. Shekari badi, Ali. badi, Shekari. (2016) Evaluation ofhuman thermal comfort using UTCI index: case study Khorasan Razavi, Iran.

Baum, A., Calesnick, Davis, G., & Gatchel, R. J. (1982). Individual differences in coping with crowding: Stimulus screening and social overload. Journal of Personality Social Psychology, 43, pp. 821–830.

Biket, AP. (2016) Architectural Design Based on Climatic Data. 1st International CIB Endorsed METU Postgraduate Conference Built Environment & Information Technologies, pp 261- 7. Ankara, Turkey

Boardman, B. (1991) Fuel poverty: from cold homes to affordable warmth. London: Belhaven Press.

B. Ozarisoy, H. Altan. (2021) A novel methodological framework for the optimisation of post-war social housing developments in the South-eastern Mediterranean climate:

Policy design and life-cycle cost impact analysis of retrofitting strategies, Solar Energy, Volume 225, pp 517-560.

Boardman, Brenda. (2012) Fuel poverty synthesis: Lessons learnt; actions needed. Energy Policy. 49, pp. 143-148.

Bolton, Laura. (2020) Economic situation for individuals and communities in Syria. London, UK: The Knowledge, Evidence and Learning for Development Programme K4D.

Brager, G. S. de Dear, Richard. (1998) Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy and Buildings, 34, pp. 549–561.

Burris, Andrea. Mitchell, Val. Haines, Victoria. (2012) Exploring Comfort in the Home: Towards an Interdisciplinary Framework for Domestic Comfort. Proceedings of 7th Windsor Conference: The Changing Context of Comfort in an Unpredictable World: Windsor, UK.

Butter, David. (2015) Syria's Economy: Picking up the Pieces. The Royal Institute of International Affairs, Chatham House: London, United Kingdom.

Cardell, Kylie. (2014) Dear World: Contemporary Uses of the Diary. University of Wisconsin Press pp. 25-46.

Carter H, Weston D, Greenberg N, et al Experiences of supported isolation in returning travellers during the early COVID-19 response: a qualitative interview study BMJ Open 2021

Carter, M., Shih, P., Williams, J. et al. (2021) Conducting Qualitative Research Online: Challenges and Solutions. https://doi.org/10.1007/s40271-021-00528-w.

Castro, M. d. F., Mateus, R. and Bragança, L. (2015) A critical analysis of building sustainability assessment methods for healthcare buildings. Environment, Development and Sustainability, 17(6), pp. 1381-1412.

Christine Sotsek, N. y Sanchez Leitner, D. y Lacerda Santos, A. P. y. (2019) A systematic review of Building Performance Evaluation criterias (BPE). Vol. 9, pp. 1-14.

CIBSE. (2015) CIBSE Guide A - Environmental design. London: Chartered Institution of Building Services Engineers. London, UK

Collins. (2003) Compact English Dictionary. Swindon: Harper Collins Publishers.

Commons, H. o., Business, E. a. I. and Committee, S. (2019) Energy efficiency: building towards net zero. UK.

Cunial, Laura. (2016) Housing Land and Property (HLP) In the Syrian Arab Republic. The Norwegian Refugee Council. Access online https://www.nrc.no/globalassets/pdf/reports/housing-land-and-property-hlp-in-the-syrian-arab-republic.pdf

Dahman, Reem. (2016) Analytical study to youth housing project in Qudsiya. Journal of Damascus University. pp. 134-140. Damascus, Syria.

Det Norske Veritas. (1987) Recommended Practice C102, Area Classification and Ventilation.

Development Data Group. (2015) World Development Indicators Online. Washington,DC: The World Bank.

Dogan, Timur and Reinhart, C. (2013) Automated conversion of architectural massing models into Thermal 'Shoebox' models. Conference:BS2013: Chambéry, France, Volume: 13. 10.13140/RG.2.1.3543.0886.

Efeoma, Meshack Oghenekaro. (2016) The Influence of Clothing on Adaptive Thermal Comfort: A Study of the Thermal Comfort of Office Workers in Hot Humid Conditions in Enugu, Nigeria. PhD thesis: The University of Edinburgh.

EIA. (2019) International energy data and analysis (Syria). U.S: U.S Energy Information Administration.

Eisenhardt, K. M. (1989) Building Theories from Case Study Research. The Academy of Management Review, 14(4), 532–550. https://doi.org/10.2307/258557

El Harrouni, Khalid. Benaicha, Mouhcine. Harrouni, Rime. (2018) Parametric Modellingand Traditional Architecture: Improving the thermal comfort of the traditional courtyard house in Morocco. MATEC Web of Conferences. 149. 02051. 10.1051/matecconf/201714902051.

Fanger, P.O. (1970) Thermal Comfort. Danish Technical Press. Copenhagen.

Felmer, Gabriel (2018) Low-Energy Dwelling Prototypes for Different Regions of Chile. PhD thesis: The Open University.

Fernández-Ahumada, L. M., Ramírez-Faz, J., López-Luque, R., Márquez-García, A. and Varo-Martínez, M. (2019) A Methodology for Buildings Access to Solar Radiation in Sustainable Cities. Sustainability: Basel, Switzerland. 11(23) pp. 65-96.

Foster, J. & Foster, S & Sharpe, Tim & Poston, Anna. (2016) Building Performance Evaluation, A design approach for refurbishment of a small traditional building in Scotland.

Fowler, K. M. (2006) Sustainable Building Rating Systems.

Fund, International Monetary. (2009) Syrian Arab Republic: Article IV Consultation: Staff Report; and Public Information Notice. Ukraine: International Monetary Fund.

Gillham, B. (2000) Case Study Research Methods. Continuum, London.

Gobat, Jeanne and Kostial, Kristina. (2016) Syria's Conflict Economy. International Monetary Fund. Washington, D.C., United States.

Goulden, Robert. (2011) Housing, Inequality, and Economic Change in Syria. British Journal of Middle Eastern Studies 38(2): pp. 187-202.

Grix, J. (2004) The Foundations of Research. New York, NY: Palgrave Macmillan.

Haddad, Wajeeh. (2018) The Housing Crises in Syria and the Challenges of housing sector reconstruction. Harmoon Centre for Contemporary studies. Doha, Qatar.

Haddad, Wajeeh. (2019) Family Expenditure Changes in Syria Before and After the War. Harmoon Centre for Contemporary studies. Doha, Qatar.

Haddad, Wajeeh & Ezzi, Mazen. (2019). The Housing Crisis in Syria: Do Social Housingand Housing Cooperatives Still Have a Role? Accessed online Jan 2022. https://syria-report.com/hlp/the-housing-crisis-in-syria-do-social-housing-and-housing- cooperatives-still-have-a-role/

Hatahet, Sinan. Shaar, Karam. (2021) Syria's Electricity Sector After a Decade of War:A Comprehensive Assessment. The European University Institute, Robert Schuman Centre for Advanced Studies.

Hausladen, G., Michael, M. de., and Liedl, P. (2006) Climate Skin. Birkhausser

Heerwagen, J. H., & Heerwagen, R. (1984) Energy and Psychology: Designing for a "State of Mind." Journal of Architectural Education (1984-), 37(3/4), 34–37.

Heerwagen, Judith. Kampschroer, Kevin. Powell, Kevin. Loftness, Vivian. (2004) Collaborative Knowledge Work Environments. Building Research and Information - Building Res Inform. 32. 510-528. 10.1080/09613210412331313025.

Herda, G. (2017) Building Sustainability Assessment and Benchmarking - An Introduction. In: Autio, V.

Hong, T., Yan, D., D'Oca, S., Chen, C.-f. and Lawrence Berkeley National Lab, B. C. A. (2017) 'Ten questions concerning occupant behaviour in buildings: The big picture.' Building and Environment, 114(C) pp. 518-530.

Hong, T.; D'Oca, S.; Taylor-Lange, S.C.; Turner, W.; Chen, Y.; Corgnati, S. (2015) An ontology to represent energy-related occupant behaviour in buildings. Part II: Implementation of the DNAS framework using an XML schema. Build. Environ.196–205.

International Energy Agency. Modernising Building Energy Codes to Secure Our Global Energy Future; International Energy Agency: Paris, France, 2013; p. 8.

Ismail, Reem. (2015) Adaptation of Housing Design to Culture Change in Syria: Conceptsand Practices in the City of Latakia. Heriot-Watt University. School of Energy, Geoscience, Infrastructure and Society. UK.

ISO. (1984) ISO 7730:1984, Moderate thermal environments— determination of the PMV and PPD indices and specification of the conditions for thermal comfort. Geneva, Switzerland: International Organisation for Standardisation.

J. Bradshaw, S. Huron. (1983) Social policy Options and fuel poverty. Journal ofEconomic Psychology 3, pp. 249-266.

J.F. Nicol, M.A. Humphreys. (2002) Adaptive thermal comfort and sustainable thermal standards for buildings, Energy and Buildings, Volume 34, Issue 6. pp. 563-572.

Jabi, Wassim. (2014) Parametric Spatial Models for Energy Analysis in the Early Design

Stages. Simulation Series. 46

Janda, K. B. (2011) 'Buildings don't use energy: people do.' Architectural ScienceReview, 54(1) pp. 15-22.

Joseph H.K. Lai, Francis W.H. Yik. (2009) Perception of importance and performance of the indoor environmental quality of high-rise residential buildings, Building and Environment, Volume 44, Issue 2. pp. 352-360.

June, Alexander. Lee Brien, Donna. McAllister, Margaret. (2015) Diaries are 'better than novels, more accurate than histories, and even at times more dramatic than plays': Revisiting the diary for creative writers. Alexander, Brien & McAllister TEXT Vol 19 No 1.

Kassouha, Sana. (2020) Transferring Experiences of Post-War West Germany in Social Housing to Reconstruction Strategies After the War in Syria. PhD thesis: Institute of Housing and Design, University of Stuttgart, Germany.

Kathryn B. Janda. (2011) Buildings don't use energy: people do, Architectural Science Review, 54:1, 15-22, DOI: 10.3763/asre.2009.0050

Kevin J. Lomas & Stephen M. Porritt. (2017) Overheating in buildings: lessons from research, Building Research & Information, 45:1-2, 1-18, DOI: 10.1080/09613218.2017.1256136

Khaddour, Lina. (2021) Strategic framework of operational energy performance improvement potential for Damascus post-war social housing, Intelligent Buildings International.

Kharseh, Mohamad. (2009) First thermal response test in Syria. Thermal Energy Storage for Efficiency and Sustainability Conference.

Kharseh, Mohamad. Nordell, Bo. (2008) Sustainable H/C Systems for Chicken Farms in Syria. Istanbul: Global Conference on Global Warming.

Kidson, Marc and Norris, Emma. (2014) Implementing the Fuel Poverty Strategy. The report by the Institute for Government and Joseph Rowntree Foundation. London, UK.

Kimpian, J. Hartman, Hattie. Pelsmakers, Sofie. (2021) Energy / People / Buildings: Making sustainable architecture work. RIBA Publishing. London, UK.

Kuchen, E. and M.N. Frsch. (2009) Spot monitoring: Thermal comfort evaluation in 25 office buildings in winter. J. Build. Environ., 44: 839-847. DOI: 10.1016/j.buildenv.2008.06.02

Kumar, Sanjay. Singh, Manoj. Kumar, Loftness, Jyotirmay, Vivian. Mathur, Sanjay. (2016) Thermal comfort assessment and characteristics of occupant's behaviour in naturally ventilated buildings in composite climate of India." Energy for SustainableDevelopment 33, pp. 108-121.

Lavinia, Poruschi. (2017) Tensions between urban life, disadvantage, energy consumption and the transition to renewable energy for Australian households: A series of essays. https://doi.org/10.25904/1912/1255

Lee, H.-J., Kim, S.-Y. and Yun, C.-Y. (2017) Comparison of Solar Radiation Models to Estimate Direct Normal Irradiance for Korea. Energies (Basel), 10(5) pp. 594.

Lejeune, Philippe. (2009) On Diary. University of Hawaii Press. ProGuest Ebook Central.

Lihidheb, Kawther. (2014) Energy Efficiency Building Code Implemention In MED-ENEC Parteners Countries. 5th International Forum on Energy for Sustainable Development: Tunisia.

Livholts, Mona. (2017) Narrative writing as art-based practice. 10-29.

Lobe B, Morgan D, Hoffman KA. (2020) Qualitative data col- lection in an era of social distancing. Int J Qual Methods.

Lond, Aron. (2018) Dispossession or development? The tug of war over Syria's ruinedslum dwellings. Accessed online. Jan 2022. https://www.thenewhumanitarian.org/analysis/2018/07/04/dispossession-or-development-tug-war-over-syria-s-ruined-slum-dwellings

Mahdavi, Ardeshir. Feurer, Silvana. Redlein, Alex. Suter, Georg. (2003) An inquiry intothe building performance simulation tools usage by architects in Austria.

Ministry of Housing and Utilities in Syria. 2009 [Accessed online October 2020]: http://mopwh.gov.sy/?page=Map&lang=ar

Ministry of Local Government. (2008) The Syrian Code for Construction and Thermal Insulation. Arabic Edition. Damascus: Syrian Engineers Association.

Mohamed, M. (2010) Traditional Ways of Dealing with Climate in Egypt. The Seventh International Conference of Sustainable Architecture and Urban Development (SAUD 2010).

Nguyen, B. K. and Altan, H. (2011) Comparative Review of Five Sustainable Rating Systems. Procedia Engineering, 21 pp. 376-386.

Nicol, Fergus & Humphreys, Michael. (1973) Thermal comfort as part of a self- regulating system. Building Research and Information - Building Res Inform. 1. 174-179. 10.1080/0961321730855023

Nicol, Fergus & Humphreys, Michael. (2002) Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings. Energy and Buildings. 34. 563-572. 10.1016/S0378-7788(02)00006-3. pp. 563-572

Nicol, J. F., Raja, I. A., Alludin, A. and Jamy, G. N. (1999) Climatic variation in comfort temperatures: The Pakistan projects. Energy and Buildings, vol 30, no 3, pp. 261–279.

Nicol, J.F. (2001) Characterizing occupant behaviours in buildings: towards a stochastic model of occupant use of windows, lights, blinds heaters and fans, Proceedings of the 7th internationational IBPSA conference, Rio 2. International Building Performance Simulation Association. 39(7): pp. 1073-1078.

Nuno Serafim Cruz, Isabel M. Torres, J. A. Raimundo Mendes da Silva. (2011) Bioclimatic Architecture Potential in Buildings Durability and in their Thermal and Environmental

Performance. International conference on Durability of building materials and components. Porto. Portugal.

O. Rakoto-Joseph, F. Garde, M. David, L. Adelard, Z.A. Randriamanantany. (2009) Development of climatic zones and passive solar design in Madagascar, Energy Conversion and Management, Volume 50, Issue 4, pp. 1004-1010.

Oda, Eiichiro. (2001) One Piece. Volume 16: Carrying on His Will. VIZ Media LLC. Omar, O. Near Zero-Energy Buildings in Lebanon: The Use of Emerging Technologiesand Passive Architecture. Sustainability 2020, 12, 2267. https://doi.org/10.3390/su12062267

Othman, Ibrahim. (2018) Country Nuclear Power Profiles, Syrian Arab Republic.Damascus: IAEA, The International Atomic Energy Agency.

Park, J., Loftness, V., Aziz, A. and Wang, T.H. (2021) Strategies to achieve optimumvisual quality for maximum occupant satisfaction: field study findings in office buildings. Building and Environment, Vol. 195, 107458.

Parsons. K. (2003) Human Thermal Environments. London, Taylor & Francis.

Philip H. Saleh. (2015) Thermal performance of glazed balconies within heavy weight/thermal mass buildings in Beirut, Lebanon's hot climate, Energy and Buildings, Volume 108, 2015, Pages 291-303, 'PLEA 88 (Passive and Low Energy Architecture).'(1987) Building and Environment, 22(3) pp. 237.

Huang, Qiang. Meng, Xiangzhao. Yang, Xiaohu. Jin, Liwen. Liu, Xing. Hu, Wenju. (2016) The Ecological City: Considering Outdoor Thermal Environment. Energy Procedia. 104. 177-182. 10.1016/j.egypro.2016.12.031.

Gupta, Rajat. Gregg, Matt. Manu, Sanyogita. Vaidya, Prasad. Dixit, Maaz.(2019) Customized performance evaluation approach for Indian green buildings, Building Research & Information, 47:1, pp. 56-74.

Elnaklah, Rana. Alnuaimi, Abdulla. S. Alotaibi, Badr. Topriska, Evangelia. Walker, Ian. Natarajan, Sukumar. (2021) Thermal comfort standards in the Middle East: Current and future challenges, Building and Environment, Volume 200.

Raymond J. Cole. Robinson, John. Brown, Zosia. O'shea, Meg. (2008) Re- contextualizing the notion of comfort, Building Research & Information, 36:4.

RCREEE. (2013) Arab Future Energy Index™(AFEX) Energy Efficiency. Regional Centrefor Renewable Energy and Energy Efficiency (RCREEE). Cairo, Egypt.

Reach. (2019) Syrian Cities Damage Atlas Report: Thematic assessment of satellite identified damage. UNITAR United Nations Institute for Training and Research.

de Dear, R., & Brager, G. (1998) Developing an adaptive model of thermal comfort and preference. UC Berkeley: Center for the Built Environment. Retrieved from https://escholarship.org/uc/item/4qq2p9c6

Roudsari, M. S. M. P. (2013) Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally conscious design. Proceedings of BS 2013: 13th Conference of the International Building Performance Simulation Association. 3128-

3135.

Rowley, J. (2002), "Using case studies in research", Management Research News, Vol. 25 No. 1, pp. 16-27. https://doi.org/10.1108/01409170210782990

Saadatian, O; Haw, L. Ch., Sopian, K & Sulaiman, M.Y. (2012). Review of windcatcher technologies. Renewable and Sustainable Energy Reviews, vol. 16, Issue 3: 1477-1495

Saheb, Yamina. Kona, Albana. Maschio, Isabella. Szabo, Sandor. (2014) Guidebook Howto develop a Sustainable Energy Action Plan (SEAP) in South Mediterranean Cities. Joint Research Centre Institute for Energy and Transport: Ispra, Italy.

Sajad, Zare. Naser, Hasheminejad. Hossein, Elahi. Shirvan, Rasoul. Keyvan, Sarebanzadeh.Saeid, Ahmadi. (2018) Comparing Universal Thermal Climate Index(UTCI) with selected thermal indices/environmental parameters during 12 months of the year. Weather and Climate Extremes Volume 1, pp. 49-57.

Saleh, P. (2018) Towards Nearly Zero Energy Buildings in Lebanon: Bioclimatic Design and Experimental Strategies. PhD thesis: University of Westminster.

Sarvimaki, Marja. (2016) Case study strategies for designers: Teaching integrative data evaluation. EAAE/ARCC 2016 International Architectural Research Conference: Architectural research addressing societal challenges - Lisbon, Portugal

Shi, Xing. Si, Binghui. Zhao, Jiangshan. Tian, Zhichao. Wang, Chao. Jin, Xing. Zhou, Xin. (2019) Magnitude, Causes, and Solutions of the Performance Gap of Buildings: A Review. Sustainability. 11. 937. 10.3390/su11030937.

Shove, E. (2003) Converging Conventions of Comfort, Cleanliness, and convenience. Journal of Consumer Policy 26, pp. 395–418.

Singaravel, Sundaravelpandian and Geyer, Philipp. (2016) Simplifying Building Energy Performance Models to support an Integrated Design workflow.

Smith, R. M. (2015) Green building in India: a comparative and spatial analysis of the LEED-India and GRIHA rating systems.' Asian Geographer, 32(2) pp. 73-84.

Stephenson, J. Barton, B. Carrington, G. Gnoth, D. Lawson, R. and Thorsnes, P. (2010) 'Energy cultures: A framework for understanding energy behaviours.' Energy Policy, 38(10) pp. 6120-6129.

Syed Ihtsham ul Haq Gilani, Muhammad Hammad Khan, William Pao. (2015). Thermal Comfort Analysis of PMV Model Prediction in Air Conditioned and Naturally Ventilated Buildings, Energy Procedia, Volume 75, Pages 1373-1379.

Syrian centre for statistics (2011). [Accessed online: Oct 2020]: http://cbssyr.sy/

Tam, Vivian. Almeida, Laura. Le, Khoa. (2018) Energy-Related Occupant Behaviour andIts Implications in Energy Use: A Chronological Review. Sustainability. 10. 2635. 10.3390/su10082635.

Tam, Vivian W. Y. Almeida, Laura. Le, Khoa. (2018) Energy-Related Occupant Behaviourand Its Implications in Energy Use: A Chronological Review. Sustainability; Vol. 10, Iss. 8. Basel.

Tetlow, Richard. van Dronkelaar, Chris. Beaman, Philip. Elmualim, Abbas. Couling, Kevin. (2015) Identifying behavioural predictors of small power electricity consumptionin office buildings. Building and Environment. 92. 10.1016/j.buildenv.2015.04.009.

The General Housing Establishment, 2010. Social Housing report. Damascus, Syria. Arabic edition.

UN-HABITAT. (2007) Slums of the World: The face of urban poverty in the new millennium. Nairobi: UN-HABITAT

Motuziene, Violeta and Vilutiene, Tatjana. (2013) Modelling the Effect of the Domestic Occupancy Profiles on Predicted Energy Demand of the Energy Efficient House. Procedia Engineering, Volume 57. PP 798-807

WEBB, C. (1964) Thermal Discomfort in a Tropical Environment. Nature 202, pp. 1193–1194.

Wenzel, Klaus. (2009) Low-energy buildings in southern and eastern Mediterranean countries. ECEEE, Summer Study: Berlin, Germany.

Wheeler, L., and Reis, H. T. (1991). Self-recording of everyday life events: Origins, types,and uses. Journal of Personality, 59(3), pp. 339–354.

Wilde, P.D. (2014) The gap between predicted and measured energy performance of buildings: A framework for investigation. Automation in Construction, Volume 41,2014,pp. 40-49.

Wilde, Pieter. (2018) Building Performance Analysis. World Bank, World Development Indicators. (2017). Energy use, https://data.worldbank.org/indicator/eg.use.pcap.kg.oe. Accessed 05/09/2021.

Yin, R. K. (1994) Case Study Research Design and Methods: Applied Social Researchand Methods Series. Thousand Oaks, CA: Sage Publications Inc.

Yoshino, H. Hong, T. Nord, N. and Lawrence Berkeley National Lab. (2017) IEA EBC annex53: Total energy use in buildings—Analysis and evaluation methods. Energy & Buildings,152, pp. 124-136.

# 7. Appendices

## 7.1. Case study photos

*Figure 45. The case study building*

*Figure 46. Oil heater in the living room.*

*Figure 47. Electric heater in the girl's bedroom*

*Figure 48. Fridge location in the Kitchen.*


*Figure 49. Drawing of the case study.*

## 7.2. Case study Configurations

*Table 13. Energy services components in the case study*

| | Heating | Cooling | Ventilation | Lighting |
|---|---|---|---|---|
| **Living Room** | AC Split unit | - | Windows | fluorescent lights |
| | Electric film under the carpet | | Windows | |
| **Girls' Bedroom** | Removable electric heater | Electric fan | Windows | fluorescent lights |
| **Master Bedroom** | AC Split unit | | Windows | fluorescent lights |
| | Gas heater | Electric Fan | | |
| **Boy's Bedroom** | Removable electric heater | Removable electric fan | Windows | fluorescent lights |
| **Kitchen** | - | Removable electric fan | Windows | fluorescent lights |
| **Bathroom** | - | - | Extractor fan | fluorescent lights |

*Table 14. Simulation parameters used in the study*

| Properties | Case Study characteristics |
|---|---|
| **Orientation** | $56^0$ |
| **Shape** | Rectangular (12 m × 10 m) |
| **Floor height** | 3 m |
| **Roof U-value** | |
| **Wall U-value** | |
| **WWR** | 30% |
| **Operable shading** | Operable window with external shutters |
| **Overhang** | None |
| **People density** | $0.05/M^2$ |
| **Internal heat gains** | 9.7 $W/m^2$ from lighting, 12$W/m^2$ from appliances |
| **Natural ventilation** | Windows and doors are manually opened if cooling is needed |
| **Thermal comfort model Set points** | $19^0$C for heating, $28^0$C for cooling (RH = 60%) |
| **Ventilation system** | None |
| **PV system** | None |

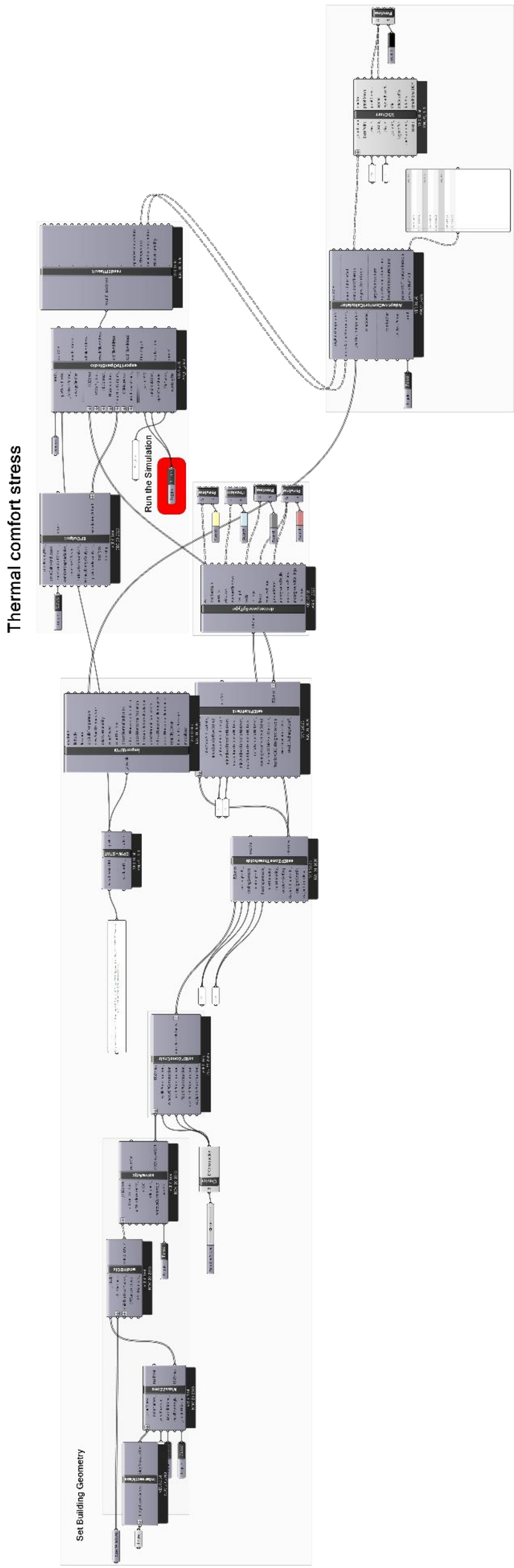



*Figure 50. Grasshopper Script for thermal comfort stress*

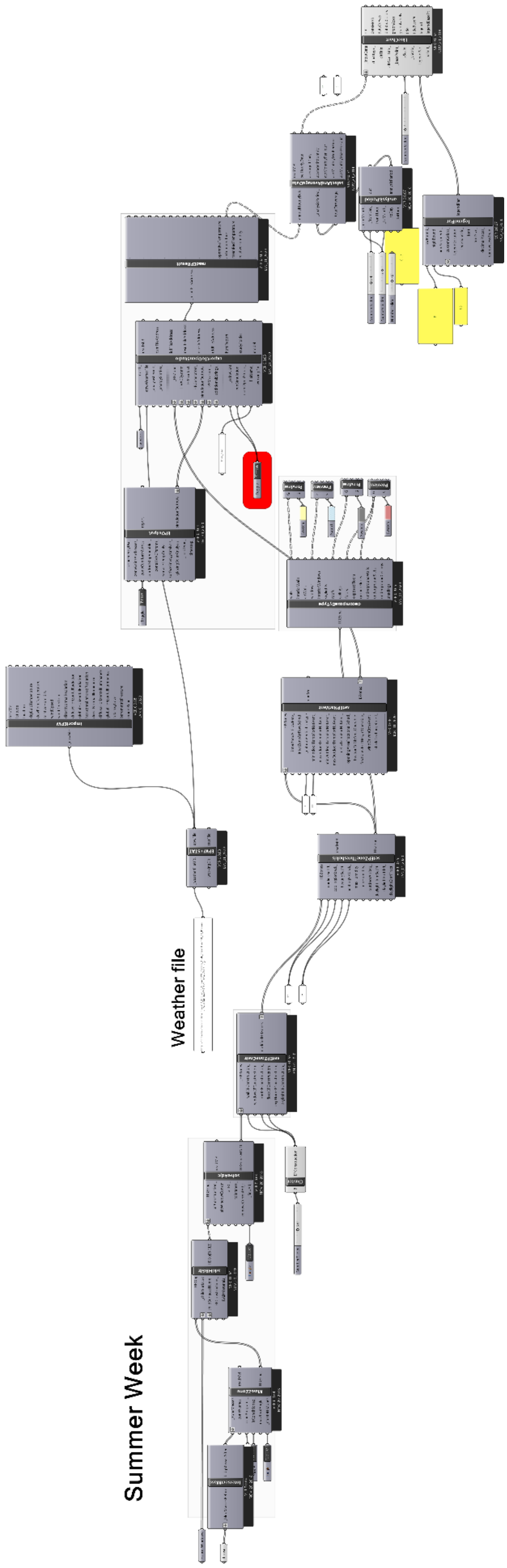



*Figure 51. Grasshopper Script for internal temperature of summer week*

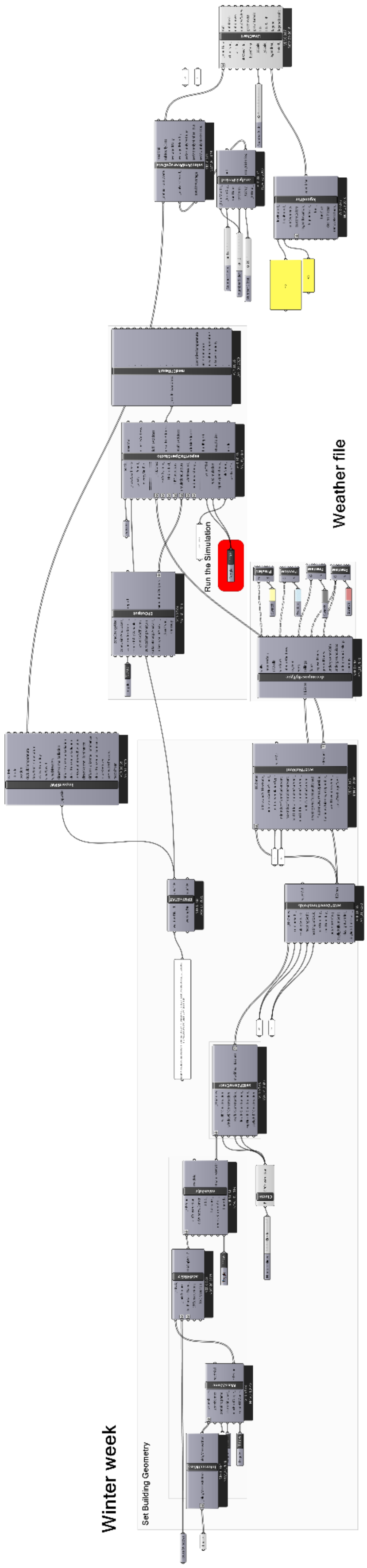



*Figure 52. Grasshopper Script for internal temperature of Winter week*

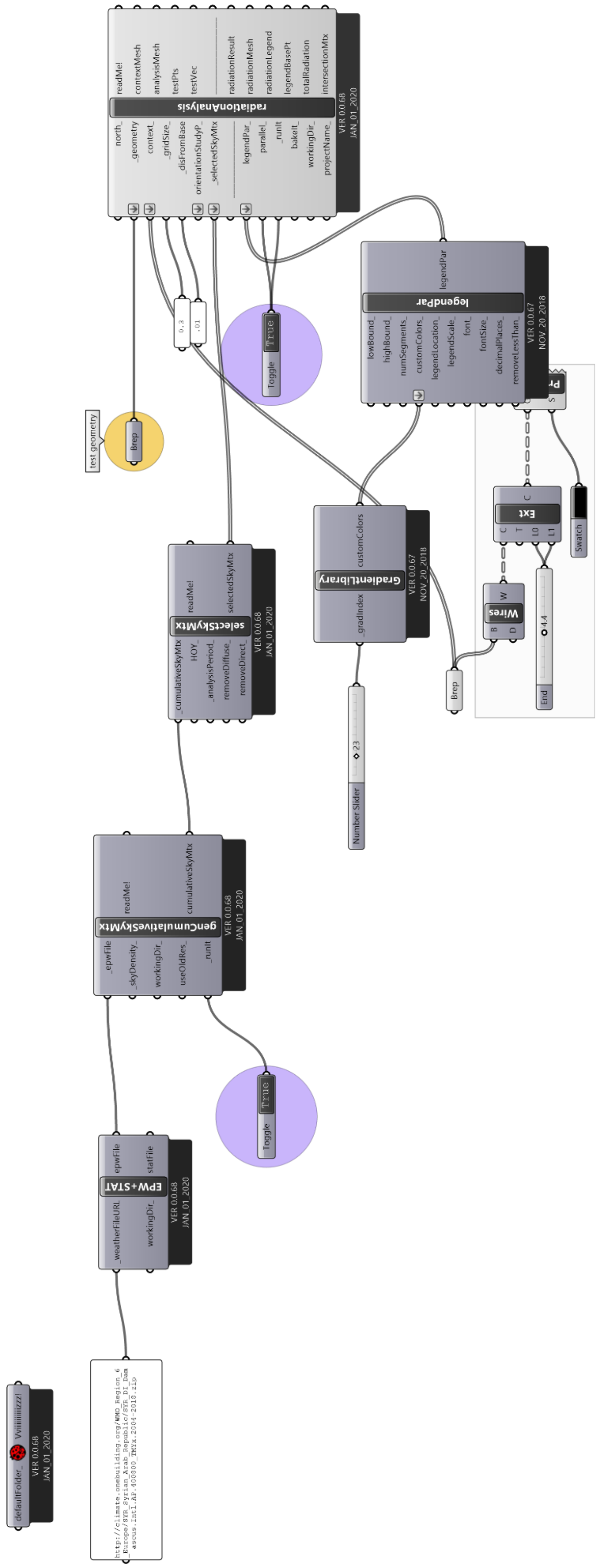



*Figure 53. Grasshopper Script for solar radiation*

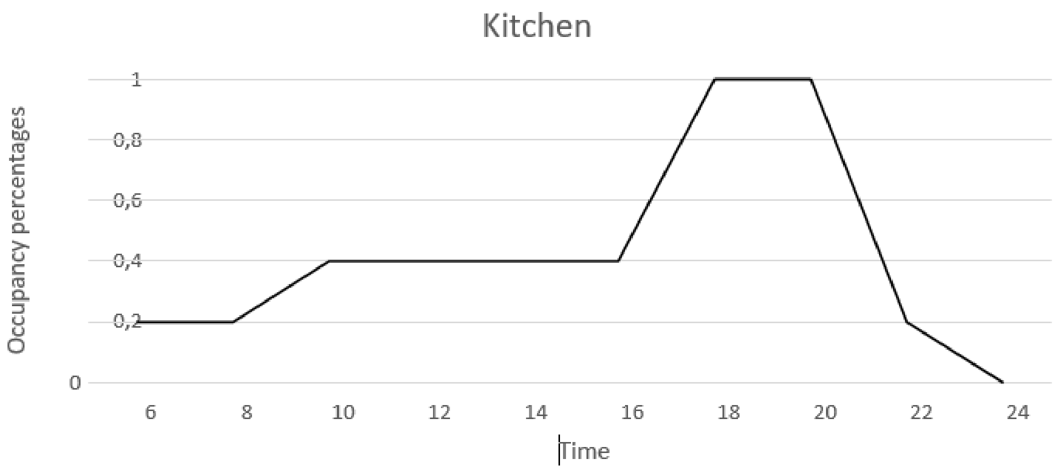



*Figure 54. occupancy profiles- Weekdays- Kitchen*

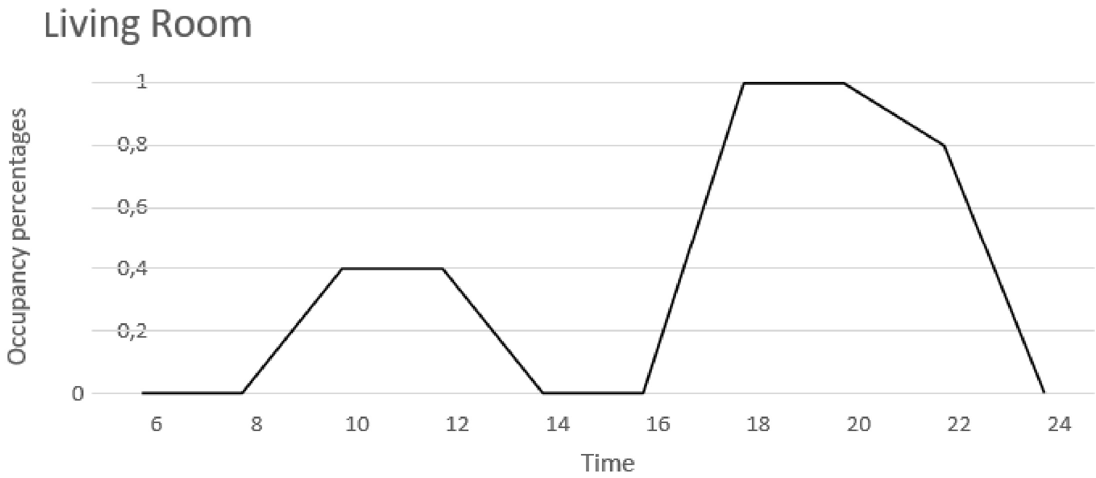



*Figure 55. Occupancy Profiles- - Weekdays- Living room.*

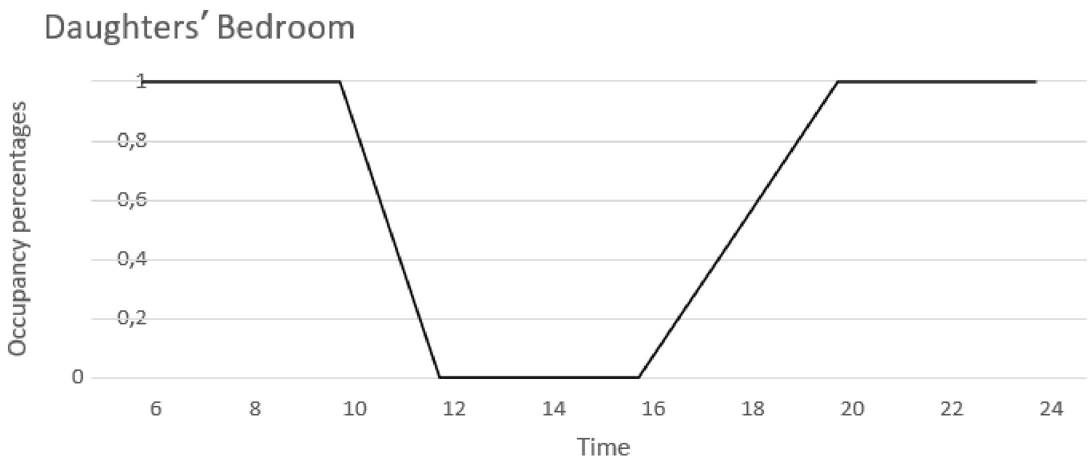



*Figure 56. Occupancy Profiles- - Weekdays- daughter' Bedroom*

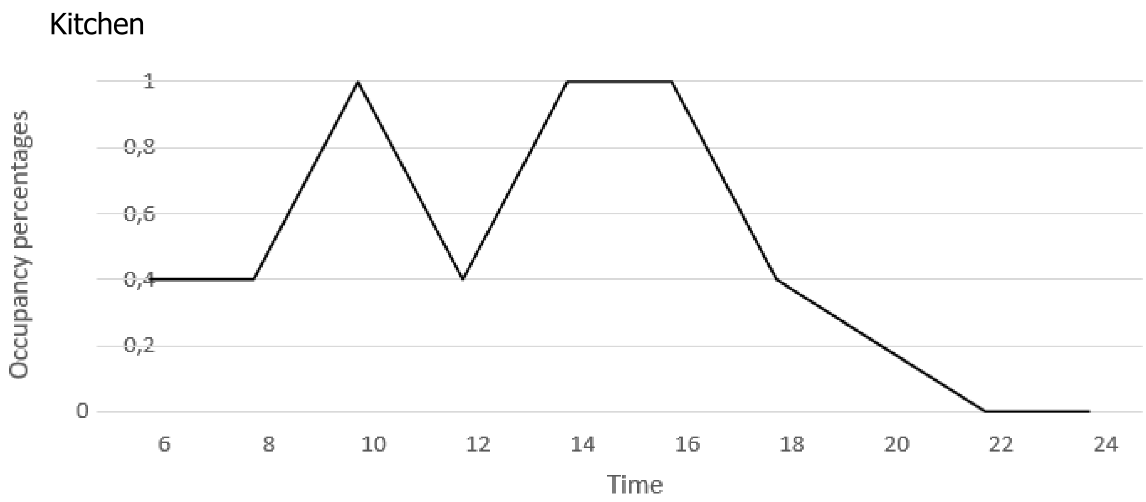



*Figure 57. occupancy profiles- Weekends- Kitchen*

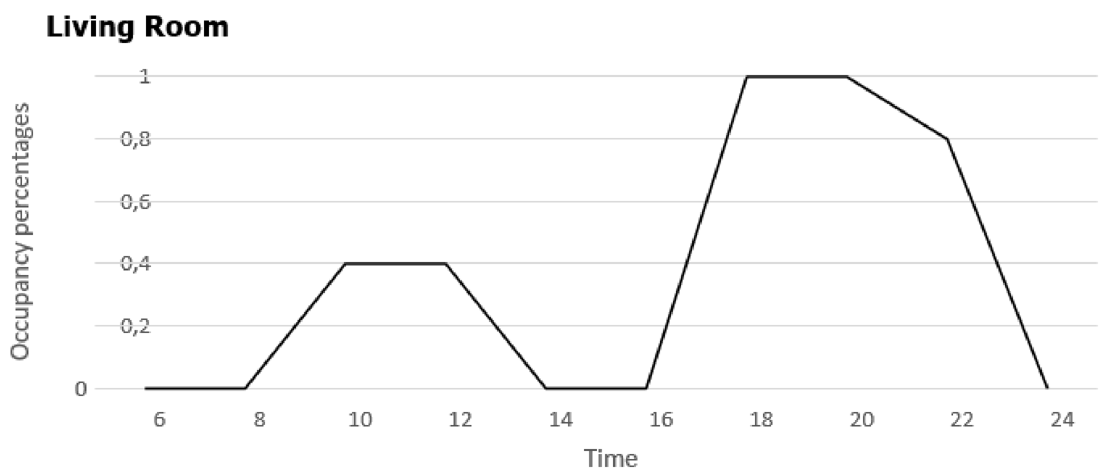



*Figure 58. Occupancy Profiles- - Weekends Living room*

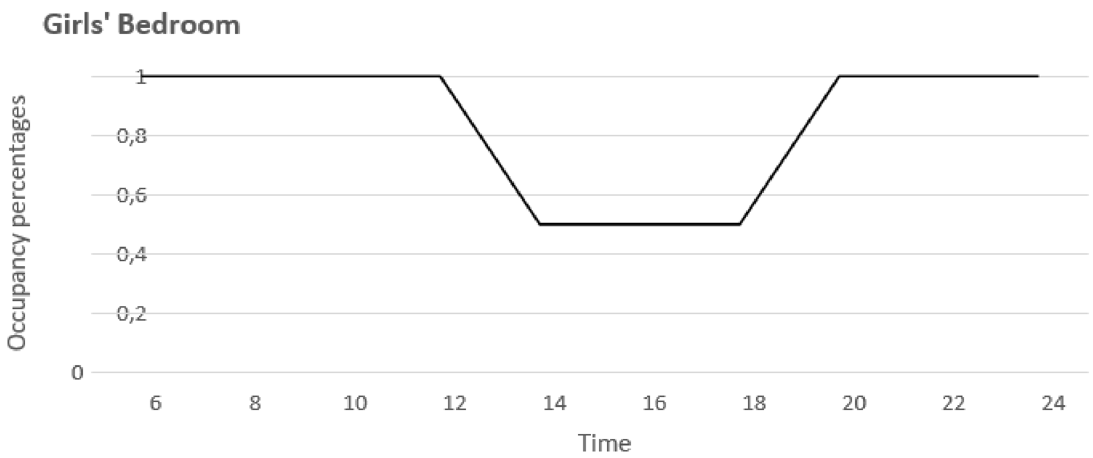



*Figure 59. Occupancy Profiles- - Weekends- Girls' Bedroom*

## 7.3. Climate Analysis Results

*Table 15. Solar square: Incident solar radiation for Damascus (2004-2018).*

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 am | | | | | | | | | | | | |
| 2 am | | | | | | | | | | | | |
| 3 am | | | | | | | | | | | | |
| 4 am | | | | | | | | | | | | |
| 5 am | | | | | | | | | | | | |
| 6 am | | | | | 44 | 54 | 30 | 2 | | | | |
| 7 am | | | 0.2 | 38 | 92 | 197 | 177 | 113 | 63 | 41 | 49 | 8 |
| 8 am | 28 | 79 | 183 | 197 | 414 | 374 | 300 | 239 | 188 | 190 | 123 | 58 |
| 9 am | 187 | 263 | 426 | 486 | 573 | 613 | 571 | 527 | 466 | 497 | 330 | 196 |
| 10 am | 309 | 436 | 580 | 640 | 676 | 694 | 750 | 744 | 698 | 674 | 522 | 322 |
| 11 am | 356 | 517 | 618 | 656 | 714 | 797 | 800 | 805 | 791 | 742 | 634 | 435 |
| 12 am | 463 | 533 | 638 | 710 | 711 | 787 | 798 | 811 | 821 | 715 | 616 | 565 |
| 13 pm | 513 | 524 | 655 | 655 | 724 | 780 | 788 | 804 | 822 | 695 | 604 | 626 |
| 14 pm | 481 | 557 | 665 | 652 | 729 | 777 | 797 | 811 | 807 | 676 | 607 | 602 |
| 15 pm | 439 | 572 | 590 | 572 | 574 | 767 | 786 | 785 | 740 | 566 | 474 | 510 |
| 16 pm | 354 | 406 | 484 | 493 | 586 | 684 | 700 | 679 | 594 | 391 | 283 | 316 |
| 17 pm | 151 | 232 | 342 | 388 | 436 | 517 | 532 | 486 | 355 | 170 | 99 | 95 |
| 18 pm | 11 | 55 | 118 | 153 | 210 | 275 | 291 | 221 | 106 | 20 | | |
| 19 pm | | | | 7 | 41 | 66 | 76 | 38 | | | | |
| 20 pm | | | | | | | | | | | | |
| 21 pm | | | | | | | | | | | | |
| 22 pm | | | | | | | | | | | | |
| 23 pm | | | | | | | | | | | | |
| 24 pm | | | | | | | | | | | | |

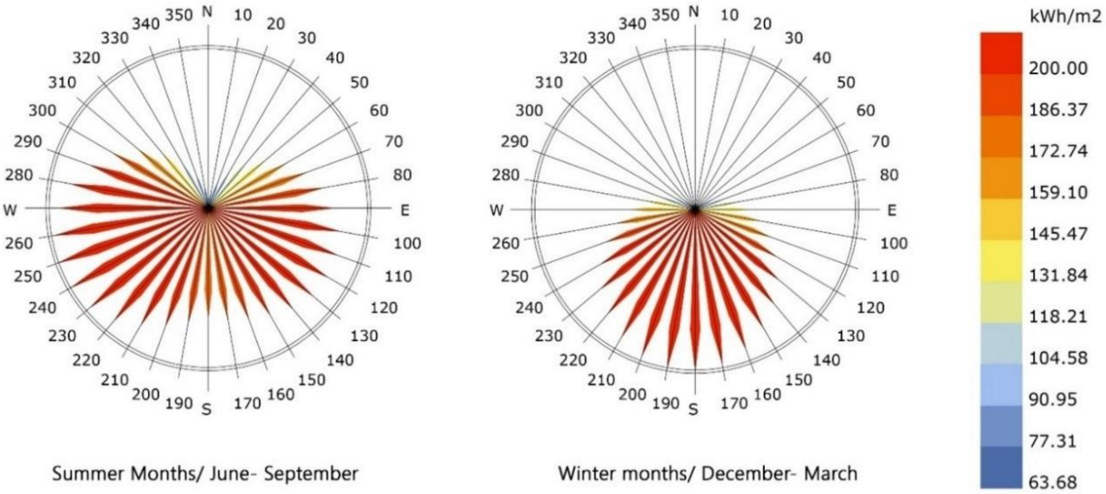



*Figure 60. Radiation Rose for summer and winter months for Damascus (2004-2018).*

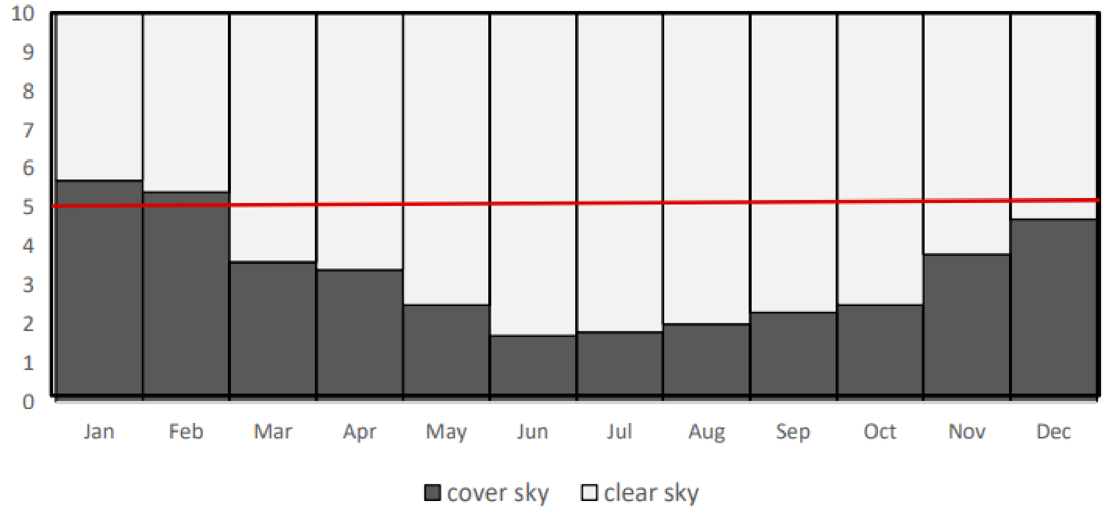



*Figure 61. Average monthly total sky cover for Damascus.*

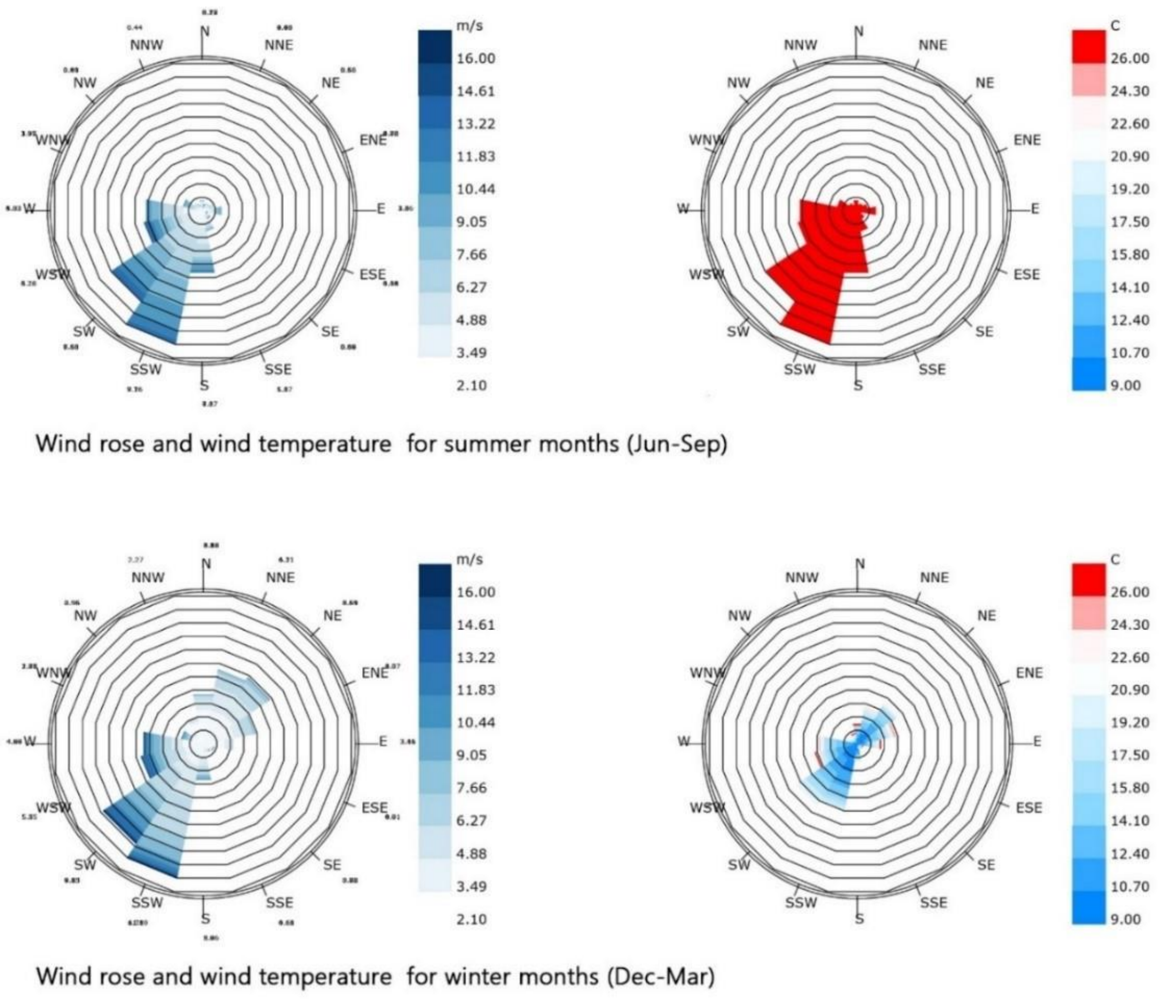



*Figure 62. Wind rose summer and winter for Damascus (2004-2018).*

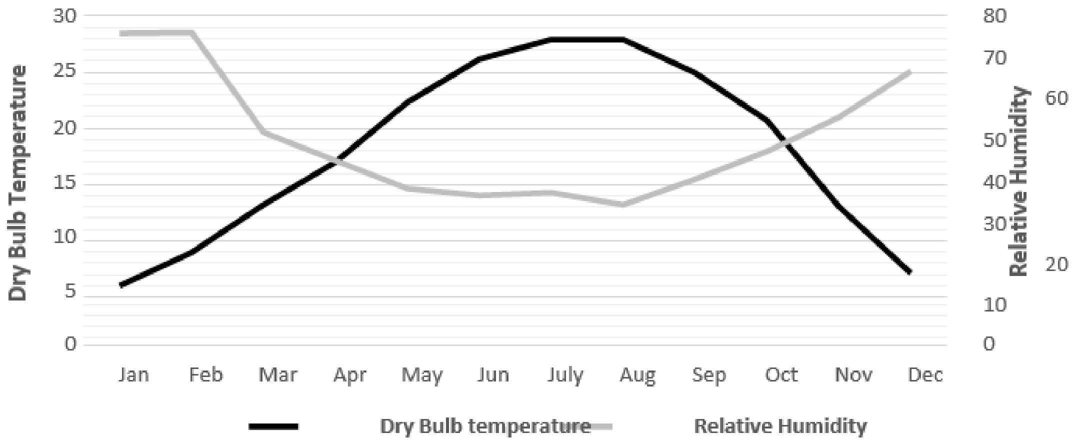



*Figure 63. Monthly average air temperature and relative humidity in Damascus from 2004 to 2018.*

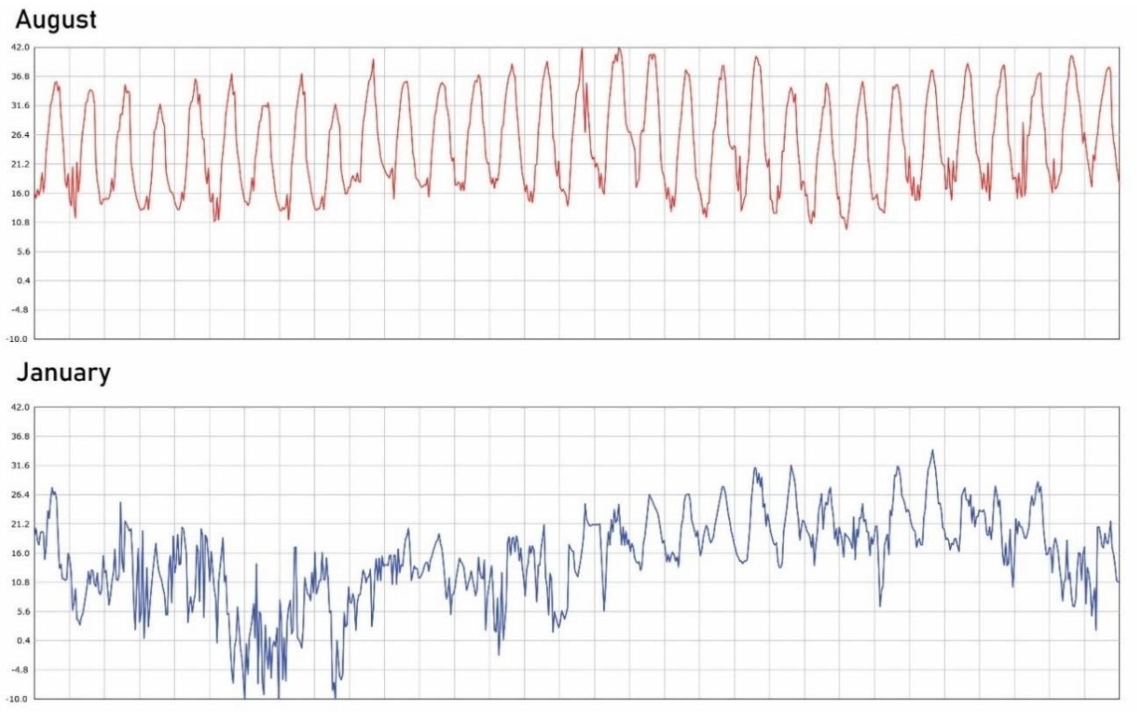



*Figure 64. Daily UTCI temperature of January and August in Damascus.*

## 7.4. Shoebox Analysis Results

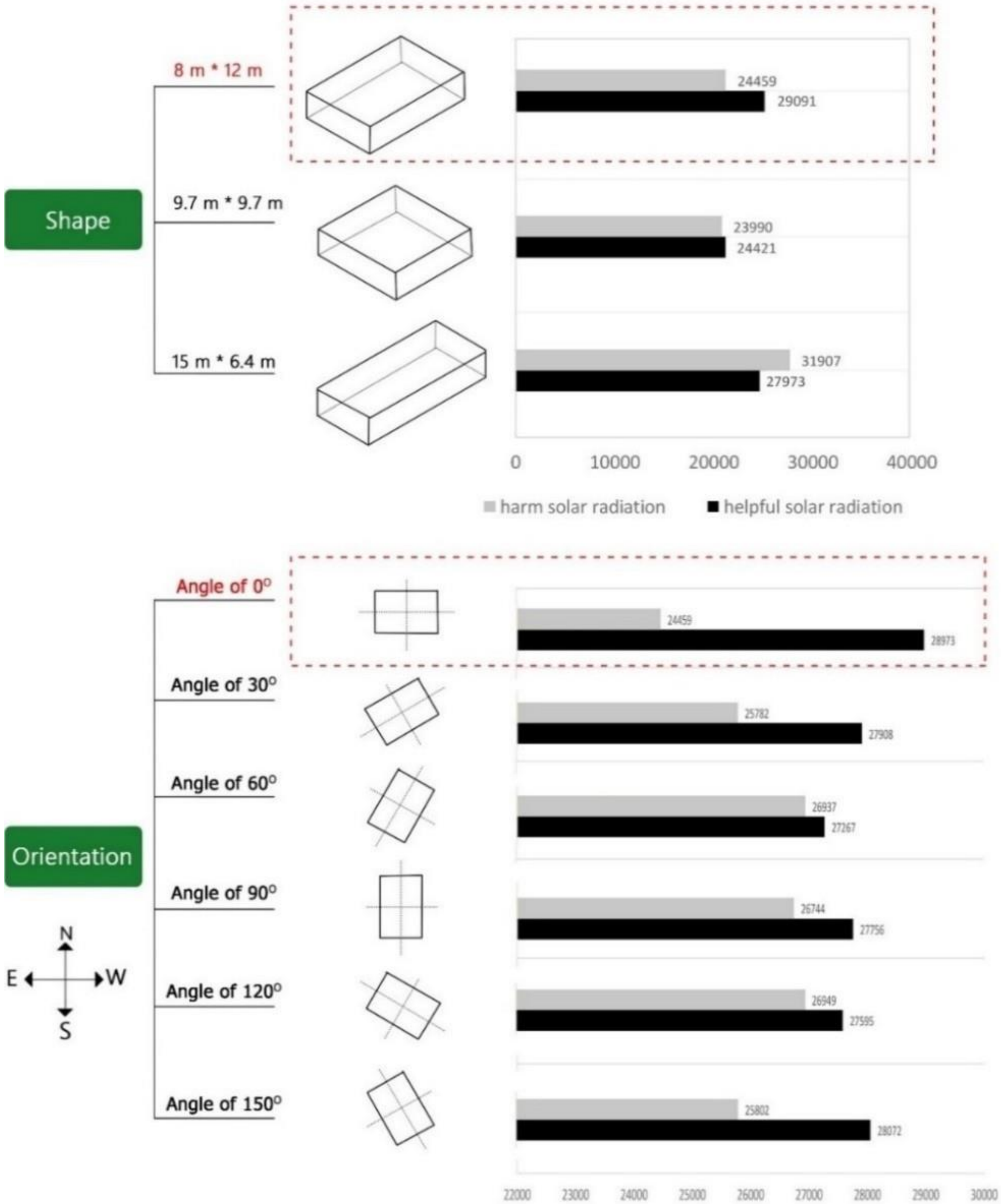



*Figure 65. Shoebox iterations for form and orientation based on Grasshopper script.*

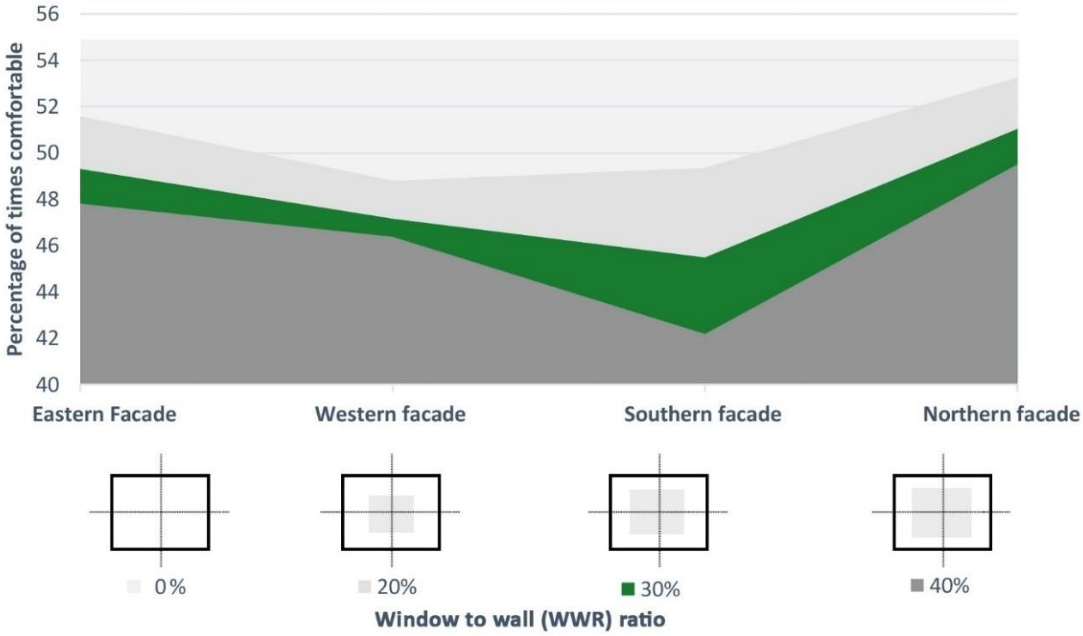


Figure 66. Impact of WWR on adaptive indoor comfort.

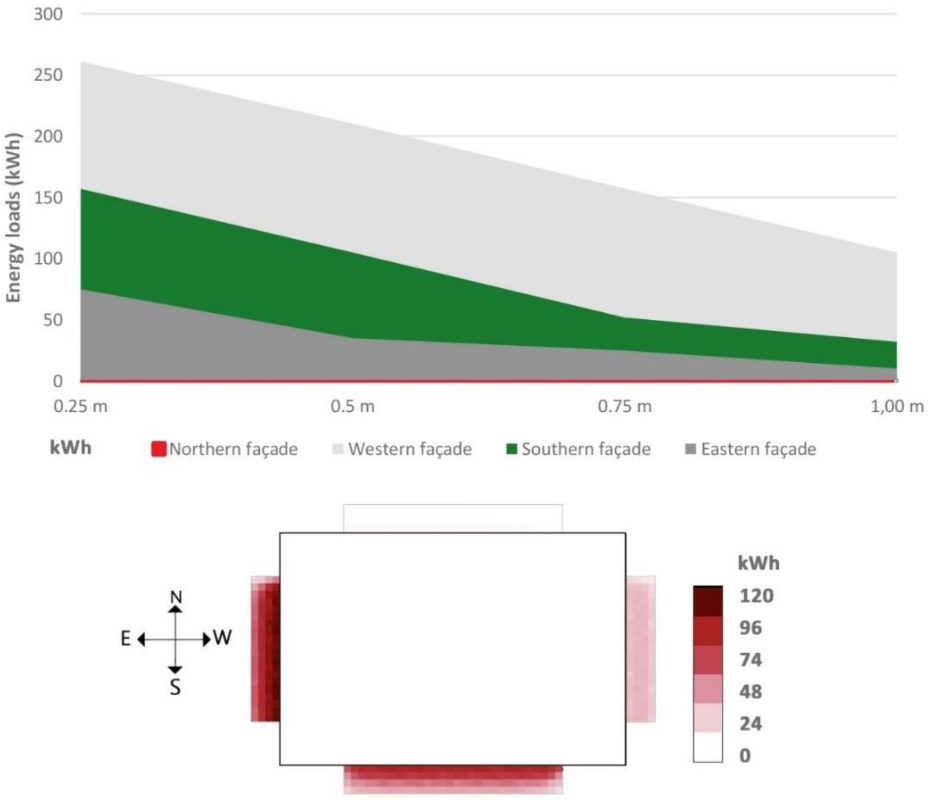


Figure 67. Shading benefit on shoebox facades.

## 7.5. Ethical Approval

09/07/2021
**Project Title:** Analytical study of low energy Social Housing Design in Syria

**EthOS Reference Number:** 31973

**Ethical Opinion**

Dear Walaa Haj Ali,

The above application was reviewed by the Arts and Humanities Research Ethics and Governance Committee and, on the 09/07/2021, was given a favourable ethical opinion. The approval is in place until 05/01/2022 .

**Conditions of favourable ethical opinion**

Application Documents

| Document Type | File Name | Date | Version |
|---|---|---|---|
| Consent Form | Consent-form- Interviews | 23/04/2021 | 03 |
| Consent Form | Consent-form- Interviews - Arabic | 23/04/2021 | 03 |
| Information Sheet | Participant-Information-Sheet- Interviews - Arabic | 23/04/2021 | 03 |
| Information Sheet | Participant-Information-Sheet- Survey - Arabic | 23/04/2021 | 03 |
| Project Protocol | Non Medical Research Protocol- Walaa Haj Ali | 13/06/2021 | 3 |
| Information Sheet | Survey2 | 13/06/2021 | 1 |
| Information Sheet | Participant-Information-Sheet- Survey | 21/06/2021 | 4 |
| Information Sheet | Participant-Information-Sheet- Interviews | 21/06/2021 | 4 |
| Additional Documentation | Amendments- Ethical application | 30/06/2021 | 1 |

The Arts and Humanities Research Ethics and Governance Committee favourable ethical opinion is granted with the following conditions

Adherence to Manchester Metropolitan University's Policies and procedures

This ethical approval is conditional on adherence to Manchester Metropolitan University's Policies, Procedures, guidance and Standard Operating procedures. These can be found on the Manchester Metropolitan University Research Ethics and Governance webpages.

Amendments

If you wish to make a change to this approved application, you will be required to submit an amendment. Please visit the Manchester Metropolitan University Research Ethics and Governance webpages or contact your Faculty research officer for advice around how to do this.

We wish you every success with your project.

Art and Humanities Research Ethics and Governance Committee

Art and Humanities Research Ethics and Governance Committee

For help with this application, please first contact your Faculty Research Officer. Their details can be found here