**THE UNIVERSITY OF KENT**

# Comparative Study of the Thermal Performance of Old and New Buildings in Ghardaia

by
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# ABSTRACT

There has been a rise in the number of initiatives undertaken by individuals and organisations to rethink the process of building design, construction, and administration in order to reduce their negative impact on the environment. Specifically, it would be helpful to learn more about how a house's thermal performance affects people's needs for thermal comfort inside the dwelling, since this would shed light on the importance of enhancing residential building design. The thesis's primary focus is on traditional homes in Ghardaia southern of Algeria. Two residences pairs were located in the Ghardaia neighbourhoods of Beni Isguen and Tafilelt. They're rated and compared in accordance with criteria including ideal climate, desired home design, and appropriate building materials. With this research, the aim was to better understand how traditional and modern settlements in Ghardaia responded to residents' climatic, cultural, and architectural preferences. A low-energy building that is suitable for modern people is therefore specified by research into the social and cultural factors that go into the making of vernacular dwellings. In this research, evaluation was carried out by the use of observation, field survey, and computer simulation. By studying how well local homes are insulated, we can learn how to improve the thermal performance of new houses. Both communities in Algeria's hot and dry interior relied heavily on passive heating and cooling techniques. A field investigation was conducted to evaluate the thermal comfort of both historic and modern Ghardaia homes.

Both case studies in the hot and arid regions of Algeria emphasised the use of passive heating and cooling systems during the monitoring and evaluation. The thermal comfort of traditional and modern Ghardaia homes was evaluated by a field survey based on observations of occupants. First, the thermal performance of old and modern Ghardaia structures was calculated and compared. Second, recognising and learning from the differences in the performance characteristics of new houses contributes to the creation of innovative and superior urban dwelling designs. The findings of the computer simulations of the interventions suggested that traditional and new homes might increase the future potential for low-energy housing in southern Algeria by increasing the thermal efficiency of the existing dwellings in both settlements. The outcomes of the investigation of two villages illustrate that a suitable indoor atmosphere may be created using locally accessible building materials and conventional environmental practices. This study partially fills a gap in the research on thermal comfort standards for Algeria and demonstrates the potential to minimise energy use in contemporary structures in hot, dry settings. The study also gives simulation-based suggestions for how buildings should be built in Algeria's hot, dry climate.

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# INTRODUCTION

# CHAPTER I

## Introduction

### 1.1 Introduction

When the outdoor temperature cannot maintain thermal comfort, natural ventilation is an important technique to preserve indoor dwellings in Ghardaia City. The sun is a primary source of heat absorption through the building envelope, which absorbs heat from the sun through the roof, walls, and windows, raising internal temperatures to uncomfortably high levels. However, establishing an air conditioning system can provide some relief. Nonetheless, installing and operating air conditioning equipment will incur additional fees in the form of high-priced bills. Furthermore, typical air conditioners use chlorine-based refrigerants, which are suspected of contributing to ozone depletion and global warming (NREL, 1994). The recent popular trend of passive architecture design has become a universal requirement where passive cooling is maintained as an alternative to employing a mechanical system to maintain a reasonable indoor temperature system for lowering energy demands. However, in Algeria's south, architectural considered options include how to create a passive design for buildings that do not have a significant impact on the environment or society's needs.

A vernacular building design can be used in the hot, dry climate of Ghardaia as a starting point for understanding how environmental pressures and climate change have an impact on the architectural features of the home as well as how buildings have the potential to be more responsive. However, according to Algerian construction codes, they did not investigate the climate design issue because conditions should occur as expected, and as a result, people's modern architecture in Ghardaia has suffered, architectural solutions are presented by designers who believe that the protection of the environment is not a priority.

As a result, the primary goal of this research was to conduct case studies in two ksars in Ghardaia, Algerian Sahara's northernmost city: Tafilelt ksar and Beni Isguen ksar. According to Ravéreau (1989), the ksar is a neighbourhood that is built on a rocky plateau and is home to a few thousand people. It is also surrounded by a wall with watchtowers, which gives it a unique look for its auction market and traditional trade.

The areas were selected since they have two different patterns of neighbourhoods with a microclimate of about 1.5 km2. The comparisons were based on urban thermal performance, building materials, and occupants' activities. These comparisons showed how differences in the urban patterns of land use and population densities affect the outdoor climate conditions and, in turn, human comfort and indoor conditions. Subsequently, this will provide a true account to suggest significant ideas on how the application of sustainable design can maintain indoor comfort. The rationale of selecting Ghardaia to be examined in this research, is that it is located in hot arid climate, it has traditional and new housing as the government and locals have tried to design new settlements utilising the old forms; in addition, the population living in Ghardaia, have tried living in both the new and old settlements and are able to provide a sensible comparison between the two which is useful in this research. The rationale of selecting Beni Isguen and Tafilelt is that Beni Isguen is the original form of designing houses (930 AD) in this region while Tafilelt (1997) is an extension of Beni Isguen that used similar building materials but different urban morphology to Beni Isguen; this is unique and will add value to this research in identifying whether the new settlement is actually better than the original, further details are provided in chapter 3 and 5. This aspect drove this research to study the impact of the urban form and the outdoor conditions on indoor thermal comfort. For this purpose, the traditional and the modern houses of southern Algeria were compared using thermal simulation and sensitivity analysis of the peak outdoor temperatures that can impact these thermal conditions in order to examine how indoor thermal conditions can be improved. In this study, some observations are relevant for a suitable ventilation strategy to be integrated within the building's design and optimisation. The thermal impact of urban developments in Ghardaia was also assessed as a reflection of an effective built environment that promotes an appropriate sustainable urban form based on the climate and a mixture of the eastern and western design patterns of old and large cities like Ghardaia.

From these standpoints, two existing neighbourhood cases are discussed in Chapter 5 and later numerically examined in Chapters 6 and 7 using the DesignBuilder software; such study has been conducted for the first time in Ghardaia. It combined climate-based tools and urban planning research to assess the thermal performance of the neighbouring outdoor spaces in these settlements.

Geographical information and methodological solutions were of vital use in getting the needed input for the simulations. Measurements were collected for two base case pairs; for each case, measurements were made for a week each in summer and winter. The results have implications for architects and urban planners by strongly relating urban form with building design typology, materials and energy consumption. Moreover, they give not only approaches for predicting the thermal performance of present-day urban land use through the urban planning thermal comfort model, but also approaches to adapt these developments to climate change by using the new urban plan with a morphed meteorological data.

### 1.2 Aims:

- Examine thermal comfort temperatures in two historic and modern Ghardaia settlements and use the findings to inform the design of a comfortable dwelling.
- How does the new settlement within Tafilelt “herein referred to as Ksar” perform compared to the old settlement “ksar” within Beni Isguen?
- How may knowledge of the new Ksar's performance characteristics assist in improving and making a more innovative urban dwelling design?
- Create standards for future Ghardaia comfortable homes using the concepts above.

### 1.3 Research Questions:

- How does the new ksar perform when compared to old ksar?
- How can knowledge of performance characteristics of the new ksar (when compared to the old ksar) lead to a better manner of designing unique urban dwellings?
- How might fresh proposals be used to set criteria for future comfortable Ghardaia homes?

### 1.4 Objectives:

The primary objective is to identify and study two building settings in the M’Zab valley: new and old buildings that both use natural ventilation systems. This will provide reliable practical advice and guidance for designers when designing new buildings that can provide a satisfactory internal environment for their occupants from thermal comfort perspective.

Furthermore, literature reviews was investigated specifically focusing on thermal comfort to various building designs and their suitability in the hot dry climate In the south of Algeria. Added to this was the researcher’s experience of living in regions with a hot and dry climate which helped to further understand the flaws with the current designs.

These problems will be investigated so that suitable solutions can be devised to adequately meet the indoor environmental requirements and reduce thermal discomfort. In this research, the climate of Algeria’s desert combined with the Islamic social way of life were used to define a an improved methodology by which courtyard houses can be modified to achieve thermally comfortable indoor climates that respect people’s beliefs and social standards as well. Therefore, through a field survey of the selected settlements, the following points outline the general objectives of the research:

- To study and explain of the difficulties and the crucial components of passive design methods and thermal performance in both the old and new ksar.
- To evaluate the internal environment and determine solutions that can provide qualitative, physical, and psychological benefits to dwelling occupants (adaptive, comfortable houses in a hot, dry climate).

- To examine the impact of the outdoor climate on building design and indoor comfort by evaluating the format of real weather data used in the simulation process.
- To create computer simulation models for the thermal performance analysis of naturally ventilated buildings and to examine the connections between passive design and performance characteristics.
- To make use of the computer models to propose features that will improve the performance of the new ksar

### 1.5 Structure of the thesis

In order to achieve the aims and objectives of the present study, the thesis is structured into eight chapters that cover four parts:

- **Part I:** A literature review and a background to desert architecture, specifically in Ghardaia
- **Parts II and III:** The methodology that covers fieldwork (survey and data collection of the temperature and relative humidity) and a computer energy simulation analysis
- **Part IV:** The findings, comparisons, discussions, conclusions, and recommendations

The chapters are organised and outlined as follows:

**Chapter 1. General Introduction:** It presents the background, problem statement, aims and objectives and explains the research strategy.

**Chapter 2. Literature Review**: It presents the literature review of the most significant aspects that are related to passive cooling techniques and natural ventilation. It looks into the issues pertaining to the thermal comfort and bioclimatic design of buildings in hot dry climates.

**Chapter 3. Ghardaia City Case Study (Beni Isguen and Tafilelt):** It provides a wide-ranging overview of the nature of the climate of the area, the outline of the vernacular architecture and the urban texture, besides the architectural characteristics that come into play adding value to the analysis of this research.

**Chapter 4. Methodology:** It explains two methods adopted for the present research. The first method is based on on-site measurements where the monitoring the local indoor and outdoor climate was collected, specifically temperature and relative humidity.

The second method uses a questionnaire-based survey to investigate people's fulfilment and perception with the environment of their homes, in both the old and new Ksar in that the structure and the coding of the questionnaire are discussed. This chapter also explains the simulation base model to suggest an enhanced model to improve building designs prevailing in Ghardaia.

**Chapter 5. Thermal Performance of the Residential Buildings in the Old and New Ksar (Case Studies):** It documents the output from the thermal measurements for the two sites including temperature and relative humidity. This was done at two levels where the individual reporting of results for the selected buildings was performed, and then a comparison between the new and old buildings was performed and discussed.

**Chapter 6. Building Simulation, Calibration and Validation:** this chapter introduces simulation modelling concept using DesignBuilder; by examining if the software is suitable to provide data for future designs. This was achieved using the results obtained in chapter 5.

**Chapter 7. Simulation Analysis:** different scenarios were suggested to study the influence of these on the thermal performance of a given building by looking at the impact on the indoor temperature using DesignBuilder. Interventions such as roof, wall modifications and combined strategies were proposed, simulated and reported in this chapter.

**Chapter 8**. **Conclusions and Recommendations:** It summarises the main conclusions of this thesis with limitations, while also presenting the general recommendations and scope for further research.

Figure 1.1 describes the above research proposal

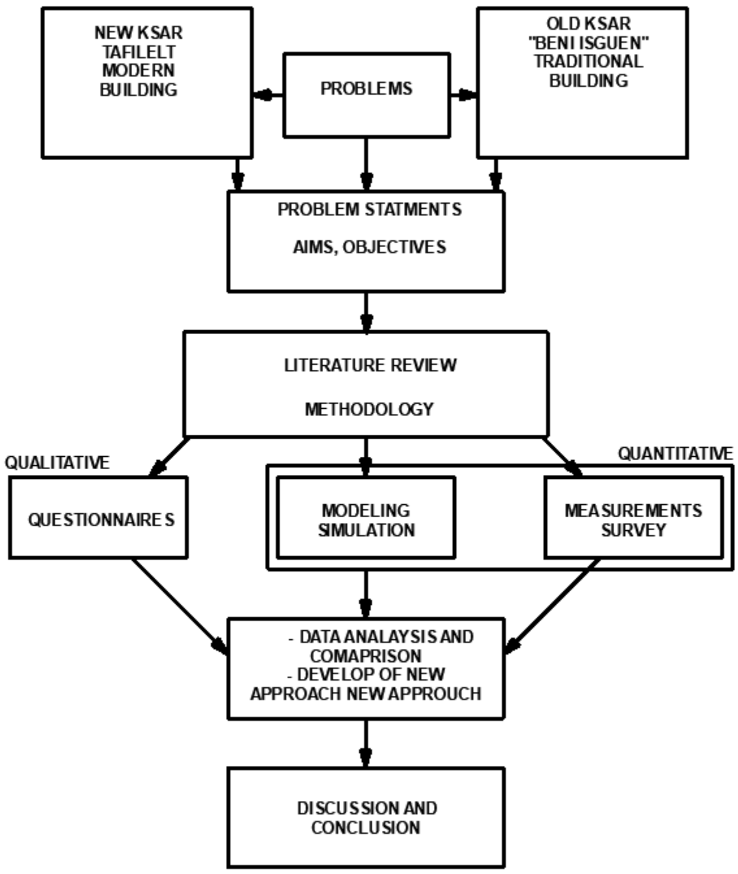


***Figure 1.1 describes the research strategy as outline in this section.***

**1.6 Publications:**
The following publications have resulted from this work:

- Mohamed Yacine Telli, R. Giridharan, Richard Watkins. Thermal characteristics of the roofs in Ghardaia with a new material extracted from date palm trees. BEO'2019 conference, February 2019
- Mohamed Yacine Telli, R. Giridharan, Richard Watkins. Thermal Conditions in Urban Settlements in Hot Arid Regions: The Case of Ksar Tafilelt, Ghardaia, Algeria. PLEA conference, September 2020
- Mohamed Yacine Telli, R. Giridharan, Richard Watkins. The Impact of the Tree in the Patio on the building microclimate and the indoor thermal environment, Case of Study south of ALGERIA. Windsor conference, May 2020

# CHAPTER
# II
# LITERATURE REVIEW

# CHAPTER II

## Literature Review: Part 1

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### 2.1 Introduction

The literature review consists of two parts:

- **Part 1:** of the literature review defines the link between urban morphology and the micro-climate by presenting the examination of analysis of the urban morphology effect on these flows considering the relevant studies of urban strategy and naturally ventilated buildings. This provides the morphological indicators influencing the comfort parameters (solar radiation, air and surface temperature, wind speed) are identified.
- **Part 2:** of the literature review focuses on the aspects related to the architectural design in a hot dry climate more specifically the desert architecture and the thermal comfort adaptation. The review outlines different aspects of local architecture that are integrated with the hot dry climate and design characteristics on comfort living as well as the potential for considering these aspects in recent building designs.

In an urban context, the main goal of environmental design is the creation of urban areas with comfortable outdoor spaces. However, unlike interior spaces of buildings, defined by relatively regular and controllable thermal conditions, exterior urban spaces are characterized by significant variations daily and seasonal microclimatic parameters, which are much more difficult to understand (air temperature, wind, and radiation, for example). The specificities of the urban environment generate perceptible climatic changes at all levels.

Understanding the relationships between urban morphology and the physical parameters of the local microclimate is essential. First, this chapter presents the definition of urban morphology as well as its different types of associated forms. Urban boundary layers resulting from thermal and aerodynamic disturbances related to urban morphology are also discussed in this first part. In a second step, we define the link between urban morphology and the microclimate by presenting the urban energy balance, the associated flows, and the analysis of the impact of urban morphology on these flows. Thirdly, the morphological indicators influencing the comfort parameters (solar radiation, air and surface temperature, wind speed) are identified.

This crossing of physical and morphological parameters aims to distinguish the most influential morphological indicators.

**2.2 Urban morphology and its impact on the local atmosphere:**

What is an urban morphology?

Research Centre in Arid zones RCAZ (2010) in Algeria, defines urban morphology as being the result of the historical, political, cultural, and more particularly architectural conditions in which the city was created and grew. It is the fruit of a spontaneous or planned development by the will of the public authorities. The related notions of "urban structure" and "urban form" are not always clear and the definitions often vary from one author to another.

According to Lévy (2005), the main object of morphology is to allow the city to be read by understanding the evolution of the urban form. The latter constitutes an object of study constructed from a definition hypothesis, a representation, and a point of view on the form. The urban form is a polymorphic notion that can be grasped from different aspects depending on the point of view taken by each urban planner and the definition adopted. By crossing the different points of view, the following notable five approaches or registers of urban form are presented below:

A. The approach of the urban form as the form of urban landscapes, for which the urban space is captured visually (colour, style, etc.) in its three-dimensionality (form and sizes) and in its architectural style (modern or high-tech movement for example) (Lynch, 1960; Castex et al., 1980).
B. The approach of the urban form as a social form, for which the urban space is studied in its occupation by various social, demographic, ethnic or religious groups (Grafmeyer and Joseph, 1984; Roncayolo, 1996).
C. The approach of the urban form as the form of urban fabrics, which consists in studying the correlations between the elements composing the urban space (plots, roads, relationship between open spaces / built spaces and morphology of blocks for example) (Panerai and langé ,2001).
D. The approach of the urban form as the form of the outlines (Pinon, 1994; Lévy, 1996) which refers to the geometric shape of the city plan (for example organic plan, checkerboard plan or radio concentric plan).
E. The approach of the urban form as a bioclimatic form, for which the urban form is considered in its environmental dimension, as an urban microclimate. It consists of geographical variations by district in terms of its variety linked to the categories of fabric (open, closed, vertical), according to the orientation (heliothermic) and the site (water, relief, vegetation) (Escourrou, 1982; Escourrou, 1991)

The bioclimatic method has sparked a significant debate on the urban forms of the future (sprawling or compact forms) in terms of sustainable development, the rise in energy consumption and its effects on the climate, and, more recently, the "optimization of physical environments in urban spaces." According to Lévy (2005), the urban fabrics approach is strongly related to other approaches. Indeed, the elements composing the morphologies of urban fabrics and layouts function as urban microclimate variation factors and cause a shifting distribution of comfort characteristics (air temperature, wind speed and incident radiation for example). However, research (Chen and Chao, 2013; Leung, 2015) has demonstrated that ventilation is an essential part of any construction, and the value of healthy indoor air is undeniable . It is possible to achieve a high level of thermal comfort and prevent moisture damage to a building by allowing natural ventilation to occur. As a result of ignoring these factors, poor habits persist, especially in densely populated urban areas, where traffic on the roads and air pollution have a negative impact on residents' quality of life.

## 2.3 The Urban boundary layers

On a city scale, the interaction between urban form and climate produces different layers of air superimposed in the atmosphere, the stability of which depend on the thermal stratification.

### 2.3.1 The surface boundary layer:

This layer extends over several tens of metres above the buildings and breaks down into two flow sub-layers (Figure 2.1): the inertial sub-layer and the roughness sub-layer. The first is characterized by the homogeneity of the vertical turbulent flows and depends primarily on the collision speed and the height of buildings (Taha, 2000). As for the roughness sub-layer, it is in the immediate vicinity of the surface and its thickness varies between 1.5 and 3.5 times the height of surrounding buildings (Rotach, 2000).

## 2.4 The urban canopy

The urban canopy (Figure 2.1) corresponds to the study scale considered in this research. This scale refers to the urban fabric integrating with the urban ground (street, green spaces), built structures (buildings, block, or district) and open spaces (courtyards or public places), because of the turbulent movements caused by the interaction of micro-meteorological parameters with urban structures.

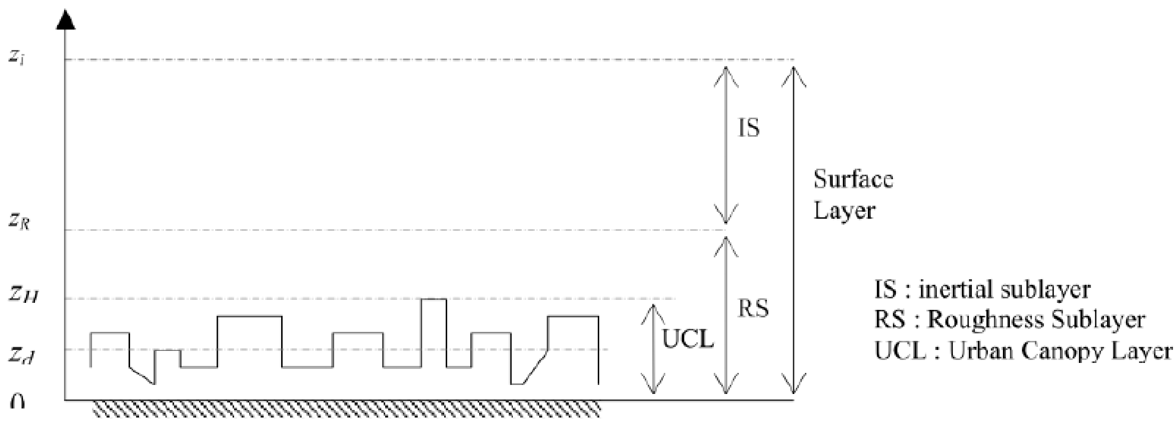



***Figure 2.1 Vertical distribution of the different layers of air circulation over an urban environment (source: Rotach. 2000)***

## 2.5 The influence of urban morphology on outdoor comfort

The relationships between the individual and his external environment are decisive in estimation of comfort situations. Taking into account the external environment requires knowledge of four important microclimatic parameters: mean radiant temperature (calculated from incident solar radiation and surface temperature), the air temperature, wind speed and air humidity (Vinet, 2000; Ali-Toudert et al.Mayer, 2007). The modification of the perceptual process of the human body depends on the intensity of these external environmental components. The body's responses appear, with the change in skin temperature, internal body temperature, sweating and speed of blood circulation. Light-colored materials have a higher albedo than dark-colored materials. As a result, cities in the South have higher albedo (0.30 to 0.45) than cities in the North (0.10 to 0.20). (Taha, 1997).

Synnefa et al. (2007) measured the albedo of several coloured roofs. Roofs painted with white coatings, for example, have a high reflectivity that can reach 72%, compared to 26% for black roofs. In addition, Akbari et al. (2003) investigated the effect of facade colour on surface temperature. Facades painted black can achieve temperatures 7°C higher than those painted white during full daylight hours. The Simpsons, urban morphology, and their interactions with microclimate and outdoor comfort McPherson (1997) investigated the effect of roof colour in the Arizona desert in the United States. In this scenario, white roofs with an albedo of 0.75 were up to 20°C cooler than grey roofs with an albedo of 0.30 and up to 30°C colder than dark roofs (albedo of 0.10). Furthermore, Bertolini et al. (2011) investigated that the commonly used colours of concrete paving blocks include natural grey and pigments of iron oxides, which contribute to its red coloration; whereas manganese dioxide is used for the paver's black coloration, which reduces the temperature, which can the surface temperature of conventional pavements reach up to 48–67 C during peak solar intensity.

According to Lin et al. (2017), the cooling effect of vegetation on surface temperature is greater than the cooling effect on air temperature. Grass and vegetative ground cover, as opposed to paved asphalt roads and squares, serve a vital role in promoting thermal comfort by maintaining a low surface temperature. To begin with, the majority of the energy absorbed by well-irrigated grass would be transformed into latent heat via the evapotranspiration mechanism, resulting in a significant fall in surface temperature. Furthermore, the albedo value of grass (0.20-0.25) is lower than that of light-colored structural materials, implying that it would reflect less radiation onto the human body and hence result in less thermal stress. The effects of urban morphology are studied in the sections that follow. Technical material is not considered, and vegetation is thus excluded from this literature review.

In the following sections, the modifications caused by the urban morphology are examined. Technical material is not considered, and vegetation is therefore not considered in this literature view.

### 2.6 Morphological Parameters linked to the irregularity of urban forms

The term "irregularity" is not usually used to describe urban form, particularly in urban typologies such as Ghardaia settlements. However, as morphological approaches to the urban environment have evolved, this term has come to refer to the roughness or discontinuity of a surface as opposed to a smooth horizontal plat-form (Ben Messaoud, 2009). At the urban scale, two types of irregularities are observed: horizontal and vertical irregularities.

#### 2.6.1 Horizontal irregularities in the urban fabric

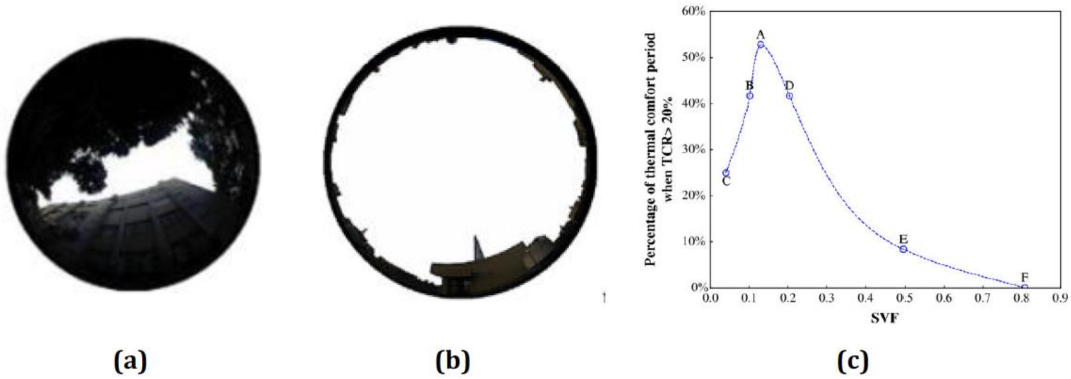
**A. Variation of the sky view factor:**

***Figure 2.2 Sky view visible from a street in Boston in the United States (source: Ratti et al. 2003).***

The Sky View Factor (SVF) (Figure 2.2) is a measurement of the solid angle of the sky perceived from an  urban space location (Sarradin, 2004). It is a dimensionless parameter between 0 and 1 (Oke, 1988), that helps in determine the heat exchange by radiation between a given location and the surrounding atmosphere. An SVF of 1 indicates that the view of the sky is completely unobstructed (flat field). Therefore, the air temperatures will be extremely near to their corresponding meteorological values. A SVF of zero, on the other hand, indicates that the view of the sky is fully obstructed and that, as a result, the temperatures will be substantially influenced by the urban setting. Thus, the sky view component influences outdoor comfort. Using the PET6 comfort index, Tzu-Ping et al. (2010) experimentally investigated summer thermal comfort in outdoor settings of a Taiwanese university campus (Physiological Equivalent Temperature). The findings of the SVF exceeded the proportion of thermally comfortable periods for various campus locations. The results indicated that location A (Figure 2. 3 (a)), whose SVF is 0.13, has the highest percentage of comfortable periods with over 53 percent (Figure 2. 3 (c)). This percentage falls as the SVF of surfaces increases, reaching zero at location F (Figure 2.3 (b) and (c)), which has an SVF of 0.81.

In contrast, when the SVF values are smaller than 0.13, the proportion declines until it hits 25% for an SVF of 0.04. (figure 2.3c). In the summer, spaces with surfaces that have a high SVF may induce discomfort.

***Figure 2.3 (a) The sky view factor of place A (SVF = 0.13). (b) The sky view factor of the place F (SVF= 0.81). (c) the relationship between the sky view factor and the percentage of comfort periods (source: Tzu-Ping et al. 2010).***




Furthermore, Ratti et al. (2003) have shown the existence of a close link between SVF and temperatures of urban surfaces, by numerically studying three different configurations in hot and arid regions. The first presents geometrically closed shapes with interior courtyards, similar to the urban forms observed in the old Europeans city Centers (Figure 2. 4 (a)). In the second configuration, the interior courtyards were removed, thus showing compact forms (Figure 2.4 (b)). Note that these two configurations present a dense fabric with a high built surface density and narrow streets. On the other hand, the third configuration presents an open fabric with airy shapes. The results obtained for these configurations show that the closed forms with interior courses show the lowest SVF values of around 0.13, while it is 0.23 for compact shapes and 0.48 for pavilion shapes respectively. Temperatures of the top surfaces are obtained for suburban forms with values of around 40.5 °C. This 5.3K higher than the compact forms and 8.6 K higher compared to closed forms with interior courtyards. Ratti et al., 2003 therefore suggest opening urban fabrics in order to promote heat dissipation and thus avoid the risk of thermal discomfort in these spaces. Zhang et al., 2015

Due to small differences, Ali Toudert et al., 2005 presented a study that related urban geometry to the problem of outdoor thermal comfort in a hot and dry climate, finding very minor changes between the two. Which The goal of this experimental effort in Ghardaia city is to provide some quantitative knowledge on the efficacy of traditional design forms in creating a suitable thermal environment outside in extreme summer temperatures. The significance of urban canyon geometry was the subject of the research. During the summer of 2003, meteorologists in the ancient Saharan city of Beni-Isguen monitored the temperature, humidity, and wind speed in a number of the city’s streets.

As a result of less exposure to direct sun irradiation, Measurement Points with low SVF tended to be slightly colder than the others. The longest period of shade from the sun is provided by the fact that both the deepest canyon and the overhanging trail are oriented near N-S (Ali Toudert et al., 2005). But the marketplace cooled more quickly than the other enclosing measuring stations, becoming 1.5 K cooler at midnight compared to 22:00 LST. As a result of the high SVF (0.67), heat can be dissipated quickly in the marketplace. Due to the low SVF values of the city streets, the air volume of the canyon keeps the heat given off by the canyon’s materials. The low vapor pressure (VP) was consistent with the usual humidity here . Between 6 AM and 10 AM, it reached around 12 hope, and between 10 PM and 6 AM, it dropped to around 10 hype. There was no evidence of a consistent effect of the local environment. It’s worth noting that the results may have been affected by the fact that many kitchens are situated on street edges, where they serve as local sources of heat and humidity.

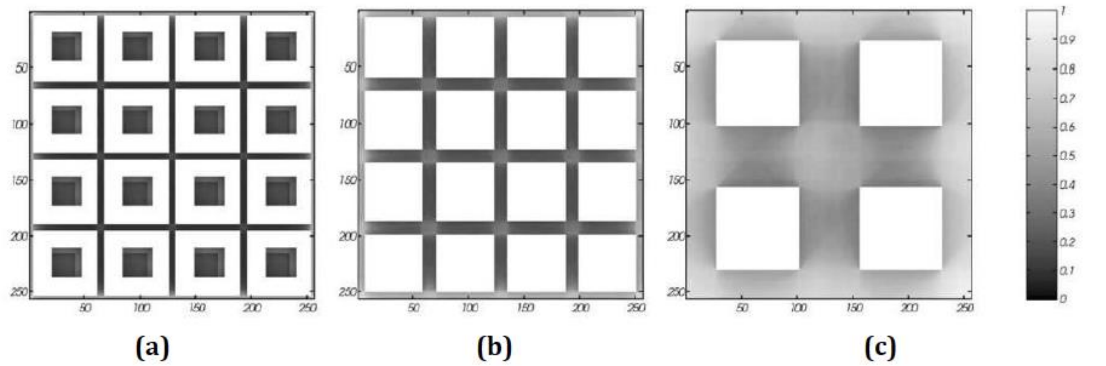



***Figure 2.4 The sky view factor for the three configurations studied. Closed forms with interior course (a), compact forms (b) and suburban forms (c) (source: Ratti et al. 2003).***

In addition, Ratti et al. (2003) have shown the preponderant role of the arrangement of tissues on their percentage of SVF. Ali-Toudert et al., 2007 have shown numerically that the tight organization and fractionated buildings of Ghardaia (Figure 2.5) reduce the SVF of façades and floor compared to an open and airy organization. They also showed that geometries with a high percentage of horizontal surfaces, especially roofs and terraces, are characterized by high values of SVF.

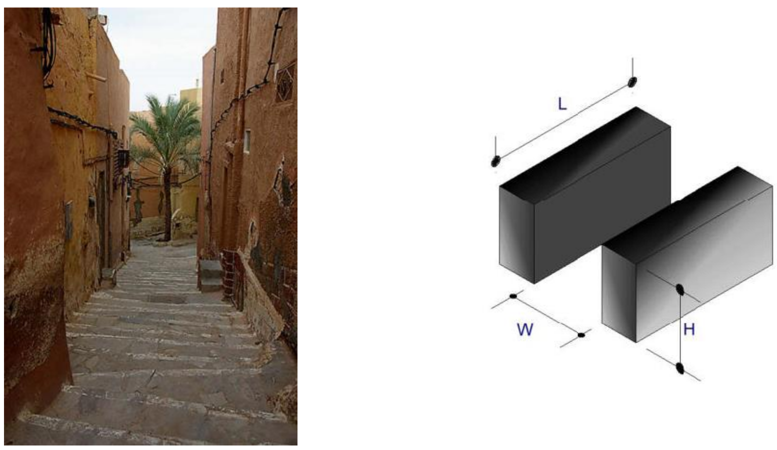



***Figure 2.5 Left: Urban canyon in Beni Isguen (source: by the author).***

## B. Variation of the H / W ratio of street canyons:

The street canyon in hot-arid locations such as Ghardaia is the most basic kind of urban fabric (Figure 2.6 to the left). It consists of a street bordered with buildings at least twice as tall as the street's width (Izard,1999). As shown in Figure 2.5, an urban canyon is defined by three primary parameters: the building height (H), street width (W), and street length (L). From these parameters, the geometric description of the canyon can be carried out through morpho logical indicators, such as the aspect ratio H / W for example. This greatly affects the amount of solar radiation incident or absorbed by a canyon. Indeed, experimental studies made by Aida and Gotoh, 1982)on street canyons with different H / W aspect ratios have showed a reduction in incident solar energy absorption from 27% to 13% when the H / W ratio goes from 0.5 to 2 (Figure 2.6). Similar results were obtained by Bourbia and Awbi, (2004), who observed that a street with an H / W ratio equal to 0.5 receives a high percentage of direct solar energy including vertical building surfaces reaching a peak surface temperature of 53°C. This thermal capture decreases when the H / W ratio is equal to 2 where the temperature peaks do not exceed 46°C.

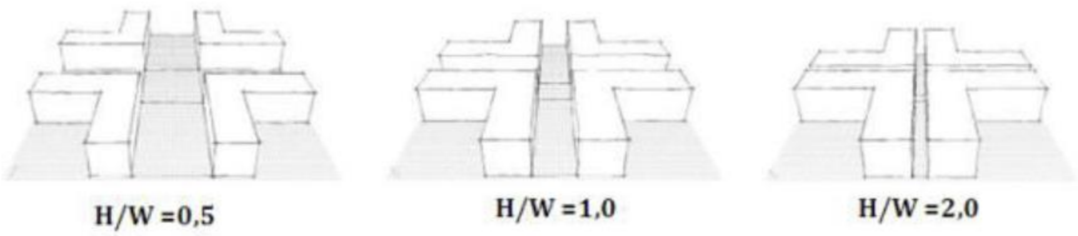



***Figure 2.6 Different aspect ratios H / W of canyon streets (source: Bougiatioti. 2006).***

However, a high H / W ratio generates another important thermal phenomenon, namely trapping heat within the street. The study of the effect of the aspect ratio of a street on its internal thermal environment shows that the greater the H / W ratio, the greater the heat storage phenomenon is marked (Sakakibara, 1996). The difference in quantity of heat stored between a canyon with an H / W ratio of 2 and a canyon with a of H / W equal to 0.7 would be 50 W / m². A summary of the impact of the H / W ratio compared to the different conditions of thermal effects which performed by Tiraoui (2000). These conclusions are specific to a canyon street located at the latitude of 45 ° North and oriented North-South.

Bakarman et al, 2015 conducted another investigation in the hot and arid city of Riyadh, Saudi Arabia. It assesses the thermal performance of traditional and modern residential urban canyons with H/W ratios of 2.2 (Deep) and 0.42 (Shallow). The study demonstrates that the exposure of urban surfaces to solar radiation is a function of the canyon's H/W ratio and orientation. They play a significant influence in determining the amount of incoming solar radiation received by the canyon's horizontal and vertical surfaces, hence influencing the ambient Ta and Ts inside the canyon. These temperatures rise as the H/W ratio falls, and vice versa. As an urban profile deepens, the exposure of urban surfaces to the sun reduces. The more solar radiation the surface receives, th' more net radiation is left at the surface and the more sensible heat is contributed to the ambient air, resulting in a significant increase in temperature.

**C. Variation of urban surface density**

Urban area density accounts for the occupation of structures built in the urban area. This corresponds to the ratio between the built area and the total urban area. Morphologically, the urban surface density varies according to the occupation of the space. At the scale of the city, the latter is based on a progression of urban forms of the most compact and dense in the city centre towards more open peripheral individual housing, with urban forms of transition. The variation in densities between the different urban portions. Thus, brings out outdoor public spaces of various sizes. From a point of view of climate, urban surface density interferes with certain urban climatic concerns like the urban heat island. Indeed, a study carried out by Boukhezer (2002) on three urban fabrics with different land use densities in the city of Ghardaia in Algeria has shown that the surface density of buildings acts on the quantity of daily energy absorbed by buildings. The historic city centre characterized by its organic fabric, its strong mineralization, and its high surface density, which presents greater quantities of solar energy absorbed compared to the urban checkerboard and scattered fabrics.

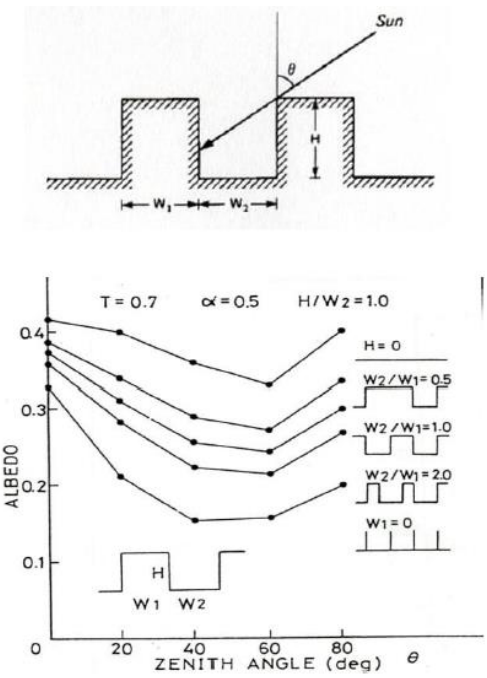


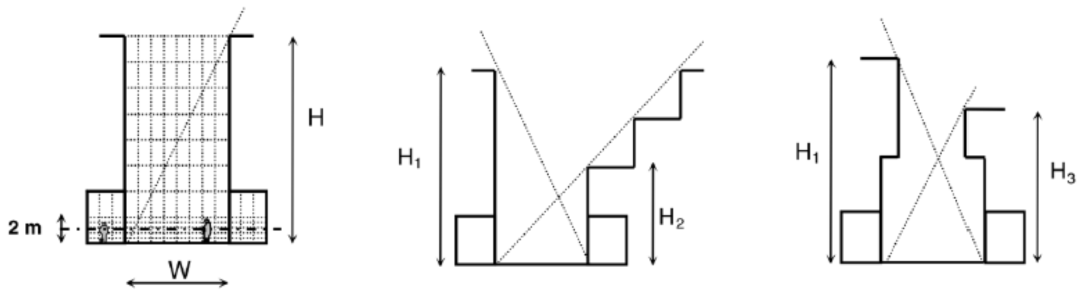

***Figure 2.7 Relationship between albedo and solar height (source: Aida and Gotoh. 1982).***

In addition, Aida et al, (1982) have approached urban area density in a more simplified way using the ratio W1 / W2 (where W1 is the width of the roofs W2 is the width of streets). This indicator was subsequently studied on a street configuration canyon by varying the parameters W1 and W2. The objective was to quantify its variation on the amount of solar energy reflected from surfaces. The results given in Figure 2.7 show that equivalent albedo values gradually decrease with increasing of the W1 / W2 ratio. In other words, the albedo of surfaces decreases with the density of surfaces built. Indeed, this density generates less energy exchange between surfaces than in the case of a fractional geometry

### 2.6.2 Vertical irregularities in the urban fabric

**Variation of the façade of street canyons**

In urban areas, not all streets have a semi-infinite shape with widths and homogeneous heights. Limiting research on these theoretical configurations reduces the relevance and applicability of the results. Thus, Ali-Toudert and Mayer (2007) studied numerically the impact of the irregularity of the façades on the thermal comfort within a street canyon, using the ENVI-Met model. Thermal comfort has been evaluated through the physiological equivalent temperature (PET). The study panel includes three canyon streets all presenting pedestrian galleries. The first street has homogeneous façades and is symmetrical with an H / W ratio equal to 2 (Figure 2.8, case I), the second is asymmetrical with a stepped façade (Figure 2.8, case II) and the last configuration is composed of two different façades with overhang devices (balconies or terraces for example) (Figure 2.8, case III).




**Case I** **Case II** **Case III**

***Figure 2.8 Schematization of the configurations studied by Ali-Toudert (source: Ali-Toudert et al. 2007).***

For the symmetrical street (case I), during the day, the percentage of comfortable summer zones in the surfaces covered with galleries is higher than that obtained in the middle of the street due to its long period of sunshine. According to Ali-Toudert and Mayer (2007), this percentage is closely linked to the geometric H / W ratio of the street and the dimensions of the galleries (height and width). However, during the night, the percentage of comfortable zones recorded in galleries remains lower than that of street surfaces. The researchers attributed this difference to the poor ventilation of the galleries compared to the street and their capacity to trap heat emitted from asphalt paved ground.

In addition, sensations of heat were identified in the asymmetrical street presenting a stepped façade (case II) due to its large opening to the sky. Indeed, this opening leads to more solar energy capture than in the symmetrical configuration (case I). On the other hand, when the solar rays are obstructed by the façades, the asymmetric street presents better thermal comfort than case I. Finally, the optimal results of feeling of comfort were obtained for the street presenting façade devices overlooking the street. This is due to the morphology of the street which presents a low sky view factor generating more shaded areas at street level and galleries.

The urban geometric shape of public places has been the subject of a thermo radiative digital study in hot and arid climates by Masmoudi and Mazouz (2004), for three places of rectangular, square, and circular shape. At first, the height of the buildings surrounding the squares is considered constant and equal to 16.6 m. The circular shape presents the optimal results of absorbed solar flux. Indeed, the amount of solar energy absorbed by the circular space at 1:00 p.m. is the lowest with only 81 Wh / m², compared to the values of the order of 114 Wh / m² obtained for squares in the form of a rectangle or square. Similar conclusions are drawn for mean radiant temperatures, equaling respectively at 36°C, 38°C and 39°C, for the circular, rectangular and square. Secondly, three building heights were considered: 16.6 m, 25 m, and 50 m. This geometric modification has very little effect on the absorption of the façades of the squares. However, at ground level, the amount of solar energy absorbed is then reduced significantly and almost homogeneous for all places.

The majority of research in the region concentrated solely on the ancient city of Beni Isguen as a case study and did not compare it to modern buildings such as Tafilelt settlement, leading to a paucity of knowledge regarding the new settlement in particular.

#### A. Heterogeneity of the height of built structures

The effect of building height on the amount of solar energy absorbed has been studied by Kondo et al. (2001) for three configurations. The first configuration presents square-shaped buildings (Figure 2.9 on the left), with a uniform height of 25 m. The second and the third have varying heights of buildings (Figure 2.9 to right), but with homogeneous frame percentages. This numerical study showed that the amount of solar energy absorbed is greater for configurations with heterogeneous heights. According to Kondo et al. (2001), this is due to the fact that a fraction of the flows reflected by the roofs is intercepted by the adjacent higher vertical walls, thus increasing interreflections and consequently the quantity of solar energy absorbed. Note also that Chimklai et al., (2004) have shown that the variation in the height of the shapes urban areas play a very important role in the amount of reflected solar energy.

This difference is readily apparent in the buildings of the old settlement in Beni Isguen due to the pyramidal shape of the palace’s morphological framework. The entire palace is built on top of the hill, which creates a contrast and gradation in the ceilings and built spaces, in contrast to the modern settlement Tafilelt, where the buildings all conform to the settlement's flat surface. And its height and level are identical.

Heterogeneity of the height of built structures


***Figure 2.9 Left: the square-shaped building model used for the digital study. Right: the second study configuration with differentiated heights (source: Kondo et al. 2001).***

## 2.7 Parameters linked to spatio-temporal factor

### *2.11.1* The orientation of urban façades

The orientation of an urban fabric is a spatial parameter making it possible to analyze the accessibility of solar energy and daylight within an urban fabric. It generates shaded and sunny surfaces causing variations in ambient and surface temperatures. Morphologically, this indicator produces forms of protection or sun exposure in urban spaces. Depending on the direction of the structure, these protections are frequently effective just at the beginning and end of the day. Indeed, when the sun is at its highest, the shaded regions in both new and ancient settlements are relatively modest.

From a climatic point of view, the impact of solar orientation on thermal behavior of urban surfaces has been the subject of several studies in low-latitude regions reported in the literature. According to Aida and Gotoh, (1982), solar height affects the amount of the reflected solar flux. Similarly, Kondo et al., (2001) found that when the solar height leads to consume a lot of energy, the value of solar energy reflected from an urban fabric increases, regardless of the value of the surface reflection coefficients.

On the other hand, when the solar height is low, the amount of reflected solar energy decreases in the event that the building surfaces have moderate reflection coefficients. Moreover, Ali-Toudert and Mayer, (2006) have minimized the role of the solar orientation of a canyon street on its thermal behavior. Indeed, according to them, when the aspect ratio of street is H / W = 0.5, urban thermal comfort is almost independent of orientation. On the other hand, when the H / W ratio is equal to 4, comfort is optimal in the same way for two East-West and North-South orientations, thus providing a much better environment thermal.

### A. Shade of surfaces

Urban structures as well as plant structures constitute sources of shadow generation, depending on the solar height and the orientation of the tissues with respect to the sun (spatio-temporal parameter). For scattered configurations, only the floor and hidden façades can benefit from shaded areas. However, for dense configurations, shaded areas may characterize several or all façades, and the floor is most often protected from sunlight. According to Ait-Ameur (2002), the shaded space is not favorable to thermal accumulation (inertia or storage) and limits temperature increases of air generated by the action of direct solar radiation. In addition, Vinet (2000) and Robitu (2005) notably mentioned that, in outdoor urban spaces, shaded surfaces record the most favourable comfort indices. Parameters related to the optical and thermal characteristics of urban surfaces.

The diversity of types of surface materials makes heat exchange more complex between urban structures and their external environment. Indeed, exposed to incident solar flux, these materials become sources of reflection of solar radiation and emission of infrared radiation. These contributions depend on the albedo of the materials as well as the inertia of urban envelopes.

In this context, Bekkouche et al, 2014 analyzed the thermal performance of buildings in Ghardaia city, which is described by the equilibrium between heat losses and heat gains, taking into consideration their heat storage capacity. Insulation level, thermal inertia use, and solar radiation management are the three essential factors of this equilibrium. A novel technique to modelling multizone structures in Saharan climate was developed.

This simplified technique is an effective way to comprehend the thermal behaviour of walls and air in a real-world structure. The suggested numerical model is one of the tested strategies that accurately predicted the experimental value of the time lag under steady meteorological circumstances and a cloudless sky. The estimation of the time lag and the decrement factor might be hampered, however, by climate fluctuations.

Solar radiation is the leading cause of heat gain in buildings. In the Saharan climate, the average daily sun insolation is greatest on the horizontal, followed by the south, east/west, and north walls. Simulated temperatures demonstrate that the best building orientation is heavily influenced by the building materials, thermal inertia, and compactness index, which describe the structure’s size, geometric form, and manner of interaction with the outside.

South has been proven to be the optimal direction for glazed openings in order to keep the sun out in the summer and allow it in during the winter.

In general, it is simpler to shade a south-facing building for summer cooling than an east- or west-facing one. In addition, it is suggested that southern exposure be used for solar heat uptake to reduce heating demands during the winter season. Southern orientation also permits the adoption of shading methods to minimize cooling loads produced by direct solar gain on south facades. During the summer, they must be fitted with shade devices, such as overhangs. These findings correspond with those of Raychaudhuri et al (1965). Based on both practical observations and theoretical calculations, it was determined that the interior climate of south-east and south-facing homes is superior throughout the year. Observed effective temperatures are found to be within the comfort zones only during the winter afternoons, while during the rest of the year, they are outside the comfort zones in every home. In contrast, we are unable to reach our comfort zone due to a variety of factors. Cold storage utilises wall stone thermal inertia. This indicates that walls will absorb cold throughout the night and release it back into the air when the temperature rises during the day. In contrast, in hot, dry areas (e.g., deserts), outdoor nighttime temperatures are almost always high throughout the summer. Therefore, it is impossible to prevent external heat from entering the home for 24 hours during very hot weather. We may maintain that the walls are thermal

As the evenings are not cool, inertia in these circumstances plays a paradoxical function.
This research instructs architects on how to choose the optimal geometric form and orientation for this sort of structure. The findings of parametric study reveal that the influence of building form on total building energy usage is dependent on the building’s compactness and amount of thermal insulation. With a compact cube form and orientation in the south-north direction, we may approach thermal comfort. Calculations indicate that, in actual weather circumstances, the time delays and decrement factors of wall.

**B. The albedo of surfaces**

Akbari et al., (2003), then Synnefa et al., (2007), have shown that the increase in reflection of the materials of urban surfaces (façades and roofs) is linked to their colour, their states of use and the nature of urban surfaces.

Bekkouche et al. (2012) examined the solar radiation in contemporary buildings in Ghardaia, which played a fundamental role in building heating. On the basis of their trajectories, these radiations may be categorised into two categories: direct and diffuse. As solar energy flows through the earth’s atmosphere, air molecules, water vapour, aerosols, and clouds absorb or disperse a portion of it. Utilizing a semi-empirical model that allows for the calculation of the energy received by various barriers is the most significant step in his research. In this regard, the Capderou model has been selected since it is the most applicable to the study location. (According to past research) However, instead of using the Capderou model to simulate the global and diffuse irradiation falling on a horizontal plane, experimental findings from a station placed at the location where the research is conducted were selected. This allows for more exact and accurate estimates of global irradiation on vertical walls. For a space so near to the outside, the two exposed walls are insulated with a 4 cm air layer and a 6 cm polystyrene layer. The western wall is insulated with a thickness of 8 cm of polystyrene. The roof is also insulated by a 4-centimeter-thick polystyrene layer. Then, to finish the insulation procedure, 4 cm of polystyrene was used to insulate the northern wall.

Proper insulation of exposed walls in building stone has been discovered to not only boost comfort but also reduce heating and cooling expenses. In prior research, it was determined that the best way to reduce energy consumption in Ghardaia is to insulate the external walls throughout both the warm and cold seasons.
- Temperature measurements suggest that thermal inertia is the primary factor governing temperature oscillations. The right application and usage of thermal mass is dependent on the current climate. Due to the fact that multiple walls are exposed to solar radiation, the thermal insulation in this instance is inadequate. In addition, stones are a good thermal mass material (owing to their high specific heat capacity and high density). In other words, during the hot season in Saharan regions, the usage of walls with high thermal inertia cannot prevent external heat from entering buildings for 24 hours. Because the evenings are not cool, we might conclude that the thermal inertia of the walls has a conflicting function in these circumstances. Therefore, even in the face of high thermal inertia, reducing energy consumption in buildings is a primary objective and a particular difficulty in arid climates.
- In the area of Ghardaia, it has been determined that altering the orientations of buildings is detrimental to thermal comfort, especially during the summer, since it contributes to overheating. The effect of a change in orientation depends on the materials used to build the floors and outside walls, the level of insulation, and how well the bioclimatic design criteria are met.

- ❖ **Impact of surface colour on albedo**

Light coloured materials have a higher albedo than dark materials. It is why cities in the South generally have a stronger albedo (0.30 to 0.45) than those in the North (0.10 to 0.20) (Taha, 1997). Synnefa et al. (2007) measured the albedo of roofs of different colours. Thus, roofs painted with white coatings have a high reflectivity, up to 72%, compared to 26% for black roofs. Furthermore, Akbari et al., (2003) studied the impact of the colour of façades on the surface temperature. During hours of full sun, black painted façades can reach temperatures of 7°C higher than those painted white. Simpson and McPherson, (1997) studied the impact of roof colour in the Arizona desert in the United States. In this case, white roofs with an albedo of 0.75 were up to 20°C cooler than grey roofs (albedo of around 0.30) and up to 30 °C cooler than those of dark roofs (albedo of 0.10). Figure 2.10 below clearly shows that the temperature of a material decreases with increasing albedo (Taha and Bornstein, 1999). Finally, stone, characterized by a high thermal capacity, is generally the most used building material, even if it presents itself as a bad insulator in general, it has the advantage of absorbing solar energy and accumulating it. To return it later, easily released at night by natural ventilation effect. It is therefore a possible asset for bioclimatic construction.

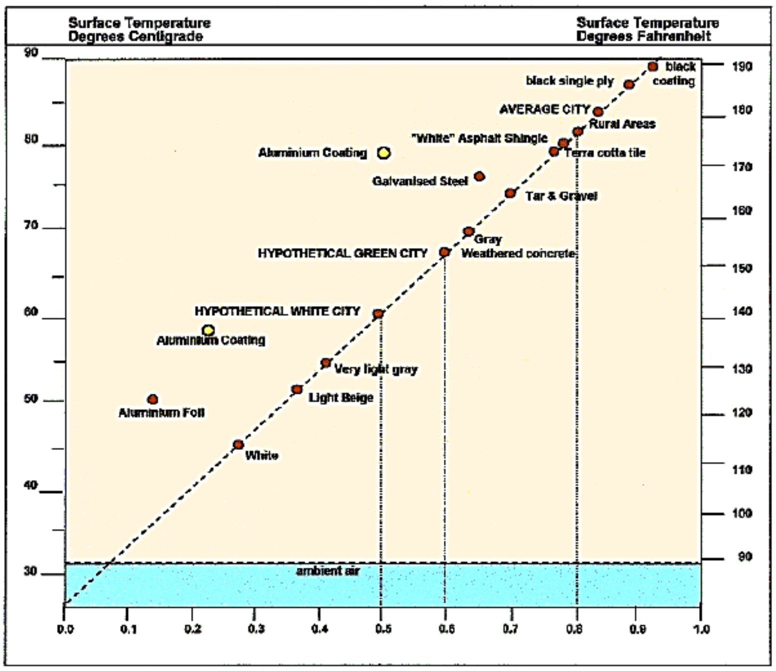



*Figure 2.10 The amount of solar energy absorbed as a function of the surface temperature for several materials (source: Taha and Bornstein. 1999).*

### 2.7.3 Morphological factors influencing air temperature

#### A. Impact of urban density

The air temperature field in an urban environment is the result of all the exchanges heat produced between urban surfaces and the atmosphere. These are widely dominated by incident solar flux. The gaps identified between city Centers and periphery are often important especially at the level of meteorological stations airports, of the order of 5 to 10 °C (Oke, 1987; Akbari et al., 1997; Santamouris and Doulos, 2001). These differences illustrate the energy effect of urbanization on air temperature, known as the urban heat island, shown in Figure 2.11.

This phenomenon has been widely observed in the literature. Akbari et al. (1992) found that temperatures in urban areas are higher than those in urban areas near rural areas which is estimated to be between 1 to 5 °C. This phenomenon is an advantage in winter because it reduces energy consumption linked to heating. At the same time, it increases the fog production. However, in hot climates, an increase in temperature leads to increased energy demand for air conditioning. In addition, a study by Oke (1988) of 30 American and European cities in mid-latitudes has shown that the openness or closeness of an urban fabric affects the urban heat island. Oke (1988) proposes an empirical correlation making it possible to characterize in heat island terms an urban fabric of street canyon type according to their aspect ratio H / W.

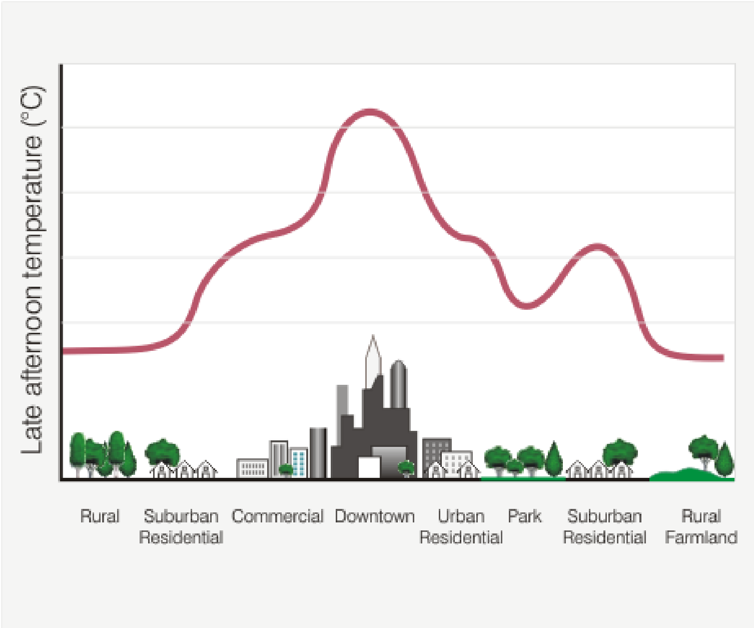



***Figure 2.11 Diagram of the heat island a schematic conurbation (source: Akbari et al. 2003).***

Furthermore, covered streets in Beni Isguen have the lowest PET values since the heat radiated from these surfaces is substantially lower compared to other canyons Tudort et al. (2007), and the protected location is practically unaffected by the daily solar radiation cycle. This substantiates galleries' utility as pedestrian walkways.

Thick, dense materials with high thermal capacities aid in reducing long-wave radiant heat throughout the day and minimising the disparities across roadways with varying geometries and orientations. However, when high thermal capacity and high aspect ratios are coupled, the night-time transfer of heat from canyon surfaces is retarded, delaying the nightly cooling of the urban fabric. According to Meier et al. (2004), while night-time outdoor comfort is of less importance compared to daytime, the cooling of the dwellings would persist longer and increase the duration of night-time discomfort. Contrary to popular belief, it was shown that the air temperature in urban canyons is somewhat lower than in undeveloped areas ($T_{max}$ = 2 K). There was no association between the aspect ratio and the air temperature. This is in contrast to the larger variances in air temperature found by Coronel & Alvarez (2001) and Grundstrom et al. (2003). In addition, being a conservative parameter, Ta responds little to urban geometry and is thus just a secondary predictor of outdoor comfort. In fact, the reason why Ta is still often employed as the primary indicator of comfort is likely due to the fact that a reduction in Ta is nearly always accompanied by higher shade and, hence, lower irradiance.

According to Ali Tudort. (2007), vernacular structures give essential information on climate-aware design, and this study calls attention to concerns that need more research, such as comparing ancient and modern typologies in the M'Zab valley. This is especially pertinent for the area where new communities and historic cities contrast sharply. These types feature much greater urban planning density, open areas, and plant coverage. These also indicate various uses, such as the open areas being more suitable for social gatherings and vehicular traffic. This research provides evidence for the existence of urban ventilation in the city's streets, despite the dense urban fabric. Furthermore, this investigation demonstrates the necessity for more continuous data to establish the relationship between air temperature and urban structure.

### B. Impact of hot urban surface

At the urban scale, the heterogeneity of the surfaces causes the thermal exchanges between the wall and the air to vary locally. These exchanges depend mainly on the optical and thermal characteristics of each face, as well as on its orientation with respect to the sun. Synnefa et al., (2007) have experimentally shown on buildings covered with concrete that the increase in albedo from 0.30 to 0.65 decreases the air temperature by 2.2K . In addition, Niachou et al. (2008) experimentally studied the thermal characteristics of a street canyon oriented in the North-East and South-West direction. They then showed that the temperature of the air measured near the façades varies according to the orientation and reflection of the walls. The air temperature near the southwest façade is higher than that of the North-East façade, the average difference in instantaneous temperatures between two façades during the day is close to 3K , while the absolute maximum difference of the air temperature is 5.4K during the day. Similar conclusions are re-ported by Oke and Nakamura, (1988) for an East-West oriented canyon street. The air temperature near the north wall facing the sun is higher than the air ambient temperature, due to convective and radiative transfers.

### C. The influence of the volume of buildings

The flows around a building result from the interactions between the wind and the built structure. By its shape and its layout, a building modifies the distribution of the different zones of pressure as shown in Figure 2. 12 (Gandemer, 1981). On the windward face of a building, appears an overpressure zone characterized by a bypass of the flow up and to the sides of the building and the appearance of a swirl roll resulting from interaction with the ground. At the edges of buildings, areas of separation appear, characterized by their relatively constant depressions with the height of the building. However, under the face of the building, the wind forms vortex movements at the origin of the wake. These eddies attenuate downstream of the building where the flow finds its upstream characteristics. Figure 2. 12 shows a diagram of the bypass by the wind of an isolated building.

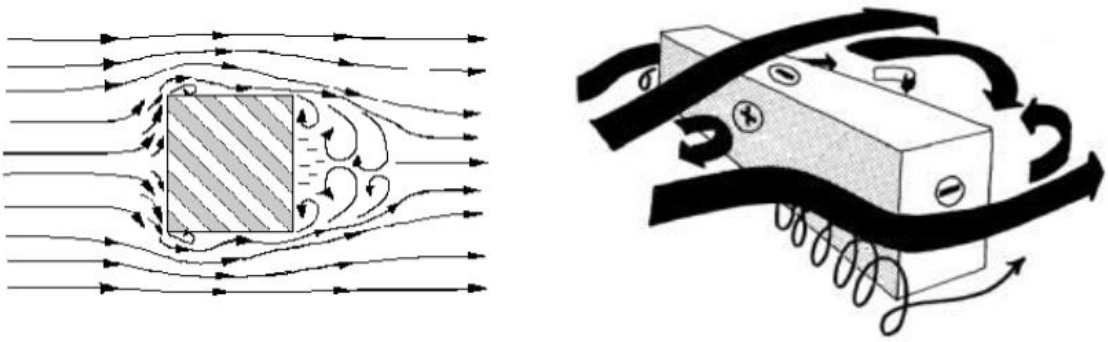


***Figure 2. 12 Schematization of the bypass of a structure built by the wind (source: Gandemer. 1981).***

At pedestrian level, annoyance effects related to the flow of the wind can be caused by the way the buildings are associated. Indeed, the dimensions, shapes, and juxtapositions of built forms condition the distribution of wind speed and turbulent intensity around obstacles. A good knowledge of the effects of wind on built structures allows us to understand the aerodynamic aspect of outdoor spaces and to lead to urban configurations that generate situations of comfort or discomfort. To respond to this problem, the Scientific and Technical Centre for Building (CSTB Nantes) carried out several wind tunnels tests on various building juxtapositions in order to study their impact on air flow. This study observed several aerodynamic effects (Gandemer, 1976) such as (figure 2.13).

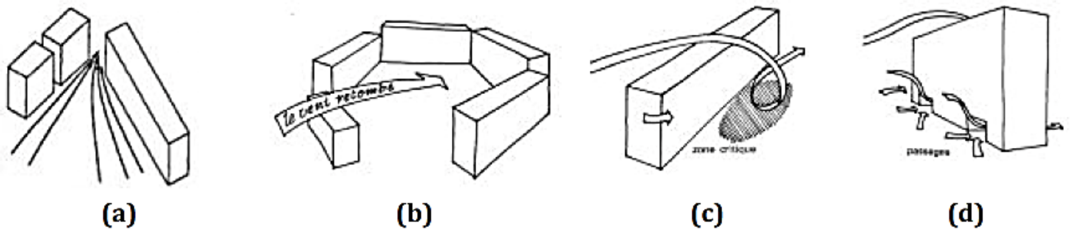



***Figure 2.13 Some aerodynamic effects of the wind: (a) venturi effect, (b) mesh effect, (c) block effect, (d) effect of passages under buildings (source: Gandemer. 1976).***

Researchers Boukhelkhal et al. (2016) looked at Tafilelt (Ghardaia, Algeria) in the summer and found that the average July temperature there was 42 degrees Celsius. Urban make-up also had a role in determining the area's high solar radiation intensities; the horizontal solar radiation may approach 1040 Wh/m2 in June and July. The wind is warm and dry, coming from the north-east at a speed of around 1.5 metres per second.  This is in contrast to Beni Isguen, where the ratio of building height to street width is lower. The amount of heat generated by the sun at any given place is directly proportional to the SVF value. In fact, the amount of natural light that gets into a building depends on its width, length, and height as well as its location in relation to streets and buildings nearby. also Both the air temperature close to the ground and the surface temperature are affected by the road's geometry, which has a profound effect on the urban climate. It is widely held that the greatest contributor to the urban heat island effect is the correlation between building height and street width. This decision was reached after considering a number of factors (SVF, RATIO, Orientation, Vegetation, Albedo, etc.). Stations are chosen along a path that traverses a variety of outside areas (plots and urban canyons) with varying shapes and orientations, with the final decision based on a number of parameters (SVF, RATIO, Orientation, Vegetation, Albedo, etc.). The amount of solar energy received is affected by the angle at which the sun is in the sky. In actuality, the street's direction, the width, the length, and the height of the surrounding buildings all affect how much sunlight enters the area.

- **The Venturi effect**: this is a phenomenon caused by buildings converging in the direction of the wind. (Figure 2. 13 (a)).
- **The mesh effect:** it is an effect caused by a juxtaposition of shaped buildings. This effect differs according to the dimensions of the mesh, according to its shape (open, closed, parallel to the wind for example) and the direction of the wind (Figure 2. 13 (b)).
- **The block effect:** it is a spiral deviation of the flow when a block passes for an incidence close to 45 °C. The phenomenon is generated if the block is isolated or in the case of several blocks of neighboring height if the spacings between the buildings are less than or equal to the height of buildings (Figure 2. 13 (c)).
- **The effect of passages under buildings:** it is a flow phenomenon which can be seen in the holes or in the passageways under the building that connect the front of the building in suppression and its rear in depression. The height of built structures plays an important role in strengthening the discomfort in these passages. Indeed, the high the buildings, the more the comfort decreases in these areas. It is comparable to the Venturi effect. (Figure 2. 13 (d)).

**The orientation of built structures:** makes it possible to determine the wind regime and control its speed. Indeed, if the orientation is parallel, the speed increases more than if the structures are perpendicular to the wind. The example of the street canyon has been the subject of several studies in order to determine the nature of the wind regime according to the orientation of the street (Oke and Nakamura, 1988; Santamouris et al., 2001).

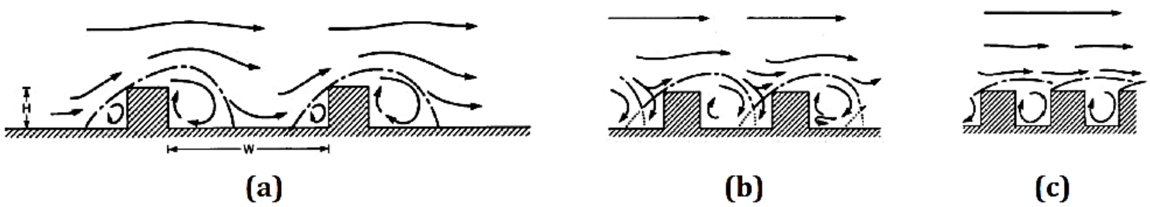



***Figure 2.14 Profile of the air circulation in a street canyon as a function of the aspect ratio H / W of the height and its width: (a) flow with isolated roughness, (b) a flow at the interference of wake, (c) skimming flow (source: Oke and Nakamura. 1988).***

It has been found that when the flow is parallel to the direction of the street, a channelling effect is observed (Figure 2. 14 on the left). According to Gandemer (1976), for the effect to be observed, the channel must be water resistant and composed of low porosity walls, with a width less than or equal to the thickness of the buildings and finally, the height of the buildings must be greater than or equal to 6 m. Otherwise, Gandemer (1976) specifies that the canalization does not constitute a hindrance. It becomes problematic when associated with an aerodynamic anomaly, during an association pipe-Venturi for example (Figure 2. 14 on the right).

A spiral movement, on the other hand, occurs when the flow is vertical to the direction of the street and the air flow generates one or more vortices; the movement may be amplified by increasing wind speed and associated thermal effects with sun-heated walls. In actuality, the rising heated air is replaced by cooler air that travels above the rooftops, perhaps enabling heat to escape from the street (Figure 2.14). Oke and Nakamura (1988) distinguished three types of flow based on the H / W aspect ratio of a street: an isolated roughness flow when the ratio is less than 1.5 (Figure 2. 14 (a)), a wake interference flow when the ratio is between 1.54 and 2.5 (Figure 2. 14 (b)), and a grazing flow when the ratio is greater than 2.5 (Figure 2. 14 (c)).D.  The influence of the density or porosity of an urban fabric.

Measuring the density of an urban fabric makes it possible to evaluate its porosity in relation to the wind. In compact and tight fabrics, only roofs and terraces are likely areas of discomfort. A set-back construction group organized in a vertical can generate a pyramid effect defined by Gandemer (1976) (Figure 2. 15 to right). This form seems judicious because it does not produce discomfort, it dispels the maximum wind energy in all directions and reduces over speeds in levels lower buildings and at terrace levels. However, porous, or open fabrics generate aerodynamic disturbances which extend over long distances. In fact, the horizontal or vertical porosity of the urban fabrics (courtyards, residential spaces for example) as well as the porosity of buildings (holes for example) modify the air flow and create risk zones linked to strong air currents. In order to limit these risks, the opening of an urban fabric must be less than 0.25 times its perimeter and that it be made up of buildings of neighboring heights (Gandemer, 1976) (Figure I. 15 on the left).

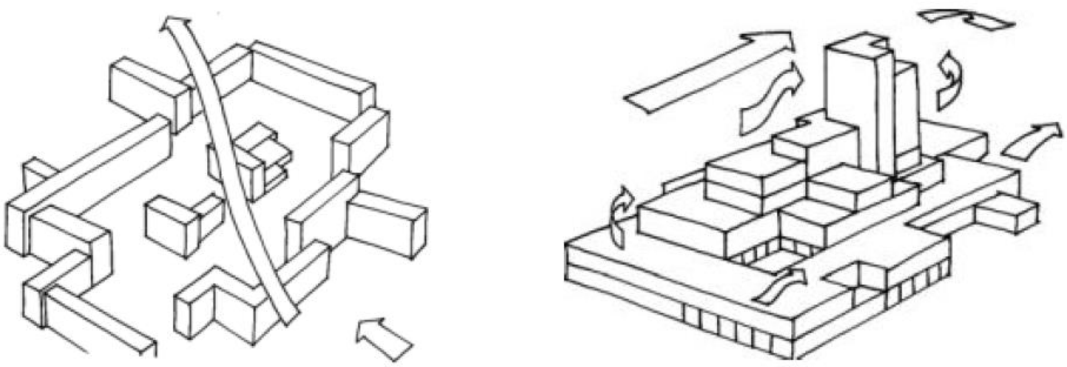


*Figure 2.15: Left: A porous fabric presenting buildings of homogeneous heights. To the right :A pyramid effect on a pyramidal construction group (source: Gandemer. 1976).*

### 2.7.4. Generic urban forms and their impact on comfort

The city is a space composed by the assembly of several urban forms each reflecting a vision or theory of the city at a given time. Every major political ideology or urban produced original urban forms, but different typologically. Indeed, the typology of urban forms varies from one district and one location to another. These variations are observed on the one hand in the organization of the building and the shape of the plots and on the other hand in urban forms and their mode of development. Indeed, the majority of cities, in particular, present historic City Centers from which arteries in the form of streets or boulevards serve the new districts. These cores historic sites are characterized by their high urban densities and vertical and horizontal regularity. Modern forms, on the other hand, are characterized by their horizontal and vertical heterogeneity and by their fragmented and porous distribution. This spatial and morphological differentiation generates modifications of the climatic parameter's conditions, which linked to outdoor comfort. A morphological and historical description of the most representative urban forms of cities as well as the main climatic changes caused by each form are detailed in the following sections.

#### 2.7.4.1.Compact form

According to Bouchair et al. (2013), the compact design of settlements or "Ksour" has been extensively adopted in Algeria's hot, dry climate in response to enforced local environmental circumstances using passive design techniques or ways. These techniques are divided into three categories: settlement planning, building design, and building components. A compact community protects the thermal environment and adapts well to extreme environmental pressures. It is designed to endure extreme heat and to reduce the strains imposed by the environment on individuals who work outside while also improving interior comfort with little energy use.

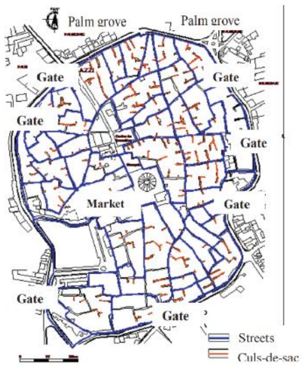
Although there are now technological methods for ignoring climate in building design, there are still compelling reasons to use passive strategies, not just for economic reasons, but also to promote environmental sustainability at both the local and global levels. This study seeks to provide an overview and full understanding of compact city ideas and techniques for dealing with the severe desert circumstances in a sustainable manner. Recommendations and basic ideas that could be useful in the future for building and designing settlements in a sustainable way are also given.

#### 2.7.4.2. The traditional island

Unlike in mild climates, where cities may be found in dispersed, clustered, and mixed configurations (Bouchair et al. 2013), communities in Algeria's hot temperature are constructed in a tight cellular pattern with limited exposed exterior surfaces. They are often surrounded by a wall for

defense and to prevent high-velocity winds and sand storms from accessing the community during the day. Figure 2. 16 (b) depicts the Ouargla Ksar, which is surrounded by a defensive wall. Inside the village, the air is more static than outside. Buildings are clustered together by tight and twisting streets, alleyways, and cul-de-sacs to mitigate the effects of severe winds and provide darkened space during the day. In a hot, dry region, this pattern creates a pleasant, comfortable microclimate that remains quite warm even on chilly nights.
According to Rosenlund et al, ( 2000). Structures use five times more energy than grouped buildings with simply a roof surface exposed to the outside environment.

Beni Isguen Ksar's tiny cellular structure with meandering streets and culs-de-sacs. To decrease heat transfer into the building, the surface area of its exterior envelope should be as little as feasible. The ratio of the surface area to volume of the building envelope or the ratio of floor area to volume defines the building's relative exposure to solar radiation. The optimum design is a patio or courtyard enclosed by walls, which is somewhat shielded from the full influence of the external air. This arrangement is especially frequent in hot, dry climates. Figure 2. 16 (a) depicts a dense tissue of Ksar El Mihan in Djanet.




*A* *B*

***Figure 2.16 Left: Mass plan of Ksar El Mihane in Djanet as a typical compact cellular lay out. . Right: Compact cellular layout of Ouargla Ksar (source: Bouchair et al. 2013).***

### 2.7.5. The Haussmannian

The Haussmannian island refers to the name of Baron Haussmann, former prefect of the city of Paris. His work consisted in making great mechanical breakthroughs called "Haussmannian breakthroughs" in the urban fabric of the city of Paris (Figure 2. 16 on the left). The goal of this operation consisted of cleaning up unhealthy habitats, to transform them into habitats for the bourgeoisie and to achieve a profound change, which consisted in transferring the working population from the Centre towards the outskirts of town. Morphologically, these breakthroughs gave birth to new urban meshes always aligned on the street and often presenting compact triangular shapes called:

Haussmannian island (Figure 2. 17 on the right). The latter is the fruit of an often diagonal cutting of the existing traditional island, thus giving birth to islands, of small and variable sizes: "The passage of these breakthroughs was not always done in the same direction of the traditional island, which in this case is divided diagonally in two parts which disrupted the fabric of the anc"ent city and favoured the birth of the triangular islet called the Haussmannian island "(Panerai et al., 1997). The city of Tafilelt was constructed in the Haussmannian style with perpendicular roads and alleyways, since this architecture enables the city to avoid a rise in the canyon's afternoon air temperature caused by the more open and exposed character of urban streets (bourbia et al 2009).

This impact may be mitigated by regulating the sky view factor and including greenery. Shade trees limit heat input by shading buildings directly and via evaporation. Adding vegetation to the surroundings, planting trees, and putting plants on rooftops may minimise UHI, energy consumption, and enhance air quality. Therefore, the geometry of urban canyons plays a crucial role in the abatement of urban heat islands. In addition, SVF is suited for incorporation into urban design assessment and decision making due to its potential position as a significant urban design geometry parameter.

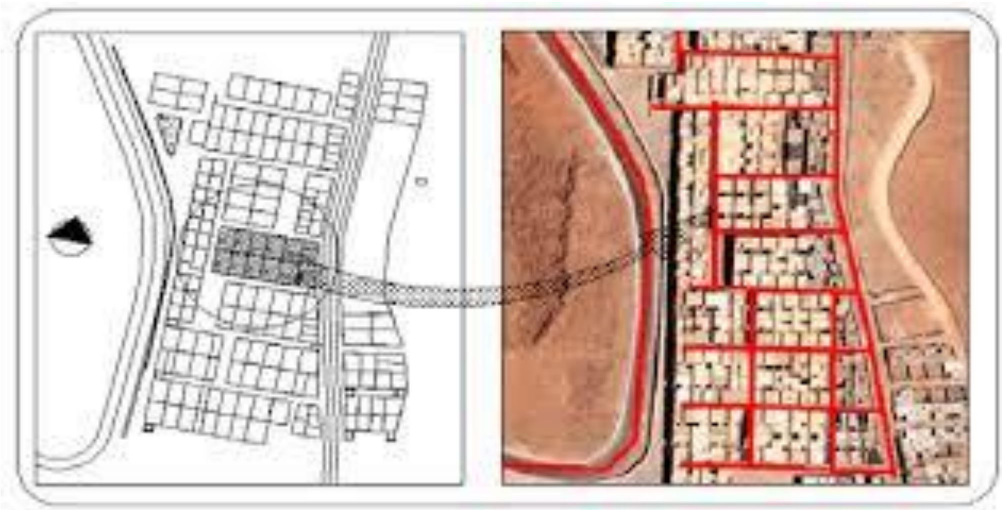


***Figure 2.17: Haussmannian block, road in Tafilelt, Ghardaia.( source: Google/images).***

In addition, the diagonal cutting of the traditional island has caused a spatial upheaval of its core island which has found its surface area shrunk, causing the migration of these functions' interior. This new situation caused a distribution of functions and favoured the appearance of the school island, the equipment island, and the building island: "it no longer functions as before, its triangular shape highlights the periphery to the detriment of the heart of the island which in this case is no longer of the same importance "(Panerai et al., 1997).

### 2.7.6 The influence of compact shapes on outdoor comfort

A compact urban fabric is generally narrow and deep. It prevents solar rays reaching public spaces (streets, squares, or interior courtyards) and generates shadows that help to increase the comfort of these spaces. Moreover, in stable weather and in hot periods, these spaces promote the phenomenon of radiative trapping thus increasing the surface and air temperatures and the risk of discomfort. This radiative trapping is due to multireflection of solar radiation from urban surfaces (Terjung and Louie, 1973; Hunter et al., 1991), reduction of albedo and reduction of sky view factor (Oke, 1981).

Solar protection for pedestrians is much more critical in hot, dry climates than rain protection (Bouchair et al. 2013). Overhangs and colonnades, of course, give shade from the sun and rain. When such constructed elements are not available, trees planted along sidewalks may give sun protection. Ground cover and wind speed at ground level are the two most important elements influencing the frequency, severity, and range of local dust storms. In a hot-dry environment, urban ventilation is secondary to street layout since high velocity is not required outside and is not sought inside throughout the day.

When there is a clash between solar and dust factors in terms of roadway orientation. This tension may be handled by using design methods to reduce urban dust levels across the city.

In hot, dry climates, the key problem with ventilation is ensuring the ability to ventilate buildings throughout the nights (Bourbia et al 2009). To the degree that such ventilation can be guaranteed by the design of the buildings themselves (e.g., by the installation of wind catchers of some kind), street ventilation is secondary, albeit gentle breezes are preferred in the streets and open areas to offset the impact of sun heating. In fact, high breezes are undesirable during the hot daylight hours because they enhance dust formation.

**2.8 Literature Review on Traditional Building Performance:**

Several studies were reported in the literature that recorded field measurements considering the thermal performance of traditional houses, the results of which indicated different parameters that influences the principal differences in the performance for example materials, local climate, orientation and in the design details Oliver, Paul. (2003); Fathi, H., (2000); and Fathi; Roaf, (1986).

Based on these studies, the traditional house design is proved to be better in comparison with the contemporary buildings; this is attributed mainly to the fact that architects and designers have ignored the climatic variable and the importance of the courtyard houses in hot arid regions.

In addition, several authors have recommended that the courtyard houses are preferred due to reduction in the external surface area leading to reduction in heat gain where the courtyard acts as a shield as it diminishes the speed and penetration of the hot, dusty winds as well as the solar radiation penetration Olgyay, (1963); May et al. John., (2010); Evans, (1980) and Steven F. and Cook M., (2010). Danby (1986) indicated that the difference in temperature between air at the roof and the main reception in another courtyard house was about 11°C between 2:00 and 4:00 p. m. Warren and Fathi (1982) studies a house in Iraq, where the differences between the air temperature at the roof and the lowest level (Serdab) was $2^0$C and was reported to be $6.4^0$C when compared with the courtyard level (see figure 2.18). Ahmed (1985) also came up with a similar results, Ahmed 1985 investigated the performance of a traditional building and a new one where it was identified that the former was on average $3^0$C below the ambient air temperature while the new building was 4C higher in the same period.

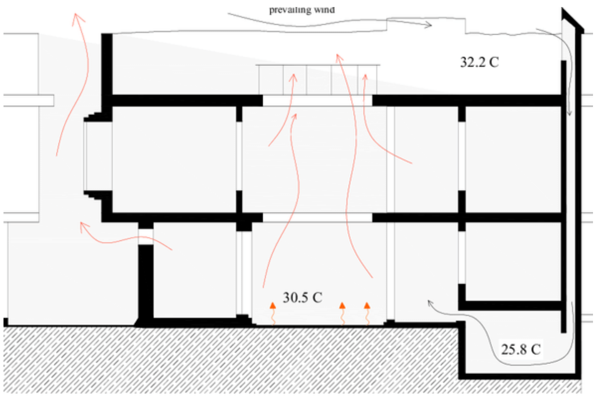



*figure 2.18: The temperature at different floors level in courtyard building, Baghdad (source: Al-Zubaidi et al. 2007).*

Al-Hafith et al, (2017), used computer simulation to monitor the impact of solar radiation on various courtyard geometries and suggested that the Arab traditional building with its courtyard in the middle is the most recommended scheme for a hot-arid climate. Al-Zubaidi, M.( 2007) studied a simulation model in Egypt, where the model was developed using average monthly meteorological data. The aim of this study was to simulate the radiation interactions taking place at the external surfaces of the courtyard envelope which are indeed typical for the hot-dry climate of Algeria. In summary, Mohsen (1979) concluded that the courtyard length in plan should not exceed its height for adequate sharing or if not alternative shading techniques e.g. overhangs and pergolas should be considered. In addition, it was also concluded from the analysis of different sizes of courtyards, orientations and proportions that adjustments to the these parameters in relation to its height significantly affect the irradiation load especially in winter. It was also noted that for a one storey building (3m height, 2.5 m x 2.5 m), the irradiation load occurred in the summer while a building of 3mg height, 4.3m x 10.7m was elongated in the east-west direction with a maximum irradiation load occurred in the winter. (Figure 2.19).

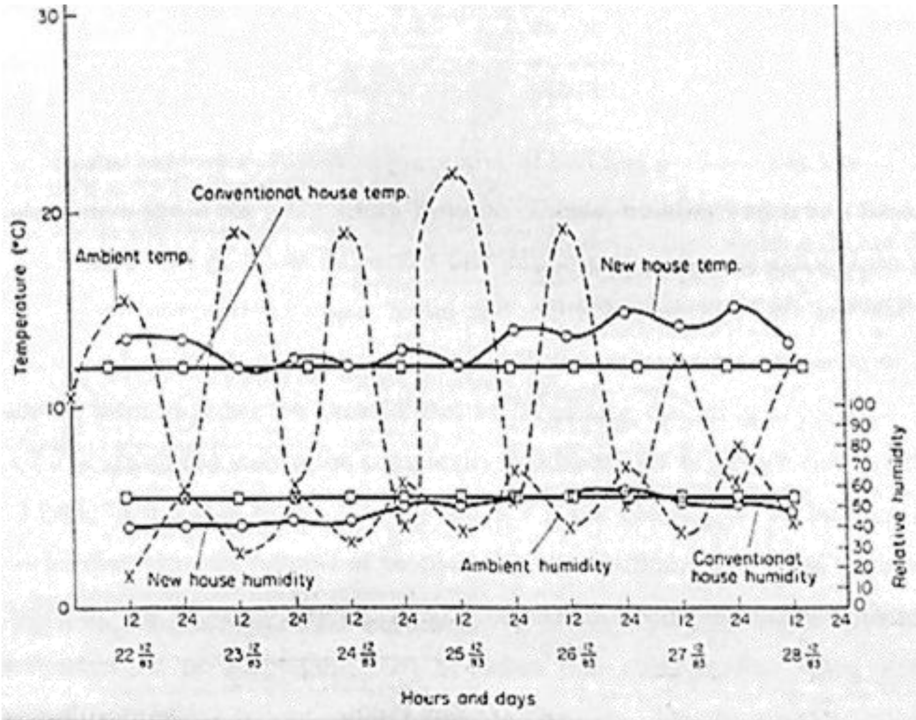



*Figure 2.19: The temperature and relative humidity for Old Building in Egypt (Source: Al-Zubaidi et al. 2007).*

### 2.8.1 Introduction to the vernacular building:

The interest in understanding the transmission of culture has given rise to a great deal of research on material culture since the nineteenth century, and the subsequent appearance of archaeology. At the start of the 20th Century, there was an increased interest in objects of martials culture by anthropologists, ethnographers and geographers but it was not until the 1960s that the vernacular world experienced invasions of researchers, and as a result, vernacular treatment methodologies lead to rapid multiplication and spread in the world of research. The methodologies of Glassie, Bourdieu, Levi Strauss, Kniffen and Rapoport, have undoubtedly marked the vernacular research in the last fifty years.

These researchers have introduced a body of work to reveal new facets of life, history, or society, whether it is the transmission of construction methods or other cultural achievements. It is a question for the researcher to close this aim by investigating and study two building environments in the M'Zab valley: new and old buildings that both have a naturally ventilated courtyard system. This will give reliable technical advice and guidance for designers when designing courtyard buildings that can provide a satisfactory internal environment for their occupants.

**2.9 Climate and Building Materials**

The environment is an important factor for any individual and be changed by it and so the environment also have a great impact on the buildings where the individual is living. It is common in North Africa that roofs are flat and at times used for sleeping and social activities while in Europe, roofs are of a gable shape to help with the frequent rains and snow during winter. In the humid tropical regions, it is common that pitched roofs are common and using grass and reeds to build the huts. Modern materials have taken a negative impact on the comfort of buildings as they replace traditional materials whereby traditional buildings using these traditional materials are still surviving and considered to be historical buildings. Shawesh (1996) indicated that new buildings in Libya using modern materials did not achieve as much comfort as traditional buildings during the summer and winter months. Shawesh (1996) attributed the discomfort to thermal storage capacity of the walls and roofs associated with small openings.

Traditional materials in Algeria include clay soils, stones, mud, sun-dried bricks, palm, palm fonds and trunks are widely used in building traditional houses. Figure 2.20 shows some of the natural materials used in Libya which tend to be similar to what Algeria uses.

In general, buildings are rectangular in shape with flat roofs that has brick pillars in their centre and load bearing walls (40 to 85 cm thick) made also of bricks. Moreover, burnt clay bricks were used in the construction of walls with an objective that these tend to insulate against the noise and achieve a low heat transfer compared to the modern materials that in turn help with the interior thermal comfort. Mud is another alternative natural material that is cheap and only requires semi-skilled labour to build with it despite the challenges of its erosion during heavy rains and as in the hot arid climate there is little rain, mud can be a good alternative. Shawesh (1996) highlighted that due to the rapid population increase within Algeria since the 1970s, new building materials were imported and were made available. Several limitations to the comfort during summer and winter were indeed reported due to the change in the materials and the design of the new buildings; this was attributed to western design influence. A number of approaches were proposed to minimise the thermal discomfort and have proven unsatisfactory from an economic point of view as the average households will not be able to afford these solutions.

Evan (1980) stated that there were several new materials introduced were indeed superior to the traditional ones. However, the described materials have not been studied as such to determine their appropriateness for climatic conditions especially in areas like Algeria.

The public sector within Algeria produced in large volumes the modern building materials to try and help with the burden of importing materials and the economic impact that it has.

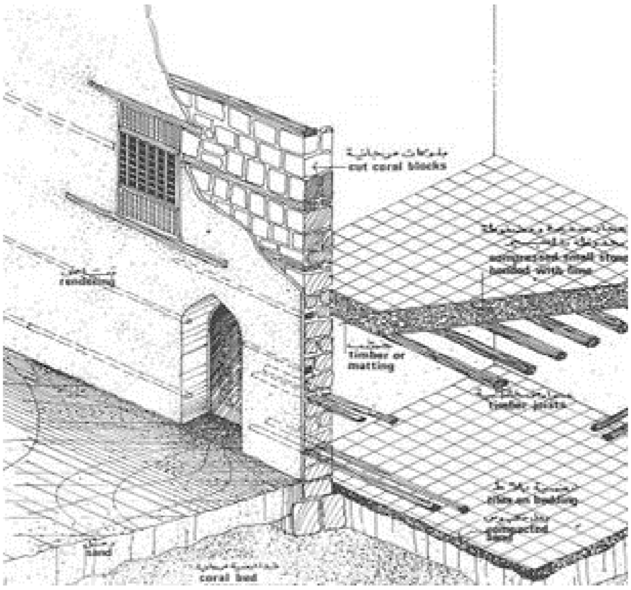



***Figure 2.20: The traditional building materials (Source: Shawesh. 1996).***

Shawesh, (1996) indicated that there is less experience in building techniques introduced from abroad in developing countries which is an issue in itself particularly when it comes to understanding the relevant properties.

Most of the projects built in Algeria between 1960-1990 time are showing serious issues e.g. cracks and even buildings collapsing (Côte, 2005). This essentially highlights the less consideration and attention of climatic factors during the construction e.g. walls were too thin (20cm) and roofs were not protected from direct sunshine. In addition, to the selection of concrete and steel that raised a number of problems. Weakness in the strength of the building blocks is noted especially during the hot summers where the high ambient air temperature and intense solar radiation has an impact on the water content within the concrete mixes. This is due to the heat exposure on other materials e.g. stockpiles of aggregates, cement and metal parts e.g. mixing drum, transport skips, formwork and reinforcing steel are all affected. The use of modern materials within Ghardaia for example influenced the occupants to use air conditioning to achieve thermal comfort which in turn can have an impact on the economic situation for the household as the electricity costs rise.

## 2.10 Aspects of the Arab Courtyard Building

### 2.10.1. Its Genesis and Definition

Fathy (1986) and Al-Azzwi (1994) named the courtyard houses as `Bayt Maftooh' (an Open House), or as Bayt Sharqi (an Oriental House), or Bayt Qadeem (an Old House); these houses are common in Algeria but not as common as non-courtyard houses nowadays. The courtyard or the patio is an internal space that is open to the sky with rooms and ancillary areas surrounding it; it is thought to provide natural ventilation and daylight. The space is certainly used throughout all seasons but more particularly during the summer period. There are different naming convention to this space such as Wast Housh (a Middle House), which literally means the space at the middle of the house; or Fina or Sahn al- Dar (the open centre space of the house). Schoenauer (1981), stated that, the concept of organising the house around an open space was established more than 6000 years ago which has evolved over the years to be reduced especially if family grows.

### 2.10.2 Social Aspects

Social aspects of the building designs are important in the Algerian culture in that most Arabic traditional buildings (e.g. in Algeria, Libya, Egypt, Iraq, Syria and Saudi Arabia) have courtyards to take into consideration the socio-religious requirements as well as thermal comfort requirements. Courtyards are private spaces such that street passers-by have no direct view of the interior of the house. The sizes range from 4m x 4m to 12m x 12m and at times, one house can have two courtyards split between the male and female occupants, again to maintain privacy. The courtyard to be occupied by the males, is usually reached directly from the street by routes that doesn’t cross the females quarters. Ghardaia is a great example in that regard where there is a complex design to the building such that privacy is maintained.

It is often observed that social tensions between neighbours can easily raise due to the design of modern buildings that has gardens instead of courtyards such that gardens are not usually used if there is someone in the balcony looking over the garden which is a private space (Jasim,2015).

New building designs in Ghardaia, on the other hand, have done away with all of the traditional architectural characteristics. This is especially true in Tafilelt, which is supposed to have been developed based on earlier models but is in no way similar to them. In order to achieve this objective, the study will make all comparisons and define the characteristics of each settlement.

### 2.10.3 Environmental Aspects

There are some influencing factors that affect the thermal comfort of the courtyard including air temperature, solar radiation, wind and heat transfer with the adjacent buildings. Courtyards has limitations in staying cooler in comparison with the outdoor temperatures, this is thought to be due to the heat absorbed or released to the air by the building materials. Moreover, the air velocity is considered to be lower than the mainstream wind where the courtyard geometry certainly plays a substantial role. As the windows and doors of rooms opening inwards the courtyard, the overheating problems can occur in the rooms if there is direct sun light exposure where shading of these openings can add value. Shawesh (1995) highlighted that Ksours in Ghardaia result in lower solar exposure on both internal and external walls and the covered passageways. Building Occupants in this region tend to relocate from the north facing summer quarters of the building to the south facing rooms of the courtyard in the winter months. The roofs are used mainly by the male occupants. More details on the use of the space during summer and winter in the selected case studies will be described.

### 2.10.4. Thermal Cycles in the Courtyard Building

Two different thermal cycles have been identified by Al-Jared (1991) namely diurnal when the heat is absorbed and nocturnal cycles is released (Figure 2.21). It was also observed the changes significantly from hour to hour due to the movement of the sun during the day and the courtyard geometry. Al-Jared (1991) defined few contributing factors that affect the rate of temperature including angle of incidence, the convection rate, the optical and thermal properties of the materials. It was noticed that heat stored is released into the neighbouring zones including the courtyard leading to an increase of its temperature (Figure 2.22).

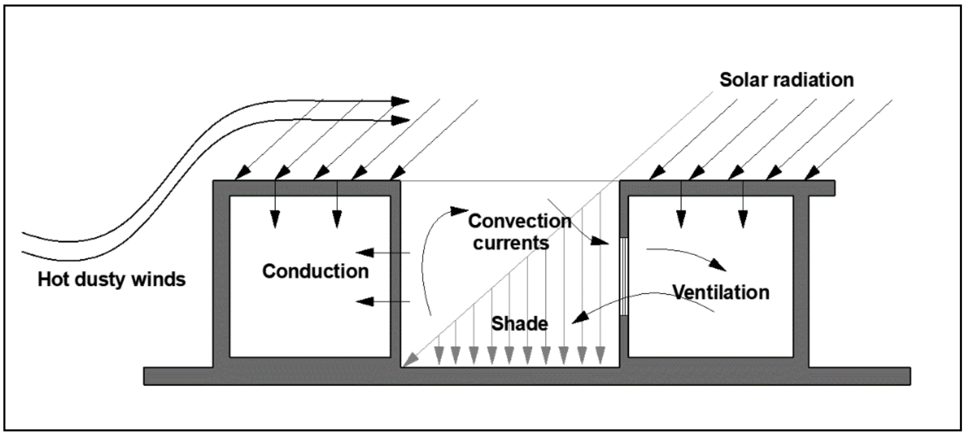



*Figure 2.21: Diurnal Cycle in the Courtyard building (Source: by the Author).*

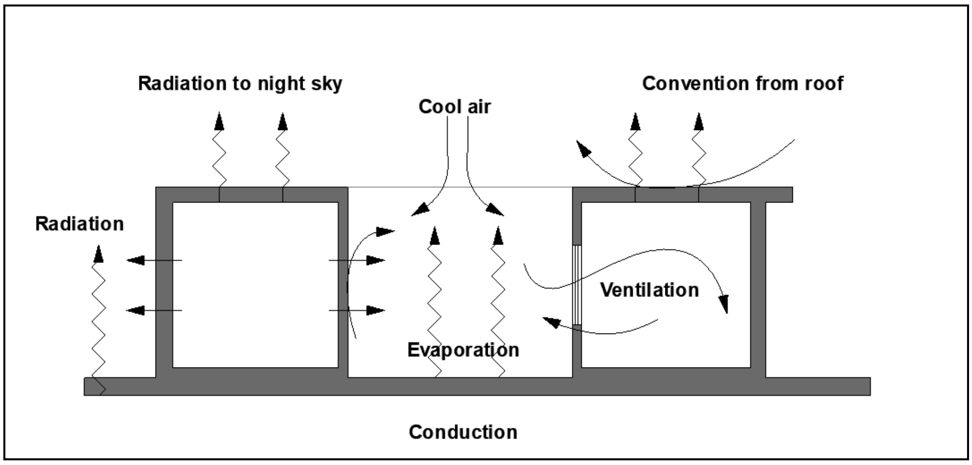



*Figure 2.22: Nocturnal Cycle in the Courtyard Building. (Source: by the Author).*

## 2.11 Passive Cooling in Vernacular Buildings

To improve indoor climate comfort, passive cooling in vernacular buildings is one of the traditional techniques used which are no longer used especially in areas like Iran and Libya (Foruzanmehr and Nicol, 2008), principally because of the changed cultural and ecological situations and so lessons learnt from these buildings are not really considered to further develop a new housing model (Al-mansuri et al,2008). This has returned that the majority of the new residents have changed their living circumstances and have grown reliant on technology in their contemporary lifestyles, which is dependent on energy-intensive usage.. It has been suggested that passive cooling techniques can accomplish its optimal performance and potential benefit if the building is carefully designed (Adenan, 2013). A number of quantitative and qualitative research have been performed to investigate the efficiency of passive cooling traditional techniques.

Taylor et al,(2009) confirmed that natural and renewable forms of energy are able to provide a comfortable environment when the vernacular architecture within the hot-dry climate of Oman was studied. Similarly, within the city of Yazd, Iran Foruzanmehr and Nicol, (2008) illustrated that the traditional passive cooling techniques are indeed acceptable especially that they reduce $CO_2$ emission

## 2.12 Passive Cooling Technique

Traditionally, night-time Ventilation is one of the established passive cooling techniques in hot-dry climatic conditions which is supported by windows opening as cross ventilation helps with the release of heat gain inside the buildings (DeKay and Brown, 2014). Givoni (1994) & (1998), Santamouris and Asimakopoulos (2001) gave a good overview of the passive cooling techniques of buildings which can be summarised as follows:

- Primarily, the use of vegetation and water surfaces that in turn help with the increase of relative humidity and lowering the air and surface temperatures. In addition, they propose methods that contribute to thermal resistance e.g., shading and glazing type.
- Secondly, enhance the thermal storage by utilising the thermal mass which in turn will have an impact on the heat gains.
- Thirdly, the use of natural cooling technique to remove internal heat.

Walker, 2010 highlighted that natural ventilation indeed helps reduce the overheating in the summer months while in winter, ventilation is not used as frequent and normally used to just remove the excess moisture and pollutants.

Moreover, the ventilation and air infiltration has a strong relationship with the thermal behaviour of the building (i.e. thermal insultation, low proportion of glazing, outdoor solar shading). Santamouris, 2005 indicated that night ventilation techniques can indeed improve internal microclimate from heat, solar protection, heat modulation and dissipation methods which can in turn increase the thermal comfort of a given building especially in the summer months.

**2.13 Nocturnal Ventilation :**

Santamouris et al. (2010) expressed that night ventilation is one of the more efficient passive cooling techniques. It is based on the circulation of the cool ambient air to decrease both the temperature of the building's structure and so this technique relies solely on the difference between the outdoor and indoor temperatures during night-time. In addition, this technique is more valuable when a particular building includes a fairly high thermal mass to absorb the heat during the day when temperatures and solar radiation are high; when at night, the outdoor air temperatures are cooler, outdoor cooler air is then dispersed through the building (Grondzik, 2006).

Credit Cavelius et al. (2009) indicated the building fabric can store the free cooling at night that can be used the following day to counterbalance the gained heat as it has the benefit of depressing daytime space temperatures by up to 3°C.

However, there are several contributing factors that has an effect on the night ventilation including time, wind characteristics, occupant's behaviour (i.e., opening or closing windows and doors) (Allard, 1998). Considering these factors, Blok et al. (2007) assured that air flow requires a driving force and an adequate number of openings which can be generated through pressure differences occurring from inside and outside temperature variations or from wind.

Kolokotroni et al. 1999 described ways of how night ventilation can be an effective way of supporting thermal comfort and reducing air temperatures as follows:

- Firstly, rely on wind induced flow cross ventilation.
- Secondly, flush the thermally massive components of the building structure with cool night-time air.
- Thirdly, by reducing slab temperatures so they can take effect as a heat sink during the following day.
- Fourthly, creating a time lag between the occurrence of external and internal maximum temperatures permitting a decline in extreme changes of alternating hot and cold temperatures.

**2.14 Thermal Comfort:**

"The American Society of Heating Refrigeration and Air-conditioning Engineers" (ANSI/ASHRAE standard 55-2010) defined thermal comfort as a "condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" as it is significant factor in maintaining human health (described as total sense of physical, mental, and social well-being) (Chappells and Shove, 2004).

There is a different definition of thermal comfort outlined by Gut and Ackerknecht (1993) who thinks that "the optimum thermal condition can be defined as the situation in which the least extra effort is required to maintain the human body's thermal balance".

Taki et al. (1999) and Ealiwa et al. (2001) specified that the use of air conditioning systems makes it difficult to identify thermal comfort criteria in new building designs especially that the building envelope design has not significantly improved with an absolutely low heating and cooling demand.

**2.15 Adaptive Thermal Comfort :**

Nicol et al. (2002) articulated that "Adaptive thermal comfort is a function of the possibilities for change as well as the actual temperatures achieved" which indicates that there is a strong relationship between the inhabitants of the building and their behaviours e.g., opening and closing of windows in case of natural ventilation or mechanical ventilation respectively. This validates the active relation between people and their daily environment with their clothing and activities (Olesen and Brager, 2004).

Taki et al. (1999) found out that the adaptive thermal comfort in hot dry climate, Ghardaia, Algeria (summer seasons of August 1997 and July 1998) felt neutral on their thermal sensation vote were 31.6°C for old buildings and 29.4°C for new air-conditioned buildings in that the adaptive model was noted to be effective in predicting the thermal comfort of the inhabitants. In addition, occupants believed that the building designs with adaptation effects have substantial implications on energy consumption.

Ealiwa et al. (2001), differentiated between PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) to measure adaptive thermal comfort within two types of buildings: old (traditional) and new (contemporary). However, the PMV model in the form of ISO 7730 (Ergonomics of the thermal environment) as a tool of analysis cannot be used in old naturally ventilated buildings without modifications, in order to predict the overall thermal comfort of the occupants.

**2.16 Adaptive Comfort Standard in ASHRAE Standard 55 – 2010:**

The adaptive comfort standard in ASHRAE (2010) applied a simple thermal index of operative temperature to characterize the indoor comfort temperature principally a combination of indoor space environment and personal factors which is acceptable to 80% or more of the occupants within a given space (see Figure 2.23).

Optimum indoor comfort in a naturally ventilated building equates to: 0.31*Tmot + 17.8$^{o}$C (Tcom = 0.31 × Mean outdoor temperature + 17.8), whereas the upper limit and lower limit can be calculated as illustrated in Table 2.1 (McGilligan et al, 2011).

In order to determine the width of comfort zone, Figure 2.23 is showing the range of width comfort zone that is arising at the 80% of thermal acceptability band with the optimum ± 3.5K, whereas the 90% acceptability band is ± 2.5K of all the naturally ventilated building (de Dear and Brager, 2001).

The relationship between the desired indoor temperature and the range of outdoor temperatures shows whether, for instance, night cooling is likely to be a viable way to keep the building comfortable in summer, or to calculate whether passive solar heating will be enough in winter (Nicol and Humphreys, 2002).

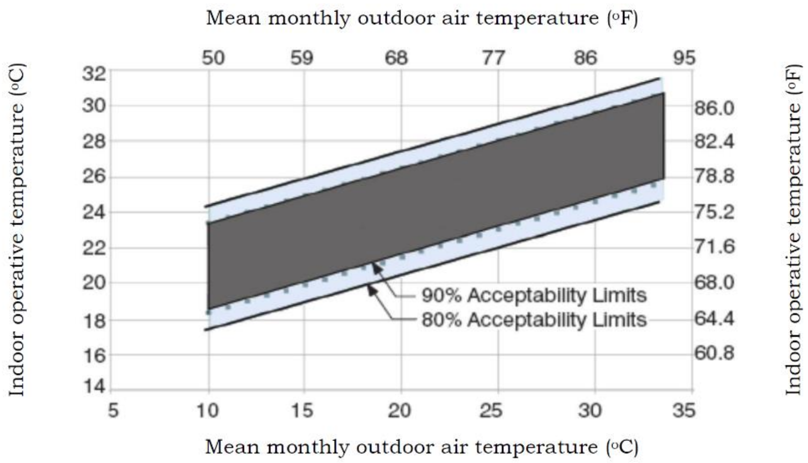



***Figure 2.23: the adaptive comfort model used in ASHRAE standard 55-2010 (Source: ASHRAE 55, 2010).***

***Table 2.1: Operative temperature limits of comfort zone adaptive standard in ASHRAE 55 (source: McGilligan et al.2011).***

| | |
|---|---|
| *Upper limit*<br>*Lower limit* | $0.31 \times T_{mot} + 17.8 + x$<br>$0.31 \times T_{mot} + 17.8 - x$<br>$T_{mot}$ = *mean monthly outdoor air temperature, where* $x = 2.5\,^{o}C$ *or* $3.5\,^{o}C$ |

In conclusion, this chapter is divided into two parts: the first part analysed and highlighted the important role of urban morphology on the low atmosphere, the microclimate, and the elements of the outside comfort. It also made it possible to draw up a panel of certain physico-morphological indicators in relation to the physical parameters of comfort. Thus, thermo-radiative indicators (the view factor of the sky, the ratio H / W, the surface density, and the albedo of the surfaces) were identified in relation to the solar radiation, the temperature of the surfaces and aeraulic (the density or porosity of an urban fabric and the nature of the arrangement of urban tissues) in relation to wind speed.

The second part has reviewed the theory of thermal comfort, proving that it is considered as one of humanity's most important requirement for designing homes by studying its characteristics; it requires an understanding of different factors such as the physiological and physical factors and their impact on predicting the optimal thermal conditions, in addition to an understanding of indexes and standards that have been developed to predict thermal comfort. In addition, this part discussed the two thermal comfort schools of thought, the classic theory of heat transfer between human body and its surroundings and adaptive approach (field studies), were broadly reviewed and compared.

In such a weather of Ghardaia where high temperature of outdoor environment in summer is prevalent, night cooling refers to the operation of natural ventilation in order to purge excess heat and cool down the building structure. This cycle allows the mass to discharge and renew its potential to absorb more heat, and this has been the most effective solution achieved in vernacular architecture. Conclusively, in hot dry climate, the superlative solution of cooling the building's interior can be enhanced indirectly by using natural ventilation that effectively contributes to providing comfortable thermal conditions for the occupants throughout the day.
The next chapter will cover the methodology adopted to study the aims and objectives of this research study as described in the introduction.

# CHAPTER
# III
# GHARDAIA CITY CASE STUDIES
# (BENI ISGUEN AND TAFILELT)

# CHAPTER III

## Ghardaia City Case Studies (Beni Isguen and Tafilelt)

### 3.1 Introduction:

The Algerian Sahara Desert is considered as one of the largest and harshest deserts in the world. It has an area stretching  more than 1,500 km from north to south and 1,200 km from east to west. It is situated on 1 million km² of barren land.

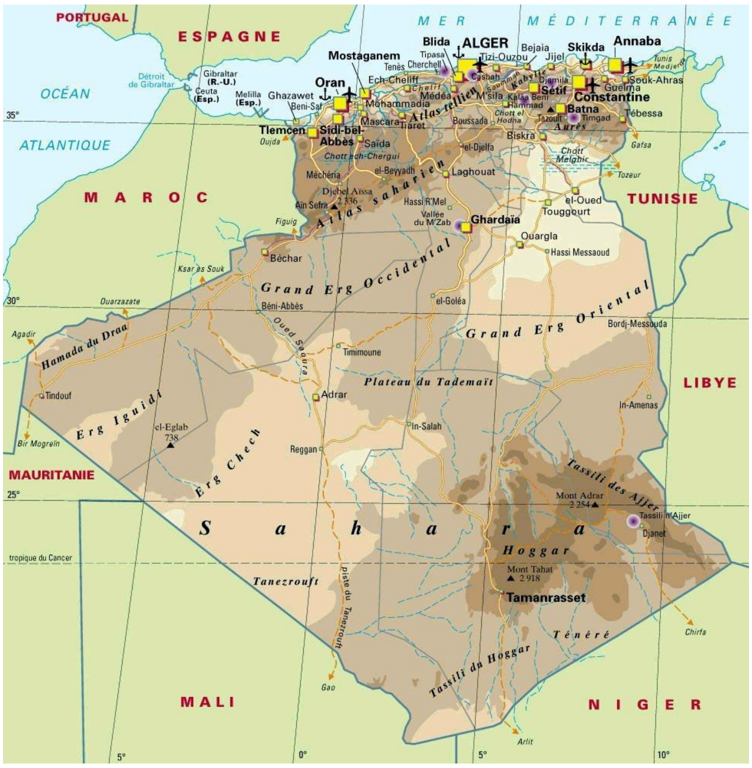



*Figure 3.1 The geographical situation of Ghardaia ( Source: Google/images).*

Of this, urban areas cover 200,000 km² of land, which make up nearly 3% of the globe. Although the desert has the potential for urbanisation, there are several obstacles to this, such as the hot climate, water shortage and vast area. Moreover, the Sahara has different soil types, such Sand Sea (ERG) and parchment flat salty soil (REG), and land types, such as rocky areas (*hamada*) and the arid mountains, as indicated in Figure 3.2.

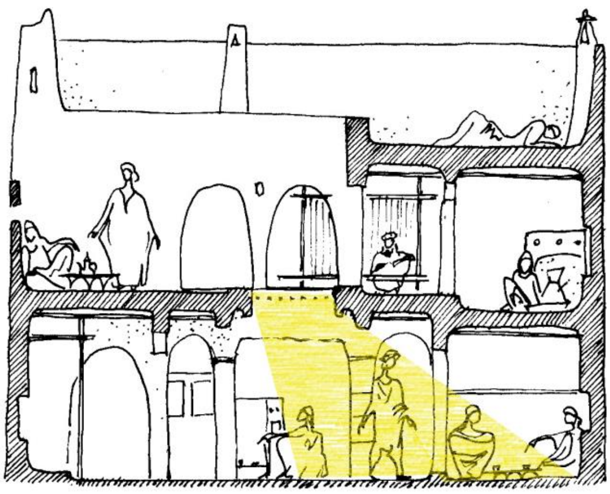
*Figure 3.2 Different types of the Sahara surface: ERG, REG, hamada and arid mountains (from left to right). ( source:Google images).*

The province of Ghardaia, including the valley of M'Zab, is supported by a so-called 'Hamada plateau' that has a northern latitude between 32° and 33° 20' and an eastern longitude of 2° 30' with an area of 86,105 km². With its nine daïras[1] and 13 municipalities, this wilaya has approximately 375,000 inhabitants and is surrounded by the wilayas[2] of El Bayadh and Adrar city to the east, Tamanrasset city to the south, Ouargla in the east and Laghouat and Djelfa city in the north (Figure 3.7).

The traditional architecture In Ghardaia comprises a diverse variety of space, ranging from extremely well-sheltered rooms on the ground floor to the completely exposed roof. This architecture is unique, as it combines the compactness of medium-height houses with minimum exposure to the sun and sufficient privacy for the residents, as shown in Figure 3.6. Furthermore, each building is surrounded by other buildings on three sides and the façade of each building facing the alleyway is covered to provide sufficient shade, helping people to sit, meet or walk comfortably. It is worth noting that only the rooftops and a few façades are exposed to the intense solar radiation. The streets are extremely narrow and shaded by the neighbouring walls otherwise, and in some places, they are further protected from the sun with trellis, cloth and awnings. The thermal inertia of the whole structural system is high as a consequence of a minimal envelope-to-volume ratio (compactness) as well as the use of heavy materials, mainly stone, which has a high thermal capacity. The mostly horizontal configuration of the city increases the urban albedo, as noted by Aida and Gotoh (1982). The use of light colours (houses are generally whitewashed or painted in light colours) further increases the urban reflectance (twice as much as that in modern cities; Taha et al. 1997).

The roofs – being the main exposed surfaces to the sun – are flat and heavy, allowing a minimal conduction of heat indoors due to the high diurnal heat storage capacity. Moreover, their large sky view factor (SVF), which is close to 1.0,  ensures a rapid night-time release of heat.

*Figure 3.3Relationship between the courtyard, sky and sunlight (source: Ravéreau A 1989).*



[1] It is a subdivision of wilaya in both countries

[2]is used to refer to the states or province

Further, house design controls solar radiation and glare through superimposed courtyards. The courtyard is the main source of light as the external façades are generally windowless. On the ground floor, there is usually a skylight that can be covered with a lattice screen see figure 3.3. This space offers respite during the hottest time of the day. Moreover, the walls are made of stone and gypsum which combined with their whitewashed coloured surfaces further reduce daytime over-heating during the summer. Even though these houses were built to cope primarily with harsh and long summers, they also offer comfort during the winter, since the southern orientation of the semi-outdoor living spaces on the terraces (galleries) and the overall heat storage capacity ensures suitable thermal conditions (Ravérau 1981). In addition, air movement occurs through small openings in the walls, and doors are left open most of the time. Furthermore, the thermal differences between the cool street, the house and the warm terrace are also capable of facilitating indoor ventilation.

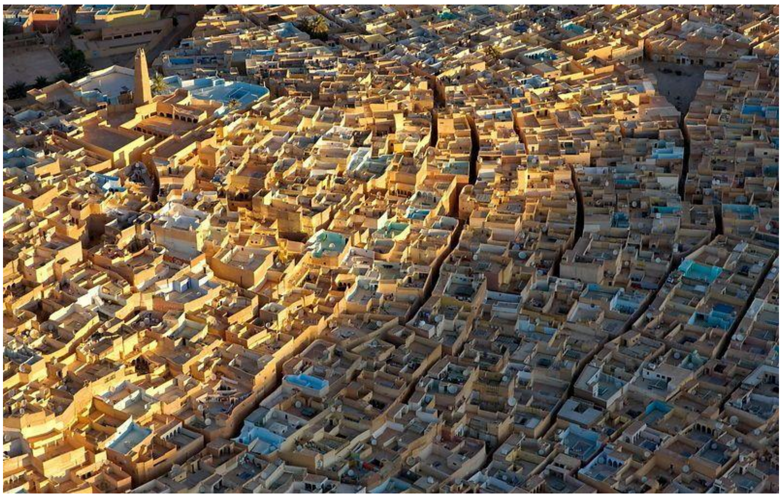


***Figure 3.4 An aerial of Beni Isguen (source: Google/images).***

The plateau of the hamada is covered by land where considerable erosion during the Quaternary period caused a limestone plateau to emerge dissected, cut into intertwining valleys and ravines. Owing to this phenomenon, the region's inhabitants started addressing it as 'chebka' (net), as shown in (Figure 3.2). Inclined from northwest to southeast, the plateau has an average altitude of 700 to 800 m in the north-western part and only 300 m in the south-eastern part. The M'Zab valley, with an area of 50 km², is over 20 km in length and 2.5 km wide (Ali-Toudert et al.Mayer, 2007).

The chebka of the M'Zab valley has a northern latitude of 32° 29' north and an eastern latitude of 3° 40. Four main valleys receive the waters of this plateau: the Metlili valley, which borders the chebka in the south; the M'Zab valley, which originates in the northwest of the chebka; the Al-Hitan valley, which originates in El-Feyd and gets lost in the M'Zab valley and the Zegrir valley, which originates in M'Daguin, waters the ksar de guerrara and then trails 18 km off the southeast of this city'.

The soil is composed of dolomites that are yellow brown on the outside and white on the inside with a crystalline structure. Their surfaces comprise fragments of greyish black quartzose sandstone. Alluvial and aeolian sands constitute the beds of the wadis. The layers below comprise dolomitic limestones, whitish grey marly limestones, subordinate sandstones, and greenish clay.
The chebka landscape is devoid of any vegetation except for a few palm groves that surround the city. It is an almost-exclusively rocky terrain within the hollow of wadi (sandy beds that are unfit for economic activities). Then, there are small arable lands, except at the bottom of the valleys, which are flooded by the valleys (M'Zab, Metlili, N'sa and Zegrir).

Despite these challenges and constraints, human settlements were built in different areas. These settlements, called the Saharan ksour, are a valuable architectural and urban heritage.
The M'Zab valley is a unique combination of five 'ksour' (fortified villages; singular: 'ksar'), spanning across an area of 75 km², situated 600 km to the south of Algiers. This conglomeration is known as the city of Ghardaia. These ksour are El Atteuf (built around 1010 AD), Melika (built in 1048 AD), Bunura (built shortly after Melika), Beni Isguen (built in 1050 AD) and Ghardaia (built in 1053 AD). They exhibit specific but not homogenous urban shapes. Figure 3.5 shows the distribution of the five ksour in the M'Zab Valley.

The M'Zab valley was inscribed under the United Nations Educational, scientific and Cultural Organization (UNESCO) World Heritage List in 1982 as a precise example of a traditional human habitat that seamlessly adjusted to the natural environment. Prior to that, it was listed as a site of national heritage in 1971. Predominantly, the inhabitants of these ksour are Ibadites, who are characterised by stringent morals and a firm belief system.

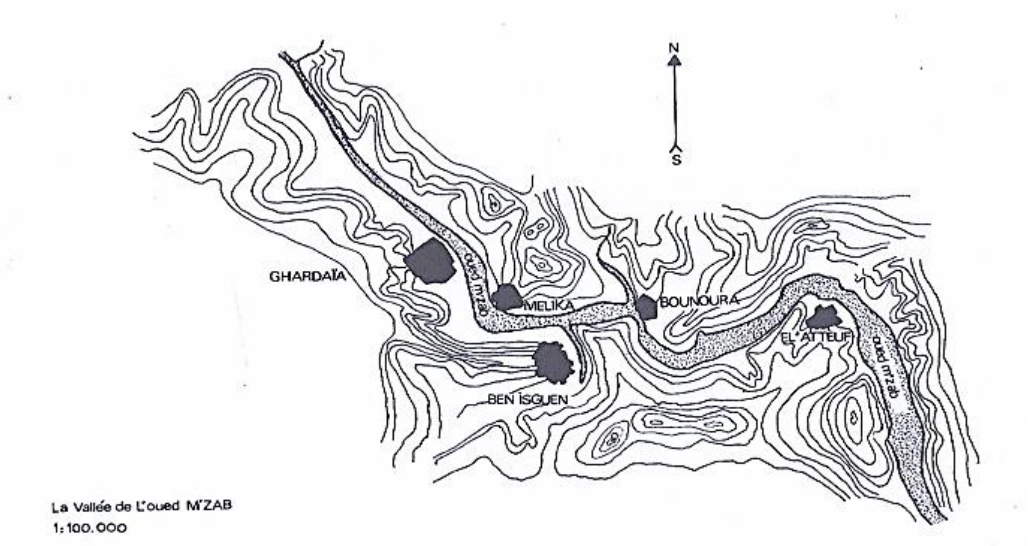



***Figure 3.5 The five ksour before the colonial period (source: Benyoucef 1986).***

With the advent of urbanisation, there were some consequential effects, such as the threat to the

existence of palm groves, that could damage the equilibrium of the ecosystem. Moreover, the inhabitants are aware of the need to protect the ksour and their agricultural lands. This triggered the creation of the 'Tafilelt project' to minimise the consequences of urbanisation.
The following section will elaborate on the old city of Beni Isguen. Some inhabitants, mainly newlyweds, moved from the old city of Beni Isguen to the new settlement in Tafilelt; this shift was in fact considered a successful social experiment for housing newlyweds.

***Figure 3.6 A view of the urban Beni Isguen (source: by the author).***

**3.2 Characteristics of the M'Zab valley:**

**3.2.1 Climate Data for Algeria:**

To refine the climatic zoning of Algeria, research was carried out by the Renewable Energy Development Centre (CDER) Algeria, the Office of National Meteorology (ONM) Algeria, and the Research unit in Renewable energies in Saharan (URER.MS) Algeria. These organisations classified all the regions of Algeria into zones and sub-zones as follows (Figure 3.7)

Zone A (coastal zone): The coastal area, extending over a small width, includes the shore of the sea and, sometimes, the northern slope of coastal chains. It is characterised by a Mediterranean climate where the winters are rainy, and the summers are hot and humid.

1. Zone B (the Tell Atlas): This zone includes the mountainous regions of Kabylia and Constantine where temperatures around 0°C are recorded in the winter. On the south of the Tell stretch, two mountain ranges – the Saharan Atlas and the Tell Atlas – are separated by high semi-arid plateaus. Their climate is influenced by altitude and marked by warmer and less humid summers with significant variations in the daytime temperature.
2. Zone C (highlands region): This zone stretches from east to west of Algeria. It has a semi-arid climate characterised by a hot summer.
3. Zone C' (sub-zone): It constitutes the Cheliff valley, which records an average summer temperature between 34.1 and 38°C. The daytime duration, especially during the summer, is approximately 11.7 h.

4. Zone D (highlands region): This zone differs from the characteristics of Zone C with regard to higher temperatures, low humidity levels and a longer sun duration (Mezred, cited by M. Dahli et al. 1997).
5. Zone E: The south of Atlas Mountains stretches out into the Sahara Desert, which covers nearly 85% of Algeria, where the climate is hot and dry. This zone includes the regions of Ghardaia, Biskra, Bechar, Touggourt and Hassi-Messaoud, where the temperatures and the daytime duration are very high.
6. Zone F: This zone, comprising the regions of Adrar and Ain-Salah, is characterised by very high temperatures.
7. Zone G: It comprises the regions in the extreme southeast of the country, such as the Hoggar and the Tassili, where the daytime duration is very high.

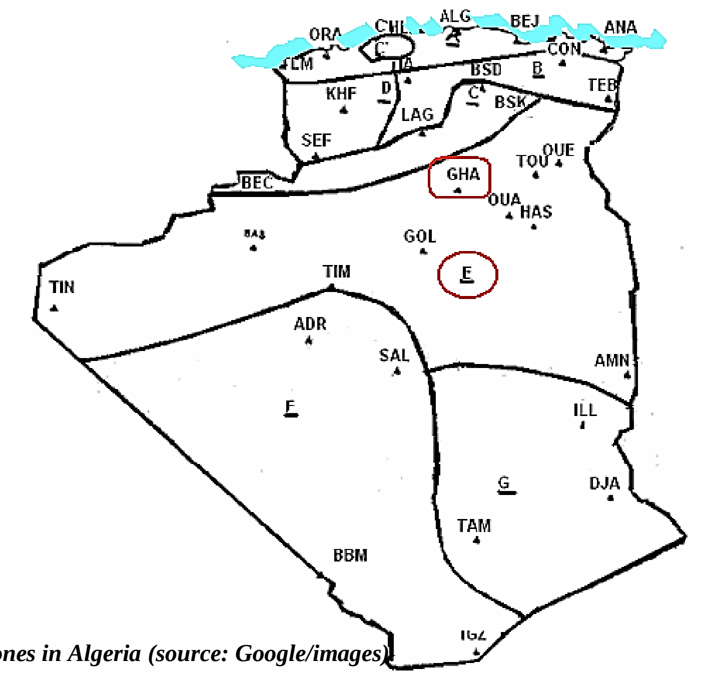



*Figure 3.7 The climate data zones in Algeria (source: Google/images)*

### 3.2.2 Climate Data for the M'Zab valley:

The climate of the M'Zab region is of the Saharan type, as shown in Figure 3.7. It is characterised by dry air combined with a low rainfall. However, microclimates play a considerable role in the desert; the presence of vegetation can locally modify the climatic conditions. A palm grove, for instance, can raise the humidity levels and contribute to thermal comfort. Coming to seasons, autumn and spring are mild, while summer is very hot. Winter is a comfortable season since it characterized as an intense brightness and significant range variation between the daily minimum and maximum temperature. Understanding this climate variation is key to more successful human adaptation to the environment, which it makes it vital that the following elements are explored.

**A- Air Temperature*:*** The annual temperature distribution is uniform. Summer is the hottest season and is marked by a large amplitude between daytime and night-time temperatures. The season begins in May and lasts until September. The average temperature recorded in July is 35.3°C, while the maximum temperature can be anywhere near 46°C. During the winter, the average temperature recorded in January does not exceed 10.6°C. The temperature is usually around 8.7°C, although it can sometimes drop to 1.5°C. The following tables and graphs indicate the temperature and relative humidity values recorded by the Ghardaia weather data station of the National Meteorological Office (NMO). It is worth noting that the meteorological office only shared data for six years due to unknown reasons, This applies to the graph in Figure 3.8, which covers only 2012. Moreover, looking at the submitted data, the temperatures seem to be lower compared to the real average temperature. Now, per the Algerian law, an area with temperatures above 50ºC is considered a 'disaster area'. In this regard, the inhabitants should not work, get government support in terms of paid absence from work and face no electricity costs, to name a few examples. The data in the tables below show some uniformity in the variation's average temperatures for the measurement periods. In fact, Figure 3.8 shows significant variations between the maximum temperature (46.2°C) in August and the minimum temperature (1.5°C) in December. However, a significant increase was noted in the average recorded in the recent years, indicating the prevalence of global warming, which is highly felt in Algeria.

*Table 3.1 Monthly average (MA) temperatures and relative humidity between 2012 and 2017( source: Ghardaia weather station).*

| Year | Months | MA tempera-ture (°C) | MA humidity (%) | Year | Months | MA temper-ature (°C) | MA humidity (%) |
|---|---|---|---|---|---|---|---|
| **2012** | January | 12.3 | 49 | **2013** | January | 10.1 | 57 |
| | February | 13.3 | 40 | | February | 14.6 | 39 |
| | March | 21.3 | 33 | | March | 18.3 | 41 |
| | April | 21.0 | 32 | | April | 21.1 | 35 |
| | May | 25.9 | 31 | | May | 26.3 | 27 |
| | June | 32.6 | 26 | | June | 31.8 | 22 |
| | July | 36.3 | 23 | | July | 35.0 | 22 |
| | August | 34.6 | 24 | | August | 33.8 | 26 |
| | September | 30.1 | 37 | | September | 29.1 | 35 |
| | October | 26.6 | 39 | | October | 22.7 | 41 |
| | November | 16.3 | 54 | | November | 17.0 | 48 |
| | December | 11.4 | 60 | | December | 13.8 | 51 |
| **2014** | January | 11.7 | 49 | **2015** | January | 12.0 | 57 |
| | February | 11.8 | 46 | | February | 14.7 | 52 |
| | March | 15.9 | 46 | | March | 17.9 | 42 |
| | April | 21.6 | 38 | | April | 20.5 | 41 |
| | May | 26.5 | 30 | | May | 23.0 | 34 |
| | June | 31.5 | 25 | | June | 30.6 | 28 |
| | July | 36.0 | 20 | | July | 33.0 | 23 |
| | August | 33.0 | 23 | | August | 35.0 | 29 |
| | September | 29.0 | 34 | | September | 27.7 | 35 |
| | October | 25.1 | 48 | | October | 24.9 | 35 |
| | November | 16.1 | 36 | | November | 14.3 | 62 |
| | December | 11.5 | 54 | | December | 11.3 | 66 |
| **2018** | January | 9.0 | 54 | **2017** | January | 8.7 | 65 |
| | February | 10.5 | 45 | | February | 12.2 | 53 |
| | March | 18.1 | 35 | | March | 18.8 | 35 |
| | April | 21.9 | 29 | | April | 23.8 | 33 |
| | May | 28.3 | 24 | | May | 28.3 | 31 |
| | June | 31.7 | 29 | | June | 31.7 | 20 |
| | July | 36.9 | 20 | | July | 34.5 | 23 |
| | August | 34.0 | 30 | | August | 33.9 | 28 |
| | September | 28.4 | 41 | | September | 26.9 | 40 |
| | October | 23.7 | 54 | | October | 24.8 | 35 |
| | November | 17.0 | 47 | | November | 17.1 | 45 |
| | December | 10.8 | 56 | | December | 11.7 | 64 |

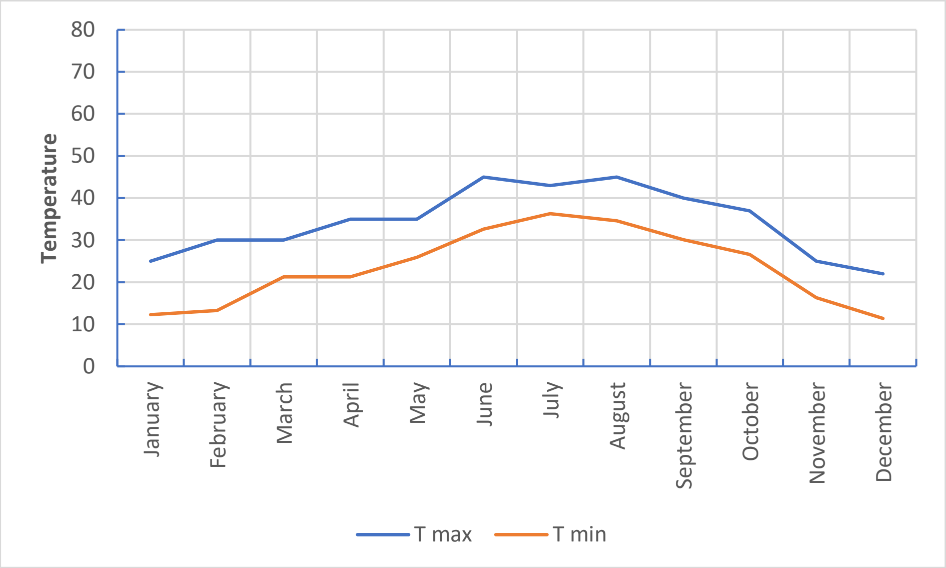



*Figure 3.8 Variation of the minimum and maximum temperatures 2012 ( source: Ghardaia weather station).*

**b- Rainfall and Humidity:** Low rainfall is one of the fundamental characteristics of the M'Zab valley. It is extremely variable, as shown in Figure 3.9, and sometimes becomes as severe as a thunderstorm. The rainy season lasts between September and January. The average rainfall is between 50 and 70 mm. Occasionally, heavy rainfall as high as 120.5 mm is also recorded.

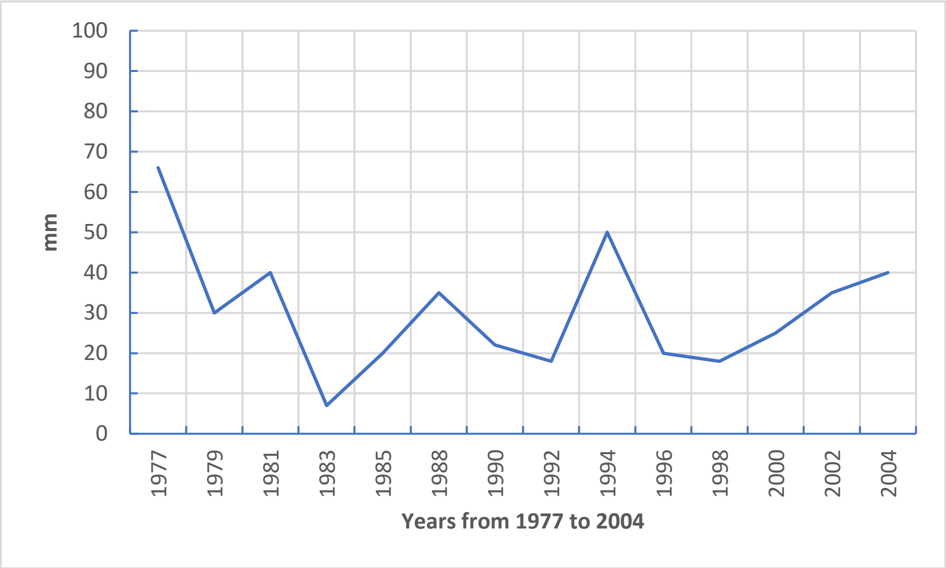



*Figure 3.9 Average precipitation between 1977 and 2004 ( source: Ghardaia weather station).*

Figure 3.10 shows the changes in humidity levels. In summer, the level is relatively low, as it varies between 20 and 30%, although it can sometimes go beyond this as well. At times, during certain periods of drought, it can go as low as between 2 and 6%. In winter, the average humidity levels can cross 55%.

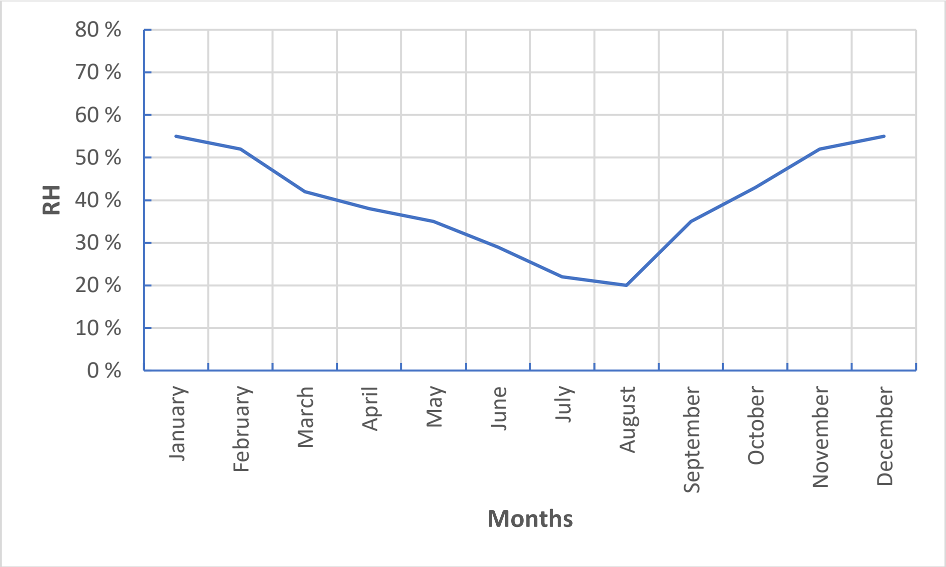



*Figure 3.10 Month Average relative humidity level ( source: Ghardaia weather station).*

**c- Winds:** The winds can also prove to be significant, given their contribution to sandstorms that can become violent and go several hundred metres high, especially during March and April. During these storms, all social and economic activities cease since storms can last up to three days or more, transporting sand masses through considerable distances, lulling only during the night. The knowledge of the local climate comes under the study of the winds (intensity, direction and frequency), which lead to the most striking climatic contrasts. Winds, with an average of 4 m/s, can be a significant factor in human discomfort. They can go up to a speed of 20 m/s and, in extreme cases, 36 m/s. Therefore, protection against strong winds, during both summer and winter, is a top priority in urban planning and design. The prevailing summer winds from the northeast are dry and hot, while the winter ones from the northwest are cold and humid. However, the measurements


*Figure 3.11 The average monthly variations in the wind speed ( source: Ghardaia weather station).*

Carried out on site by Kitous for his doctoral thesis show that the aeraulic conditions depend on the location of the site in relation to the relief provided by the surrounding areas (Kitous et al 2006). According to the NMO, a minimum speed of 15 m/s can trigger a sandstorm that usually lasts between 15 min and 3 h. These storms are mainly from the west/southwest, west/northwest and west directions. As for the Sirocco, the researcher noted an annual average of 11 days per year from May to September.

**d- Solar Radiation:**

Algeria has one of the most important solar fields in the world since the field is rated as capable of receiving more than 3000 h of sunshine per year. According to the president of the Algerian-German Chamber of Commerce and Industry ( reference), which quotes the conclusions of a German study on the subject, the energy received is around 1700 kWh/$m^2$/year in the north regions of the country and 2263 kWh/$m^2$/year in the southern. The M'Zab valley is one of those regions that has a vital and valuable solar resource in the Algerian territory, as shown in Table 3.2.

***Table 3.2 sunshine hours for each month during the seven years ( source: Ghardaia weather station).***

| **Month** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** |
|---|---|---|---|---|---|---|---|
| **January** | 267 | 251 | 263 | 222 | 262 | 261 | 211 |
| **February** | 287 | 251 | 267 | 234 | 241 | 239 | 231 |
| **March** | 279 | 294 | 283 | 269 | 252 | 224 | 321 |
| **April** | 298 | 302 | 286 | 290 | 296 | 299 | 293 |
| **May** | 297 | 315 | 266 | 321 | 334 | 309 | 272 |
| **June** | 351 | 332 | 350 | 350 | 318 | 301 | 314 |
| **July** | 351 | 322 | 298 | 323 | 370 | 295 | 357 |
| **August** | 348 | 289 | 263 | 351 | 378 | 312 | 333 |
| **September** | 274 | 262 | 282 | 267 | 307 | 272 | 275 |
| **October** | 255 | 232 | 275 | 189 | 228 | 271 | 297 |
| **November** | 245 | 208 | 225 | 264 | 205 | 252 | 261 |
| **December** | 235 | 226 | 246 | 242 | 220 | 237 | 211 |

The average daily Solar Radiation on a horizontal plane is of the order 6000 Wh/$m^2$ as an annual average radiant energy distributed, as shown in Figure 3.10. All surfaces directly exposed to the sun, be they walls or roof, absorb a lot of heat during the day, which gets released during the night.

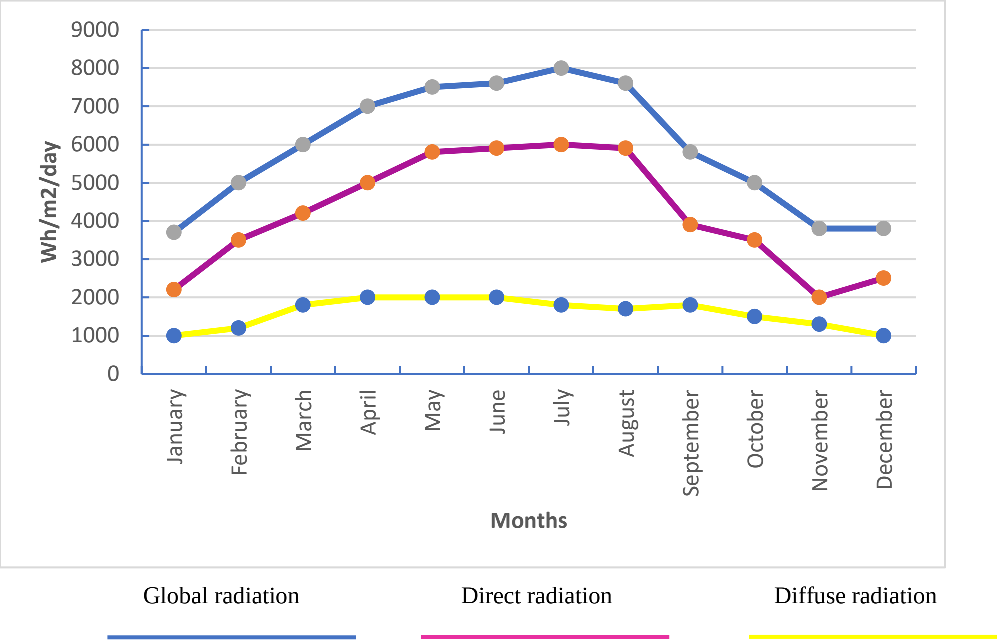



**Figure 3.12** ***Variations in solar radiations*** **(Wh/m²/day)** ***( source: Ghardaia weather station).***

**e- Summary of the Climate Data:** Based on the climate analysis, it can be summarised that the valley is characterised by an extremely hot and dry summer with mild winters. In terms of humidity, winter is characterised by a relative humidity of between 40 and 70% and in summer between 20 and 30%. The rainy season lasts from September to January, recording a precipitation rate between 50 and 70 mm. However, it can also get severe like the Winter 2008 floods.

In the winter, the cold and humid winds originate from the north, west or northwest directions with a west–north–west preference; their frequency is as follows:

6 to 15 m/s: 20%    1 to 5 m/s: 60%    Calm: 20%

In summer, hot and dry winds blow from the north, east or northeast directions with a preference towards northeast; their frequency is as follows:

6 to 15 m/s: 25%    1 to 5 m/s: 55%    Calm: 20%

The dust storms arise from April to month of June come from the west direction, the Southwest, West / Northwest and West and Sirocco (South) starting from May to September.

The global irradiation is of the order 6000 Wh/m² and can reach 8000 Wh/m² in July. Solar exposure varies, starting from 231 h in December to reach its maximum in June and July with 350 h.

### 4.3 The Ksar of Beni Isguen in the M'Zab Valley:

The ksar of Beni Isguen, the intellectual centre of Ibadism, is located on the side of a peak equidistant between the ksour of Melika and Bounoura. It is at the confluence of the M'Zab and N'tissa valleys. This ksar originates from an old town – Tafilelt – which occupies the upper part. The palm grove of Beni Isguen stretches along the N'tissa valley and has many structures, hydraulic systems and summer houses.

The inhabitants of the old ksar of Beni Isguen have a unique way of using the space inside their house, depending on the season. For instance, each family uses the heavyweight ground floor for the summer season and the relatively lightweight first floor for the winter. Moreover, the open roof is used for sleeping during summer nights. Therefore, in the old ksar, some buildings are still occupied and in reasonably good condition despite being nearly 1000 years old. When the new couples were moved to the nearby new town about 10 years ago, some parts of the traditional buildings in the old town, unfortunately, started to deteriorate. Several lessons can be learnt from the experiences of how people have constructed dwellings over the ages to satisfy their social needs while providing a good-quality environment. which represents a unique traditional human settlement and is considered an apt representation of the southern Algeria towns.

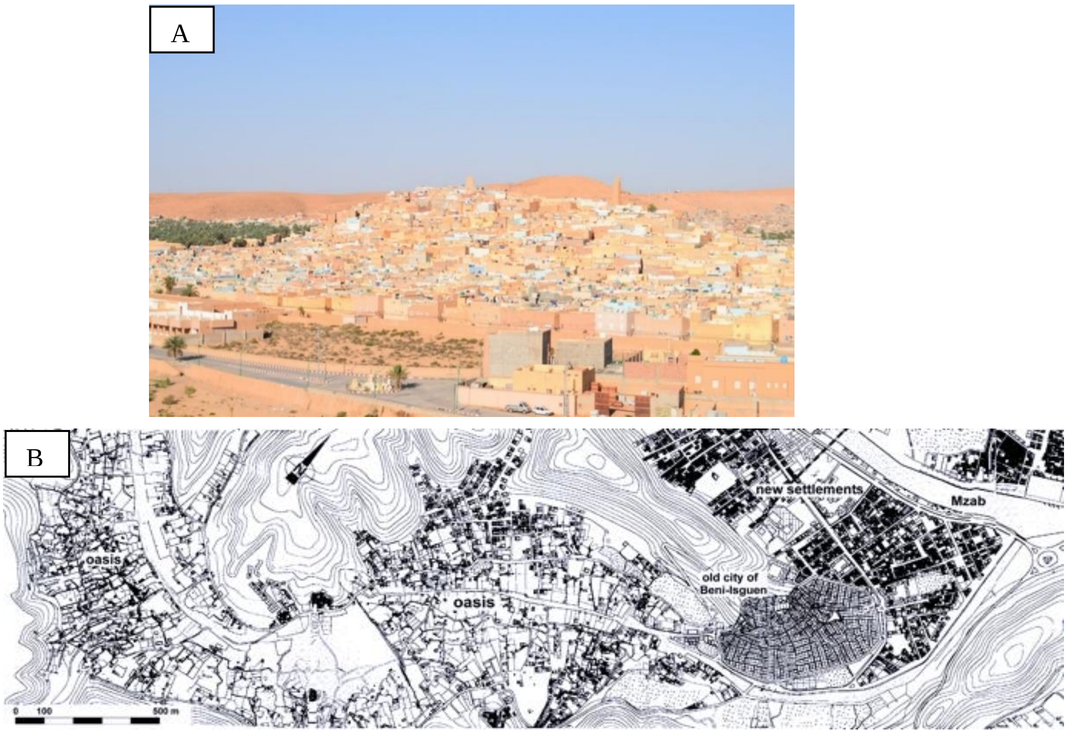



***Figure 3.13 The old city of Beni Isguen: (a) its oasis in the M'Zab valley (b) Algeria (source: Ali-Toudert 2007).***

Moreover, the old town of Ghardaia comprises more than 30,000 dwelling units, mosques, markets and other public squares where the inhabitants gather and meet. It has a total area of 82 ha, including buildings, gardens, public places, and palm groves.

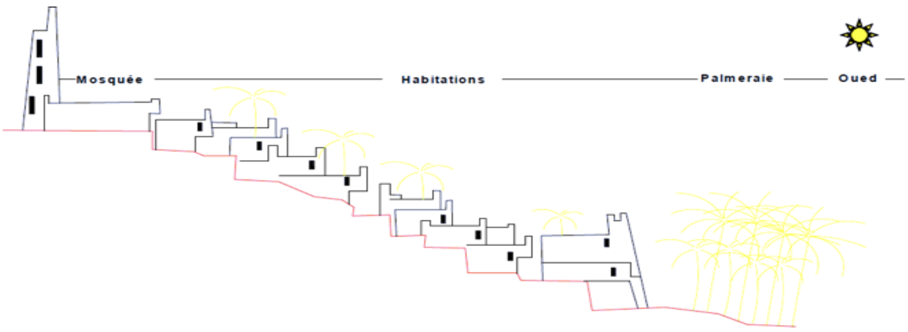



***Figure 3.14 A view of the ksar of Ben Isguen's urban section (source: Ali-Toudert 2007).***

### 3.3.1 Urban Data:

**a-General Principles:** The urban layout of the ksar of Beni Isguen is such that every 100 m, a street in the direction of the contour lines can be found, while one can be found every 50 m in the opposite direction. The existence of a ksar depends directly on the availability of water resources, a condition that ensures the creation of palm groves, which act as vital microclimates essential for human habitation Figure 3.15.

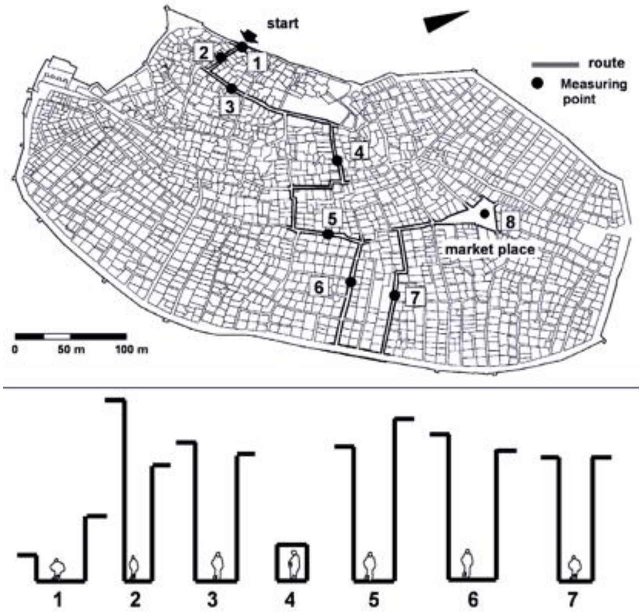



*Figure 3.15 Beni Isguen routes with the measuring points at different positions (source: Ali-Toudert 2007).*

Certain writings report that to accommodate demographic growth in the ksar, once population growth exceeds the capacity of a mosque, another must be built and a new city be founded around it (Chabbi ,1985). This rule has been a constant principle in the urban development of ksour over the centuries. It would not be surprising if it were followed for the construction of the new ksar of Tafilelt as well. The fortified morphology of the ksour still reminds us of the historical need to protect them from external threats and help them survive various bioclimatic conditions. To ensure this, compliance with the required town planning rules, architectural design principles and construction techniques is essential. The following points describe the urban scale, scale of the buildings, architectural scale and construction to help one better understand the characteristics of a ksar:

**b-Urban Scale:**

- In winter, rocky peaks overlooking the valley shelter the houses from floods. In summer, the houses enjoy cool air conditions despite the city being ‘overheated’. This is because they are built at the level of the palm groves.
- The circular view around the piton facilitates the defence of the city alongside the rampart, helping to get a better look at the nomads and strangers approaching the ksar.

- The highly compact urban morphology is a result of the climate and social practices, the southern orientation, which shields the area from the northerly winds, and a regular and radial concentric adaptation of patio houses with the mosque at the top. Moreover, the streets are narrow and sometimes firmly protected by corbels, extensions on the houses or lightly protected by trellises or tarpaulins Figure 3.14.
- The influence of the covered passage manifests itself in a strong acceleration of the air even when the winds are weak (less than 1 m/s on average) above the roofs. Under these conditions, unlike open streets where the average air flows do not exceed 0.3 m/s, air movements with an average intensity of 0.6 to 0.7 m/s and a maximum instantaneous value of 1.5 m/s are observed in the ksar under a covered passage of 15 m length. These light winds, highly appreciated in summer, play a significant role in street ventilation.
- A reduction in exposed surfaces, with the exception of terraces and the frontage of the street, reduces the impact of solar irradiation.

**c-Buildings' Scale:**

Many buildings are clustered and arranged the same way around the Centre in a hierarchy that results in the ksar. All the ksour are established, generally, according to common morphological principles. They share a succession of significant historical events, which creates a strong social cohesion between the population.

**d-Architectural Scale:**

The beauty, deep harmony and unity of thoughts emerging from the architecture of M'Zab are the aspects that immediately strike the imagination of the researcher. Its beauty can be found in its almost-organically curved lines, which harmonise the pastel shades of blue, ochre and white, making the sun dissolve in their ambient light. Houses with patios to deal with the impact of the extreme climate characterise the ksour of M'Zab. Organised in the middle of the house, the patio is very often fully covered but has an opening (chebek) at the top and in the Centre, which, more or less, provides air and light. The houses are linked to the street by a chicane entrance called squifa, designed to maintain the residents' privacy. As seen in Figure 3.16, it also has the following features:

- A distribution of space on two levels, with some sun exposure. According to Orf (local town planning law), there are certain guidelines to be followed, such as one house cannot cover the neighbouring one (to allow sun exposure) and should respect the inhabitants' privacy.
- An introverted structure that does not open directly to the outside.
- A distribution of parts around the patio and terrace. A concept first taken up by André Ravéreau for his economic housing project in Sidi-Abaz (Figure 3.16), it facilitates ventilation through doors, cracks in thick walls and the chebek of the patio.

- A superposition of the patios to reduce the heat in the functional terrace, which is reserved for women and used by them for sleeping at night. It is made up of a heavy flat slab that reduces the heat transfer in the house through convection.
- A cellar which, through the thermal inertia of the soil, provides freshness during day.
- the orientation generally on the south to benefit from the sun's rays during the winter, which become vertical in summer
- A height defined by the maximum of the sun in winter (approximately 33° at noon Figure 4.14) to allow the neighbouring façade to benefit from the sun's rays.
- The covered/open spaces in the form of arcaded galleries, generally south-oriented, to take advantage of the ambient heat in winter.
- The use of suitable heavy construction materials (e.g., stone), characterised by a high heat capacity. It is the most preferred method despite these materials being poor insulators in general. However, they store solar energy and dissipate it at night-time with the help of natural ventilation, thus ensuring better thermal comfort conditions. The method is, therefore, a potential asset for bioclimatic construction.

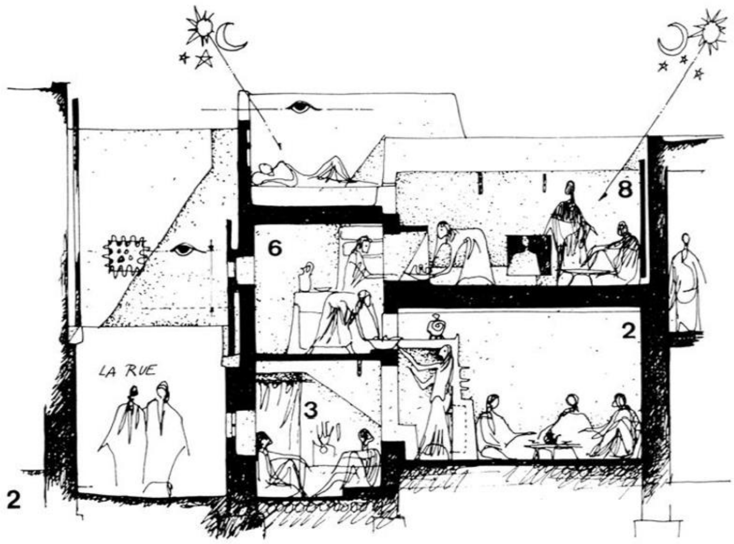



***Figure 3.16 A section of a traditional house in Beni Isguen (André Ravéreau.1989).***

**e-Constructive Scale:**

Traditional knowledge and know-how in the face of a hostile environment coupled with few resources require the development of techniques that can facilitate the better use of water and land regardless of whether their availability is perennial or cyclic. In sedentary establishments, the need for protection from wind and sun is manifested in the design of architecture and town planning. It has led to the formulation of suitable technical solutions and their combination with art, giving homes and urban fabric a particular aesthetic. In the M'Zab valley, the main features of the buildings are rationality and simplicity, incorporating the use of materials that harmonise perfectly with the environment in particular:

- Stone: Coarse blocks of variable dimensions are extracted from the regular strata of white limestone without being pruned. Flat stones are reserved for horizontal fittings.
- Sand: Given its clayey texture, it is used to compose binders for mortar.
- Timchent: It is a sort of traditional plaster, grey in colour, obtained from a hydrated gypsum found in the chebka.
- Lime: Carbonates are abundant in chebka. Their calcination, similar to that of timchent, is carried out in furnaces about 2 m in height; however, they require five to six times more wood.
- Palm tree: This tree, fully usable, is not used until after its death. The construction employs the stipe (or trunk) for beams or carpentry planks, while the palm and the sheath (base of the palm rib) is used for support because of its resistance.
- In addition, if the inhabitant takes its architectural forms from a cultural tradition, the building concept creates its appearance, texture, colour and typology of the building, the elements of the construction are made according to the same technical rules, which cover:
- **Foundations:**

Foundations do not exist as such. The natural soil of the ksour is mostly composed of rocks. In this case with use of the palm trunk on sandy soil, the stone wall begins, and allows the wall to stand on compact sand. Good soil is always kept close to the surface.

- **Supporting Elements:**
  - **Walls:** They are composed of rubble, more or less large, which form an irregular masonry. The thickness of exterior walls varies along the base, reaching nearly 1 m: further, the parapet wall always between 1.50 and 1.80 m high, for privacy considerations.
  - ❖ **Pillars**: They are made up of rubble. Although timchent is the predominant material, pillars can also contain clayey sand. Their dimensions vary between 0.2 and 1 m height.
- **Horizontal Crossing**:

Space crossings constitute two types: linear crossing (beams, lintels and arches) and surface crossing or cover (floors, vaults and domes).

❖ **Linear crossing:**

*3)* **Beams and lintels:** large pieces of wood carved from the stipe of the palm tree are used. Palm trees are readily used as a building material for house walls, rafters and roofing. The fibrous wood is pulled apart and woven together as thatch for roof covering and small posts are fashioned for hanging hammocks. This fibre is also woven to make the carpet and wall coverings and the leftover is salvaged for forage, fertilizer and firewood.

**b) Arches:** They are made of rubble stones laid over successive courses using two techniques: The arc can be defined by a few props when setting the timchent or by means of a lost formwork. To make arches between two pillars, the palm ribs are bent so that the pillars are sealed with timchent and then mounted to the rubble.

❖ **Surface crossing:**

a) **Floors**: For the supporting structure of the floors, joists made from dried palm stems are used. These joists are 2 to 2.50 m long, and they are arranged in a triangular manner. They are spaced from 30 to 60 cm apart. The ceiling is constituted either by a tight lath of palm ribs, flat stones or vaults formed of stones linked to the timchent between the joists (Figure 5.30). On terraces exposed to air, sun and rain, this base is then covered with a groomed sand layer up to 30 cm thick, which serves as thermal insulation, and protected by a screed lime mortar, whipped with a broom formed by a bunch of dates stripped of their fruits in order to fill the interstices resulting from the implementation and to obtain a better seal. The screed is finally brushed with lime milk. Its white colour reflects the sun's rays. Moreover, the colour makes it possible to fight against the phenomenon of urban heat islands. In general, the above-listed aspects allow the researcher to highlight the following fundamental principles of constructing a bioclimatic habitat for a hot and dry climate:

- Compact organisation of the houses to limit the surfaces exposed to solar rays in summer and minimise heat loss in winter.
- Southwest orientation (the first-floor portico, living room) to capture the sun's rays in winter and protect the adjoining spaces in summer while providing a shield from the prevailing winds
- Narrowness of the streets to limit the number of sun-exposed surfaces
- Sinuosity of the streets to constitute screens against the winds and sands
- Ventilation using the front door as the only opening in the lower part of the house
- A patio or central opening (chebek) to ensure a permanent thermal draft and natural lighting for the living spaces on the ground floor. The chebek is often covered over summer
- No airtightness in the openings
- Maximum dissipation of heat through natural ventilation
- Zoning of the house to shift rooms, depending on the time of the day
- Arrangement of spaces according to the course of the sun, such as the tizefri (reserved space for women), which receives the sun's heat throughout the morning during winter
- Clear raw lime renderings or a tinted light colour to reflect the solar rays (light and heat)
- The roughness of the coating surfaces of the exterior walls to cast a shadow on the wall itself.

This characteristic also allows one to see which items are unimportant or counterproductive, such as open large windows, which can lead to heat input and privacy issues, unlike the ceiling opening of the patio. It is also vital to use materials that do not return one's own heat to oneself but rather absorb it, making one feel afresh. The ideal house for this hot climate is a 'thermal mass and inertia' house built around a thermal chimney (patio), leading to a constant air displacement, which in turn cools this mass and its occupants and dissipates heat. These dwellings generate an internal atmosphere that does not exceed the limits of thermal comfort but also does not consume energy for heating or air conditioning, either.

The Mozabites now build modern houses using hollow concrete blocks of cement, on which they put large watertight glazed windows, which are then concealed with perpetually closed shutters. This endows the structure with thermodynamic air conditioning, without which residing in these buildings would be impossible.

### 3.4 Presentation of the Tafilelt Ksar:

The ksar of Tafilelt, initiated in 1998 by the Amidoul Foundation as part of a social project, is built on a rocky hill overlooking the ksar of Beni Isguen. This urban complex, comprising 870 housing units, has numerous features, such as small square streets, alleys, covered passages, playgrounds, shops, schools, sports halls, libraries, community centres and religious facilities (Balalou 2008). It is considered to be the extension of the old ksar of Beni Isguen and was built thanks to a financial package given by the Amidoul Foundation to the beneficiary – the state (the framework of the formula ‘Participatory Social Housing’) and the community. Using the architectural characteristics of the old ksar to ensure an uplift of the thermal comfort conditions in the new settlement, certain architectural principles and traditional urban planning were updated.

***Figure 3.17 A view of the ksar of Tafilelt (source: by the Author).***

The Ibadi doctrine, which is at the origin of the formation of the Mozabite community and of the creation of its cities, shaped the culture and history of the Amidoul Foundation, which is well-known for its architecture (Ravereau 1982). Moreover, in general, it also established the foundations for the ksar's structure, organisation, way of life, ethnicity, and economic base (Mumphord 1964). When deciding how to construct their dwellings, the Mozabites use religion as their primary base before considering factors like security, climate, and geography. Quite often, ritual prescriptions preside over the mode of housing group (Moussaoui 2006). It is on this basis that the urban characteristics and architectural features emerge.

### 3.4.1 Urban Scale:

- The highly compact urban morphology is a result of the climate and social practices, the southern orientation, which shields the area from the northerly winds, and a regular and radio concentric adaptation of patio houses with the mosque at the top. Moreover, the streets are narrow and sometimes firmly protected by corbels, extensions on the houses or lightly protected by trellises or tarpaulins.
- The influence of the covered passage manifests itself in a strong acceleration of the air even when the winds are weak (less than 1 m/s on average) above the roofs. Under these conditions, unlike open streets where the average air flows do not exceed 0.3 m/s, air movements with an average intensity of 0.6 to 0.7 m/s and a maximum instantaneous value of 1.5 m/s are observed in the ksar under a covered passage of 15 m length. These light winds, highly appreciated in summer, play a significant role in street ventilation (Kitous et al 2006).
- A reduction in exposed surfaces, with the exception of terraces and the frontage of the street, reduces the impact of solar irradiation.
- The shape adheres to a principle of organicity wherein a distinction is made between the different appropriation and environmental scales (Zune 1994).
-

### 3.4.2 Architectural Scale:

A house in the ksar of Tafilelt has the same characteristics as that of an ancestral house:

- A distribution of space on two levels, with some sun exposure, according to Orf's town planning law.
- An introverted structure that does not open directly to the outside (Cuperly 1987).
- A distribution of parts around the patio and terrace. It is a concept first taken up by André Ravéreau for his economic housing project in Sidi-Abaz (Ravéreau 1983).
- A superposition of the patios to reduce the heat in the interiors (Kitous et al. 2006).
- A functional terrace, which is reserved for women and used by them for sleeping at night. It is made up of a heavy flat slab that reduces the heat transfer in the house through convection (Ali Toudert et al. 2005).

- A cellar which, through the thermal inertia of the soil, provides freshness during day (Kitous et al. 2006).
- Generally the house oriented to the south to benefit from the sun's rays in winter and the rays that become vertical in summer.
- A height defined by the maximum of the sun in winter (approximately 33° at noon [Figure 3.2.4]) to allow the neighbouring façade to benefit from the sun's rays (Ali-Toudert et al. 2005).
- The covered/open spaces in the form of arcaded galleries, generally south-oriented, to take advantage of the ambient heat in winter.
- The use of suitable heavy construction materials (e.g., stone), characterised by a high heat capacity. It is the most preferred method despite these materials being poor insulators in general. However, they store solar energy and dissipate it at night-time with the help of natural ventilation, thus ensuring good thermal comfort conditions. The method is, therefore, a potential asset for bioclimatic construction.

### 3.4.3 Constructive Scale:

Traditional knowledge and know-how in the face of a hostile environment coupled with few resources require the development of techniques that can facilitate the better use of water and land regardless of whether their availability is perennial or cyclic. In sedentary establishments, the need for protection from wind and sun has manifested in the design of architecture and town planning. It has led to the formulation of suitable technical solutions and their combination with art, giving homes and urban fabric a particular aesthetic (Sidi Boumediene et al. 2003). In the M'Zab valley, the main features of the constructions are rationality and simplicity, incorporating the use of materials that harmonise perfectly with the environment, insofar as they are extracted on site (Benyoucef 1994). We find, stone, sand, timchent (traditional plaster), lime and palm. If the habitat takes its architectural forms from a cultural tradition, the building concept affect its aspects, texture and colour (European Commission MEDA-Euromed inheritance and COR-PUS (Construction, Rehabilitation, Heritage Use 2002) and building typology, where the building is executed according to the elements and characteristics are mostly the same.

**The foundations**

Foundations do not exist as such. The natural soil of the ksour is mostly composed of rocks, which that help build the wall on sandy soil, where always kept the good soil close to the surface.

**Supporting elements**

The walls (imouran in Berber) are composed of rubble, more or less large, which form an irregular masonry. The thickness of exterior walls varies along the base, reaching nearly 1 m; further, the acroterion, measuring, for privacy considerations, between 1.50 and 1.80 m high, is only 15 cm in thickness. The binder is often composed of lime and sand. The pillars (amoud in Berber) are made up of rubble. Although mortar and sand are the predominant materials, pillars can also contain clayey sand.

❖ **Horizontal crossing**

Two types of space crossings characterise a Mozabite house: linear crossing (beams, lintels, and arches) and surface crossing or cover (floors, vaults, and domes). For beams and lintels, large pieces of wood carved from the stipe of the palm tree whose ends are embedded in the timchent are used. The palm tree is delicate because of its fibrous texture and possesses low resistance; this is why these beams and lintels are extremely sensitive over time, which urges the residents to treat it with special paints to live longer. On the other hand, arches are made of rubble stones laid over successive courses using two techniques: The arc can be defined by a few props when setting the timchent or by means of a lost formwork. To make arches between two pillars, the palm ribs are bent so that the pillars are sealed with timchent and then mounted to the rubble.

**a)** For the supporting structure of the floors, joists made from dried palm stems are used. These joists are 2 to 2.50 m long, and they are arranged in a triangular manner. They are spaced from 30 to 60 cm apart (MEDA-Euromed and CORPUS 2002). The ceiling is constituted either by a tight lath of palm ribs, flat stones or vaults formed of stones linked to the timchent between the joists (Donnadieu et al. 1986). On terraces exposed to air, sun and rain, this base is then covered with a groomed sand layer up to 30 cm thick, which serves as thermal insulation, and protected by a screed lime mortar, whipped with a broom formed by a bunch of dates stripped of their fruits in order to fill the interstices resulting from the executing operation and to obtain a better sealing. The screed is finally brushed with lime milk. Its white colour reflects the sun’s rays. Moreover, the colour makes it possible to fight against the phenomenon of urban heat islands. As for the vaults, their construction is based on the same technique as that used for arches.

The Tafilelt ksar project aimed at making housing accessible to everyone, without undermining the natural environment and upholding ancestral traditions based on faith, self-reliance and mutual aid. It is noteworthy that while respecting the requirements of the comfort of contemporary housing, Tafilelt – which considers the traditional principles of urban and architectural scales and combines practices and values of social cohesion promoted by the Touiza – was completed in ten years (2006).

### 3.4.4 Urban Scale:

**a-Compactness of Tafilelt:** The ksar is organised to incorporate a road system with a rectilinear geometry, a profile wider (3.50 m) than that of the streets of the old ksour for the requirements of modernity (the car), where the roads were designed deeper and intersect at right angles. The houses occupying the entire plot are constructed side by side as much as possible (Figure 4.18), making it possible to reduce the surfaces exposed to direct sunlight, except for the main façade and terrace. The introversion of homes, through their organisation around a courtyard, greatly reduces the number of surfaces exposed to the exterior (Ghrab 1992). This makes it a suitable solution for the prevailing climatic and social situation.

*Figure 3.18 The Tafilelt ksar and its compact organisation (source: Google image).*

**b- Solar Exposure:** The analysis of the sunshine at the Tafilelt site is based on the study of the streets' geometry. At the level of the general organisation, the road structure is of a hierarchical chessboard type (regular layout) where the streets are oriented in two main directions (east–west and north–south). The roads are classified into three categories:

- ❖ The primary tracks with an average width of 9.50 m, which serve the ksar with the exterior, showing a prospect (H/L) of 0.89.
- ❖ Secondary or junction tracks with an average width of 5.80 m connect the primary tracks with the service ones, presenting a prospect of 1.45.
- ❖ The tertiary or service roads are relatively narrower; they vary between 3.60 and 3.80 m, showing prospects from 2.35 to 2.22. Measurements taken at Ghardaia show that diurnal air temperature variations are very low for street prospects between 2.7 and 6.2 (Kitous et al. 2004). Regarding these reference values, the east–west streets of Tafilelt, especially the service streets whose prospect is close to 3 m, can improve their relationship to the temperatures of the vertical surfaces of the façades through small interventions. This is because the main heat gain of the façade comes from diffuse and reflected solar radiations (which depend on the albedo of the surfaces).

For primary streets with low prospect, the high rate of the reflection of solar radiation causes overheating of the southern walls. In this regard, protection by vegetation would be most preferred. Conversely, horizontal walls such as wide street surfaces are highly exposed to direct sunlight.

**c- Natural Ventilation:** The Tafilelt ksar, located on a plateau overlooking the M'Zab valley, is exposed to the winds from all directions (Figure 4.17), compared to the palm grove which is able to protect itself through its self-sufficient behaviour. In the ancient ksour, the association between the geometry of the streets (high prospect, sinuosity and oblique orientation) and the wind direction influences the attenuation of the flow velocity of air, unlike in the Tafilelt ksar, because of its location on a plateau, many elements that greatly promote the penetration of the wind, like the roads orientation at the summer and the winter, which caused the inhabitants embarrassment.

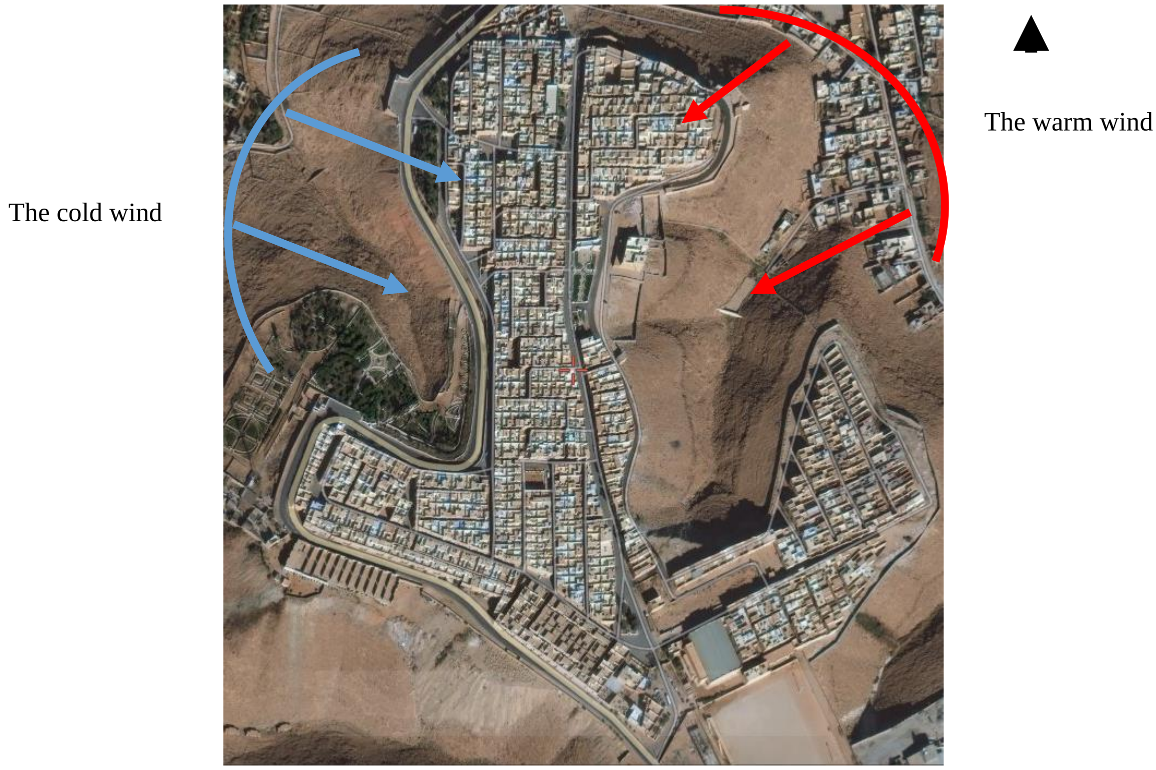



*Figure 3.19 The wind directions in Tafilelt (source: Google maps).*

### 3.4.5 Architectural Scale:

**a- Form:** The shape (form) has an important role with regard to the distribution and number of the walls in contact with the outdoors. To limit the fluctuations in interior comfort due to exterior phenomena (sun, wind, etc.), it is the rule to seek as much interior space as possible in order to minimise the surface area of the exterior walls. The rectangular shape of the Tafilelt houses, combined with a joint ownership with the neighbouring houses, allows minimal heat loss in winter and minimal heat gain in summer. The gains and losses are limited to the walls, from the exterior façade to the terrace and openings, considering that the courtyard is covered during both the hot and cold periods.

**b- Location and Orientation:** The location of the Tafilelt ksar on a bare plateau, stretching from north to south (approximately 600m x 200 m) and being exposed to winds from all directions, makes it experience cool air temperatures (2.5 to 4°C in winter and 2 to 3°C in summer) compared to the valley, especially when the city is 'overheated' (Cote 2002).

**c- Spatial Organisation:** In a traditional house, the climatic functions of ventilation – protection and lighting – are subordinate to the morphology of the patio, as they differ between the ground floor and the upper floor(s). The lighting of various rooms on the ground floor is quite minimal. Ventilation is provided by the air currents that flow between the opening of the patio, which remains open at night, and the open front door, and a few windows at the front façade. On the first floor, the semi-closed spaces open onto the patio (in the old ksour, the patio is located upstairs) through a loggia oriented largely to the south. The loggias receive the solar radiation regardless of the season. Due to this, the first floor is well protected from the sun and becomes a daytime space, especially during the winter. As for the terrace, the most open space in the house, it is protected by parapets up to 1.80 m in height, making it an ideal space on summer nights.

In the present case study, the spatial organisation is less hierarchical than that of the traditional houses, so that the climate analysis of the organisation of spaces shows an inconsistent distribution with the principles of bio-climatic architecture applied to hot and dry environment, such as the kitchen which in direct contact with the outside (Figure 3.20), and very open to the living room. Since the living room gets overheated, it would be judicious to isolate the areas of overheating and ventilate them separately. The first floor is almost identical to the ground floor, with a narrowing of the courtyard following the cantilever of the living room in the eastern direction. This morphology of the courtyard gives it a better ventilation that is in line with the Venturi effect. Moreover, it helps provide better shade to the walls on the ground floor.

The superimposition of the windows and chebeks causes an increase in the air temperature and a decrease in the relative humidity on the first floor, the temperature reaches 39.9°C then it is 37.5°C and a relative humidity of 21.7% while it is 26.8% respectively. To avoid this overheating, it would be thermally more coherent to reinterpret the climatic operation of the chebek on the ground floor associated directly with the patio (open space upstairs). The researcher proposes the displacement of the chebek towards the corner of separation between the Tizefri and the hall so that it can dissipate the heat stored in these spaces, even during the day when all the openings are closed. Through convection, the hot air on the ground floor can rise due to the decrease in its density.

To prevent it from traversing through the floors, the chebek is insulated by a wall of heavy material (stone). Only a single opening is given on each floor to dissipate the hot air. Inspired by the Badgirs and Malkafs (Persian wind towers), the chebek is isolated from the terrace by a circular stone wall, the height of which exceeds that of the parapet (1.80 m). This enables the chebek to intercept the outdoor temperature and sandy wind through small, oriented openings to the north, northeast and east, equipped with a shutter that one just needs to open to catch the slightest breeze. Following the capture of the winds around a tank filled with water in the chebek, the air in this tank – through forced convection – starts to cool and refreshes the spaces inside the house. In addition, the well of chebek is covered to avoid the penetration of solar rays during the summer. This wind–sun coupling is a unique concept that could redefine a climate effect already used in vernacular architecture. The natural ventilation inside spaces allows the dissipation of overheating by exploiting temperature gradients through outlets producing a chimney effect, such as the thermal operation of the traditional chebek.

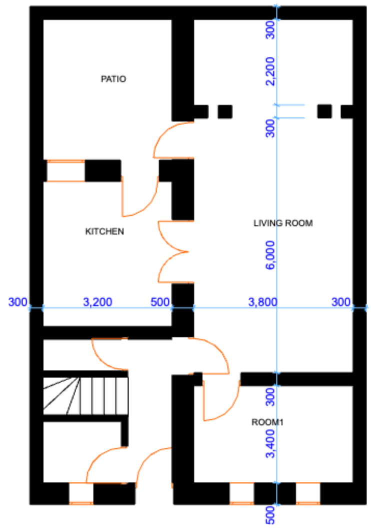



***Figure 3.20 A layout of the ground floor in the Tafilelt houses (source: by the Author).***

**d- Courtyard:** The organisation and layout of the courtyard benefits the bioclimatic aspect of the house. A courtyard with dimensions such as 4.00m x 4.00m is used to effectively provide shade. It also allows, which is unique to the ksar typology of the M'Zab valley, better natural lighting of enclosed spaces. Moreover, it can embody the role of the patio through its capacity as a thermal regulator, and it can be enhanced by using the vegetation and water to provide shade and cool the air by evaporation. Over the night, cool air is retained because of its heaviness compared to warm air. In the M'Zab valley, where dry heat and sand winds dominate, such a courtyard proves efficient since it is quite small (H/R = 3.81). The sole requirement is to not create sensitive depressions, as the dynamics of the thermal exchanges established between this courtyard and the interior space are conditioned by the morphology of the latter. In the traditional houses, the patio is likened to a court-yard placed at the centre, where insufficient lighting of the ground floor is rectified by the chebek. Thermally, this opening allows cooling during periods of strong heatwaves. In fact, in the summer, it is covered during the day to prevent the inflow of solar radiation and opened at night to allow the relative freshness to penetrate. In winter, this hole is closed during very cold nights and opened during the day to let in the sunlight in order to warm the house.

**4.4.6 Building Materials:**

The study of building materials comes down to defining their level of adaptation to the climate, which concerns the management of solar and terrestrial radiation through the walls. It looks at the materials that constitute those buildings, their thickness, and their coating. In regions where daytime temperatures are high, materials with high thermal inertia, such as adobe, rammed earth, stone, or various combinations of these elements, are used to reduce the inflow of heat, which have the characteristic of absorbing the heat during the day and dissipating it during the night via natural ventilation. The construction materials used in Tafilelt (stone, plaster) are available locally, which does not require their production, their transport which leads to reduce the excessive energy expenditure which generates pollution harmful to health and the environment. The 0.45m thick stone walls constitute the main structure construction of the house as well as all the walls on the façade.

The separation walls are made of 0.15 m thick hollow blocks (concrete chipboard). As for the exterior cladding, the designers and builders of the project were inspired by traditional techniques which consist of the use of an aerial lime mortar and dune sand, which is spread over the surface of the wall using a bunch of dates, the high proportion of lime and the presence of fine sand allow better malleability mortar. The use of the palm tree branch allows the texture of the surface to be roughened (see figure 5.13) to provide shade to the wall and reduce excessive heating of the wall. The use of stone, associated with local lime mortar, represents a heavy material with high thermal inertia, corresponding to the principles of bioclimatic architecture and old construction techniques. The thickness of the load-bearing walls (45 cm) allows heat to be stored during the day and released at night (beneficial in winter) when the windows can be opened for its dissipation under the effect of ventilation (in summer). However, in times of strong heat, the structure ends up having absorbed so much heat that it takes more time. This phenomenon then encourages the systematic association of strong inertia with good nocturnal ventilation by chimney effect of the chebek and the volume of the courtyard.

As for the terrace floor, the part most exposed to solar radiation, the materials used are concrete for the compression slab, reinforced concrete joists that are spaced 0.65 m and plaster vaults to ensure thermal and sound insulation as well as a proper structure. The gap between the compression slab and the arches is filled by a mixture of lime and sand. Care should be taken to avoid the heat input from the walls and the roofs that receive very strong solar irradiation due to the large angle incidence of solar radiation. One of the solutions to this is to increase their insulation and inertia (Givoni 1998) by offering reflective surfaces to the sun or by limiting the hot air infiltration into the building. The researcher proposes the use of a mortar based on polystyrene beads, over plaster, to ensure good thermal performance. The multitude of measures undertaken by the applied research unit in the renewable energies' centres of Ghardaia and Bouzaréah (Koussa et al. 2006) indicates a high level of lighting. To exploit this energy resource for thermal comfort, especially during the winter, the thermal insulation of exterior surfaces and the interior of the walls facing the exterior can be reinforced. This also includes the insulation of courtyards built in agglomerate (hollow concrete blocks with a high thermal conductivity of 0.8 W/m°C). The proposed insulation, within the framework of the principles of sustainable development, is made of local natural materials sourced from the restoration of the trunks and branches of palm trees cut in autumn.

### 3.4.7 Openings:

The glazing of windows has a significant impact on air conditioning use, which can represent a range of 50% to 80% of the total load of air-conditioned premises (Bougriou et al. 2000). For this reason there was considerable interest in research on the openings of the houses in Tafilelt. Indeed, the designers – with the aim of allowing natural lighting – had to increase the size of the openings (0.30m x 0.70m in the old ksour, 0.50m x 0.80m for the bedrooms and 0.40 m x 0.80m for the kitchen) to provide a French window opening onto the courtyard for the stays. However, to limit the heat inflow, the designers developed a form of sun protection reminiscent of the moucharabiehs of Muslim houses. This mode of protection covers the entire surface of the window with a lattice while providing natural light through the openings. For a better climate adaptation, a white paint is applied as well. However, considering the very high temperatures in summer, double glazing is necessary to increase the insulation effect.

## 3.5 Summary:

It can be summarised from the study of the Tafilelt ksar that certain urban and architectural principles for better climate integration are an improvement upon those used in the ancient ksour. The objective of its construction was to create thermal comfort through urban practices while respecting the existing ecosystem, ensuring compactness (to reduce the surfaces exposed to adverse outdoor conditions) and synchronising the orientation of the streets with the aeraulic conditions prevailing on the plateau. At the architectural level, a set of architectural principles, spatial organisation, socio-cultural requirements, and arid climate constraints were considered and handled in line with the old principles.

The aim behind the analysis of the new Tafilelt ksar is precisely to show that one can still provide general and social housing in harmony with the climate and its inhabitants by considering the traditional habitat as an architecture lesson and bioclimate as a basic principle. The case study of Beni Isguen ksar gives one a good lesson on development techniques that existed long before the conceptualisation of sustainable development.

# CHAPTER
# IV
# RESEARCH DESIGN
# AND METHODOLOGY

# CHAPTER IV

## Research Design and Methodology

This chapter presents the research philosophy and methodological frame-work, which includes the research design and the methods employed when carrying out the required investigations to answer the research questions and reach the desired goals. The chapter starts with outlining the relevant research philosophies and how they fit with the nature of this thesis and then moves on to the detailed framework.

### 4.1 Introduction:

This chapter outlines the survey and monitoring methods utilised for this investigation. Through the field studies, these sets of goals were tried to reach: first, the study tried to get a full picture of how people feel about their thermal comfort in buildings through thermal comfort surveys; second, the environmental performance of existing buildings around the selected case studies for monitoring in the hot, dry climate of Ghardaia was gathered through post-occupancy surveys and environmental monitoring; and third, dynamic building simulation was used to try to predict how buildings will behave in the future.

The research philosophy and methodological framework presented in this chapter include the research design and the procedures used to conduct the necessary investigations to answer the research questions and achieve the study's aims. This chapter first provides an overview of the appropriate research philosophies and how they relate to the focus of this thesis, before moving on to the specific framework. For the purpose of this research, both quantitative and qualitative research methodologies were selected .

Two sample dwellings in each community (Tafilelt and Beni Isguen) were monitored to determine the indoor and outdoor temperatures and relative humidity levels as part of the quantitative study technique. This was used in a comparison of thermal performance to help draw attention to the variances.

Eighty participants, including occupants of the house being measured and of neighbouring buildings, were questioned according to a set process. using a predetermined protocol for the qualitative research approach, and their responses helped the researcher gain a richer understanding of the participants' experiences in all four homes. After reviewing the relevant literature, the researcher decided on a mixed research methodology approach because it is clear that quantitative data plays a major role in defining the primary differences between the two settlements and because no data currently exists to reflect this comparison for this region. Berman Brown and Saunders (2008) echoed this point, noting that quantitative data is quantitative, making it suitable for statistical analysis or other evaluation of disparities, levels of impact and influence, or whatever the subject of study may be. The survey was utilised to shed light on domestic comfort, which was based on the effectiveness of both traditional and contemporary architecture, and the results were used to establish a causal relationship between the two sets of data.

The aforementioned methods helped the researcher comprehend the distinctions between the two structures as well as the residents' perspectives on life in each community. As a natural consequence, this will be used to shape the area's architectural future.

## 4.2 Data Collection Procedure and Strategy

This section will discuss the ethical clearance, subjective questionnaires' (post-occupancy and comfort survey) development, subjective questionnaires' testing, and target population and sampling.

### 4.2.1 Ethical Clearance

The University of Kent's Faculty of Humanities Research Ethics Advisory Group for Human Participants has reviewed and approved the following materials:

A summary of the research project and its significance for understanding the existing situation and prospects to improve the houses was included in the Participant Information Sheet. The plan for putting the acquired data to use in this study is laid forth as well.

A consent form to record that participants agree to participate in the study after reading the information sheet and realising that their responses will be deidentified before analysis.

-Residential Comfort Survey with Three Parts:

(1) General Information.

(2) Energy Use Data from Building Attributes.

(3) A Description of Indoor Temperature and Humidity.

The thermal comfort of these homes was assessed with a daily comfort survey. According to the guidelines laid out by the Data Protection Act of 1998 and the principles of ethical research practice, only the approved papers were translated and utilised in the course of conducting the survey.

### 4.2.2 Target population

There was a comparison made between the family sizes in Tafilelt and Beni Isguen, which led to the selection of a description of the building type in both communities. The main way they were defined was as occupied buildings with two storeys or less.

### 4.2.3 Sample selection and sampling

Community meetings, satellite maps from Google Earth and Google Maps Pro, and visits to these places were used to find the neighbourhoods, individual homes, and streets. The households that participated in the survey were selected through the use of a method called multi-stage area sampling. The census of housing types was carried out in both the new and the old communities, with geographic affinity and socioeconomic variables determining which community received which sort of survey. In the fourth chapter, the selection process is considered more clearly. These case study locations were selected for the post-occupancy survey. Also, two homes were chosen for monitoring at the same time in the different ksars of Tafilelt and Beni Isguen. This brings the total number of houses for the comfort survey and environmental monitoring in the four places in both ksars to four.

The post-occupancy locations chosen were reflective of Ghardaia's low-income and low-middle-income residential distribution.

### 4.2.4 Questionnaire:

During the hot and cold seasons, the study collected samples from occupants of the comfort survey dwellings to learn more about their thermal comfort in the dwelling. The purpose of the post-occupancy study was to compile a comprehensive profile of the dwellings in Ghardaia. The assessments were also intended to provide a complete picture of how thermally comfortable the dwellings have been and how they well perform for their occupants.

The ASHRAE Standard 55 served as the foundation for the questionnaire's layout. The study began with an introduction detailing its aims, followed by a main body that looked into how people's perceptions of temperature in indoor transitional spaces affected their comfort levels. There were three distinct parts to the questionnaire's main section's content:

**-Section 1:** is for gathering relevant personal information, such as participants' gender, age, occupation, and what they wore when taking the questionnaire survey.

**-Section 2:** looks into participants' interactions with the building and the interior transitional area they occupied.

**-Section 3:** looks into how participants rate their thermal satisfaction, sensation, and preference. Thermal satisfaction is graded on a 5-point scale ranging from very poor to very good. The

ASHRAE 7-point thermal sensation vote scale is used to assess thermal sensation (i.e., -3 cold, -2 cool, -1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, and 3 hot). The temperature preference will depend on how the occupants want the temperature to change.

The questionnaire was completed after **57** questions were answered., and the data was analysed using the statistical software package SPSS for quantitative data analysis. Mean and standard deviations were used to describe the data, and the results from the two types of buildings were compared in a fair way.

A separate Arabic version was made so that participants who don't speak English can understand and answer correctly.

### 4.3 Comfort Surveys:

In addition to taking physical measurements, a comfort survey was also conducted to see how the weather affected people inside the building throughout the year.

Subjective questions were included in the comfort survey as did Darby and White (2005), Adekunle and Nikolopoulou (2014), and other researchers to find out how the users felt about seasonal heat and cold.

For the comfort survey, four dwellings were chosen, and each day, the occupants of those homes filled out a questionnaire about their level of comfort, the insulation provided by their clothing, and their preferences. In addition, during a week in both the hot and cold seasons, residents' reactions to discomfort were measured at various times of the day, including the morning, afternoon, and night.

The entire comfort survey consisted of only 26 quick questions and took no more than 5 minutes to complete. The poll starts with several demographic questions like "how old are you?" "what gender are you?" and "where do you now live?" Participants were asked to rate how warm or cold they felt, how comfortable they were, and how they would have ideally liked to be (See Questionnaire Appendix 1 and 2). Furthermore, residents were polled on how they prefer to regulate the temperature in their living spaces, using a variety of alternatives such as venting the space with an open window or door, turning on an electric fan or the air conditioning and heating system, or using a hand fan. Also looked at were the things people did in the last 15 minutes, like watch TV, cook, walk, read, etc.

The occupants were given a selection of clothing options consistent with the ASHRAE standard, from which they could choose the items they were wearing at the time of the survey.

The whole survey is provided in both Arabic and English in Appendix 1and 2.

### 4.4 Environmental Monitoring

#### 4.4.1 Data Collection Strategy

Site measurements, a survey questionnaire, and software simulation are all components of the mixed technique described in the next section.

#### 4.4.2 On-site measurements:

During this stage, the monitoring of the indoor climate of residences in both building locations (Tafilelt and Beni Isguen) to measure air temperature and humidity was carried out during both winter, which was the coldest period within the region (01/01/2019 to 30/01/2019), and summer, which was the hottest period within the region (01/08/2018 to 30/08/2018). This was done to compare the results of the measurements taken during winter and summer.

#### 4.4.3 Outdoor monitoring:

Figure 4.1 shows the placement of a single HOBO logger at a height of 2.5 metres within a narrow street in Beni Isguen. This was done in order to monitor the microclimate of the environment and to compare the differences in the microclimates of the urban vernacular settlement of Beni Isguen and the urban modern settlement of Tafilelt. The HOBO sensor was hung from the wall at an angle and put in a radiation shield to keep the loggers from getting any direct sunlight and giving falsely high readings.

***Figure 4.1 A HOBO data logger was placed outside of Beni Isguen houses (source: by the Author).***

#### 4.4.4 Indoor Monitoring:

In order to verify and analyse the indoor thermal performance and conditions, it was necessary to conduct indoor site monitoring to compile a database of indoor air temperature and relative humidity levels. Each dwelling had three rooms: a bedroom on the first floor , a living room combined on the ground floor, and a patio in the back. The loggers were assigned to various rooms within the dwellings.

*Figure 4.2 A radiation shields was placed outside of Beni Isguen houses (source: by the Author).*

## 4.5 Installation of loggers and radiation shields:

### 4.5.1 Data loggers

Indoor climatic data, such as relative humidity and dry-bulb temperature, were captured by the HOBO data loggers during the course of the winter and summer. Each dwelling had a bedroom on the upper storey, a bedroom on the first floor, a living room on the ground floor, and a patio outside the living room that were all monitored every 15 minutes. It is important to note that the loggers were placed further away from these sources at a height of 2 m from the ground so that young occupants could not reach them, as recommended by ANSI/ASHRAE Standard 55 guidelines and Occupants' guidance regarding the most used places within the dwelling and where heaters/air coolers are used within the space. Despite the fact that this is taller than what ASHRAE recommends, the researcher found that it would not have a substantial impact on the overall evaluation (1.10 m). Before being installed, each data logger utilised in this study underwent a thorough calibration in accordance with the manufacturer's instructions to ensure precise results. Four hours before the commencement of measurement, the loggers were set up. Through HOBO ware pro V.4.1, the HOBO data logger was connected to the computer. This made it possible to manually transfer and store data about the temperature and relative humidity inside.

### 4.5.2 Radiation shield

During the dry season in Ghardaia, temperatures can soar to 45°C outside due to the prolonged hours of sunshine (Easy Weather station, 2017). Therefore, it was important to reduce the impact of sunlight on readings of air temperature and relative humidity. The data recorder was shielded from radiation and severe weather like rain, wind, and hail by an enclosure. The logger and radiation shield were set up 2.5 metres off the ground. Wall brackets found in old building were used to hold the screen 500 mm away from the exterior wall (Figure 4.3 and 4.1).

***Figure 4.3 data logger was installed at a height of 2.5 metres above the ground (source: by the Author).***

**HOBO loggers:**

The HOBO U10-003 is a temperature and relative humidity data logger that has the capacity for 52,000 measurements and features a resolution of 10 bits. It also has two measurement channels. Launching the logger from a computer, where the data can be read out, is accomplished by a direct USB link. It comes equipped with the following characteristics (Onset 2012):

**Measurement range:**

- ❖ Temperature: –20 to 70°C (–4 to 158°F)
- ❖ Relative humidity: 15 to 95%

- **Accuracy:**
  - ❖ Temperature: ± 0.53°C from 0 to 50°C
  - ❖ Relative humidity: ± 3.5% from 25 to 85% over the range of 15 to 45°C
- **Response time in airflow of 1 m/s (2.2 mph):**
  - ❖ Temperature: 10 mins, typical to 90%

- ❖ Relative humidity: 6 mins, typical to 90%

### 4.6 Thermal assessment

The relative humidity and air temperature were recorded and exported to Excel for data analysis for the positions under consideration. Since the researcher could not identify any local standard defining the range of what is considered a pleasant temperature (Tcomf), ASHRAE 55 was used since it is generally used in such investigations. ASHRAE 55 anticipates the acceptable range of indoor operative temperature as well as the mean outdoor air temperature that can be employed in locations that do not have an active cooling or heating system. According to the ASHRAE 55, 2013 standard, there is a 0.31K per K linear relationship between mean outdoor air temperature and pleasant temperature. This model takes into account two acceptable limits for indoor temperatures: 90 and 80%, with 5 K and 7 K between the lower and upper temperatures.

A number of studies in hot regions employed the ASHRAE 55 model and found that it can be used in situations where cooling systems are not available (see e.g. Nicol et al., 1999; Wong et al., 2002; Bouden and Ghrab, 2005; and Indraganti, 2010).

As globe thermometers were not available at the time of the study, the researcher made the assumption that the average of the indoor air temperature and the mean radiant temperature (ANSI/ASHRAE Standard 55, 2010, page 13) are within a similar range. Because of this, the researcher assumed that the average temperature of the air and the mean radiant temperature were within a similar range.

The comfort equation for naturally air-conditioned buildings, which is generated from the RP884 ASHRAE database, serves as the foundation for the zones:

Tcomf is the best temperature for comfort and To is the mean outdoor temperature for the survey. Tcomf may be calculated using the formula $T_{comf} = 0.31To + 17.8$.

While $T_{accept} = 0.31T_o + 17.8T_{lim}$, where $T_{accept}$ gives the limits of the permissible zones and $T_{lim}$ represents the range of acceptable temperatures (80% if $T_{lim} = 3.5$ K, 90% if $T_{lim} = 2.5$ K), it is important to note that $T_{accept}$ does not take into account the temperature itself.

For the purpose of this research, the standard was used; nevertheless, the researcher felt that a regional standard might more accurately represent the area if it were more specific.

### 4.7 Software Simulation:

The meteorological data that was acquired was utilised for simulation analysis in order to validate the results and optimise the indoor thermal performance of the structures that were used as residences in Ghardaia.

Understanding energy is one of the many elements that influence the design of a building. In general, the design of a building is based on a variety of factors. As a consequence of this, simulation software has been utilised in recent decades in order to provide a more comprehensive grasp of the building design, taking into account the thermal comfort of the occupants as well as an overview of the manner in which a building behaves under a variety of different conditions.

In this regard, the thermal modelling creation and analysis of these residential buildings was carried out with the assistance of Design Builder, detailed in Chapter 7. The software was version 7.0, and it was obtained from the Kent School of Architecture. In addition to using the material that is accessible on the Design Builder website, multiple training online sessions were held on the use of the software.

In a nutshell, in order to accomplish what was set out to do with this research, the following activities were carried out:

Before this research could go forward, the ethics committee at the University of Kent had to give permission.

Temperature and relative humidity readings were taken using Hobo loggers, which were placed both inside and outside the chosen dwelling.

The people living in both homes were invited to fill out the survey at the same time that measurements were being taken.

Using computer simulation, additional work was done to improve the layout of future homes (being built).

**4.8 Summary:**

In this chapter, the researcher described the research approach that was taken. The research philosophy, methodology, study layout, sample size, and data collection strategies were all highlighted. In addition, the study's limitations were outlined, as were the ethical standards that were upheld during the course of the research. In Chapter 5, "Results," there is an overview of the study's most important findings, along with an interpretation of those findings in light of the literature review and the chosen methodology.

The purpose of this research was to examine the actual and ideal indoor conditions of Ghardaia's residential buildings and the perceptions of the city's residents. The first was a post-occupancy survey of homes similar to those in the case study buildings. They helped to round out the findings of the separate case studies and provided further evidence for those findings.

The second part, environmental monitoring, included recording data on the air temperature, relative humidity, and solar radiation outside the four homes for the comfort survey during the dry and rainy seasons.

A thermal comfort survey, in which residents are polled three times a day about their level of thermal satisfaction, was the third chosen approach (using the seven-point ASHRAE thermal sensation scale and a five-point preference scale). These numbers were used to back up numbers that were measured physically at the same time.

The fourth method modelled four of the ten houses monitored during the survey using the dynamic thermal simulation application DesignBuilder to fully comprehend the thermal circumstances when the modifications were made to improve the indoor conditions. As part of the simulation work, two buildings were chosen, one from each of the two case study locations; one with natural ventilation and one with air conditioning. These representative case studies accurately reflected the region under investigation.

# CHAPTER
# V
# FIELDWORK AND SURVEY

# CHAPTER V

## Fieldwork and Survey

This study employed post-occupancy surveys, environmental monitoring of the indoor environment, and comfort surveys. Chapter 4 discuss the research methodology and survey and monitoring protocol used for this study, including post-occupancy surveys, environmental monitoring of the indoor environment, and comfort surveys. The quantitative data for this study were analysed using the SPSS-16.0 statistical software and Microsoft Excel. Exploratory factor analysis is employed in the development of the scale and in the extraction and classification of the major factors. In analysing the frequency of satisfaction within the subscales, descriptive statistics were employed. Four types of building samples were subjected to an Analysis of Variance (ANOVA) test, and the resulting statistic was utilised to assess statistical hypotheses. In order to analyse the post-occupancy and thermal comfort survey, recurring themes were collected. These were combined with survey results to provide context for the findings.

Lately In this section, the research team provides a detailed assessment of the summer and wintertime physical characteristics, energy performance, and indoor thermal conditions of a representative sample of dwellings. Also investigated are the occupants' direct experience and understanding of the building's thermal behaviour and the means by which comfort can be enhanced in the two settlements. The data gathered from this type of study will be used to inform the creation of computational models and the formulation of context-specific, optimal strategies for improving the residential building stock as a whole.

In this chapter, the data from four case studies, each of which represents a group of households with similar socioeconomic characteristics, is scrutinised.

### 5.1 Survey Introduction:

Fieldwork survey was conducted in Beni Isguen and Tafilelt among the same occupants and houses during the summer and winter seasons. Measurements were taken using the Hobo data loggers in different parts of the houses to collect temperature and relative humidity values. A questionnaire survey was carried out at the same time to gather information on the way each house was used and the occupants' perceptions of comfort in the two seasons.

### 5.2 Site Measurements and Methods:

When conducting the survey to assess user satisfaction, three types of measurements were taken. First, air temperature, humidity and wind speed data were collected from the meteorological stations, located at around 2 km from the case-study areas, during the winter (01/01/2019 to 30/01/2019) and summer (01/08/2018 to 30/08/2018) seasons. Second, the microclimate conditions around the case-study areas were recorded using the Onset HOBO UX100-003 Temperature/Humidity Data Logger. Third, four spaces inside a building (living room on the ground floor, patio, a room on the first floor) were monitored during both the seasons around (from 01$^{st}$ August to 30$^{th}$ August 2018 and from 01$^{st}$ January to 30$^{th}$ January 2019). The weather data collected were used for a case-study comparison and, later, for the simulation to validate the results and adjust the indoor thermal performance of the Tafilelt buildings.

### 5.2.1 Outdoor Monitoring:

Wind velocity (v), globe temperature (Tg) and global radiation (K) were collected from the meteorological stations located around 2 km from the case-study areas. All the environmental parameters that influence human thermal comfort in outdoor spaces, including air temperature (Ta) and relative humidity (RH), were recorded using the HOBO UX100-003 Temperature/Humidity Data Logger and radiation shield mounted on the exterior wall's fence, which provided full data on the outdoor microclimate conditions and delivered an accurate climatological reading during the comfort survey. The device was programmed to take measurements every 15 minutes. The data was then downloaded and uploaded on a secure laptop and also saved a copy on a CD as a backup. All the loggers were battery powered. The data loggers and radiation shields were provided by the Kent School of Architecture. Each logger was mounted and carefully assembled on an exterior wall at a height of 2.5 M from the ground and was hung 50 cm away from the wall by tying it to a protruding surface via a wire. The temperature sensors for the logger were shielded from solar and terrestrial radiation to provide acceptable air temperature data. Moreover, the loggers were secured from the occupants to avoid any possibility of any mistakes, loss or damage.

### 5.2.2 Indoor Monitoring:

A database was created to monitor the indoor spaces in both buildings in different settlements at the same time as mentioned before and during both the summer and winter seasons. The data gathered in the process were used for air temperature and relative humidity comparison using the HOBO UX100-003 Temperature/Humidity Data Logger at living room, patio, and the first-floor room were plotted at 1.8m height from the floor which programmed to take measurements every 15 minutes, (see Chapter 3). This comparison helped verify and evaluate the indoor thermal performance. The data were then used by the design builder for analysis of the building model, which is covered in Chapter 7.

## 5.3 Questionnaire-based Survey:

A questionnaire-based survey was carried out during both the seasons. The questionnaire was translated to basic Arabic so that all the occupants, regardless of their education level, could comprehend it. Moreover, during the survey, all parts of the questionnaire were explained to the participants and the importance of their involvement in this work conveyed.

Essentially, the survey focused on identifying a perspective of the occupants who are trying to cope with the extreme and hot weather by understanding and taking into account human behaviour around the building usage.

### 5.3.1 Purpose of the Questionnaire:

Generally speaking, feedback of the occupants tend to be extremely useful as they know what to look for in a building as an improvement (Cohen et al, 2000).

In the present study, one of the main objectives was to obtain and understand a general overview of occupants' thermal satisfaction and 'preferences regarding clothing'.

The questionnaire provided two types of data: qualitative and quantitative. The qualitative data revealed the participants' perception of the existing situation and described the various difficulties faced by them. On the other hand, the quantitative data used numeric values to provide a detailed picture of the participants' indoor life. However, the question of comfort has always been examined through interviews/interactions with people 'in order to include objective votes and to correlate them with the measured climate parameters and also used the available standards for thermal comfort that were exclusively based on laboratory tests for a long time (Gossauer and Wagner, 2007).

### 5.3.2 Target Survey Area:

The field survey targeted old buildings in Beni Isguen and new buildings in Tafilelt. In this regard, a representative sample of people who have lived in residential buildings that represent different locations in both settlements was selected. Each household was given a questionnaire in summer 2018 and then in winter 2019; overall, the questionnaires were distributed as follows:

- 40 questionnaires to the Beni Isguen's occupants sample
- 40 questionnaires to the Tafilelt's occupants sample

The survey was carried out at the case-study sites with the occupants in both sites. The aim was to assess the participants' actual mean vote (AMV) on the 7-point ASHRAE sensation scale (using which environmental variables such as air temperature, relative humidity is measured) and 4-point comfort scale along with general questions about their well-being and behaviour. For more details, please see Appendix 1.

### 5.3.3 Structure of the Questionnaire:

The questionnaire was divided into two parts: residential comfort questions (e.g., personal details (age, employment status etc), building attributes and indoor thermal conditions) and daily comfort questions. The latter section covered the participants' views on thermal sensation, their preferences and the air movement and humidity. In addition, the participants were asked about their clothing choices and activities during the last hour before filling in the questionnaire (see Appendix 1).

The questionnaire had 57 questions structured into four main parts:

- Part (1) covered general information about the respondents e.g. address, gender, age, marital status, employment, socio-economic status, education level.
- Part (2) included details related to the house type and number of rooms
- Part (3) was allocated into two sections that explored the ventilation type and thermal performance.
- Part (4) gathered information about the clothing types that are usually worn by the respondents during different seasons.

There five types of questions:

1. The first type required answers in ‘Yes’ or ‘No’
2. The second set comprised multiple-choice questions
3. The third type included a series of suggestions
4. The fourth comprised open-ended questions to better describe the current situation. This was in the form of additional comments at the end of a given section that the respondent feel that they need to add to help with the analysis.
5. The fifth type assembled knowledge regarding the percentages of opening doors and windows, number of people, their occupancy hours in each room and the best orientation. These data were used as variables for the thermal simulation input.

### 5.3.4 Questionnaire Administration:

It was essential to translate the designed questionnaire into Arabic before it was distributed to the households within Tafilelt and Beni Isguen. Following the initial translation by an approved translator, there was back translation performed to ensure that the meaning of the questionnaire has not changed. It can be said that the translation process worked as the language within the questionnaire was clearly understood. The researcher conducted a short training session for administration staff, within Ghardaia City Development department describing the purpose and the contents of the questionnaire so it can be relayed to the selected respondents. The researcher with the administration staff then distributed the questionnaire and provided general instructions to the respondents in order to fill in the questionnaire.

### 5.3.5 Coding of Questionnaires:

To understand the degree of satisfaction of the interviewees, a scale was established for coding purposes as indicated in Appendix 1.

The self-administered questionnaire was reviewed and subsequently approved by the 'Sheikh' (head) a religious chief of Beni Isguen, as well as the 'Cadi' (judge) who judges on the Islamic Law. Public moral behaviour is severely regulated by the 'Azzaba' (Clergymen) who granted the researcher the permission to contact the local residents and provided the researcher with guidance on how to do that. As well as a selective interview with a priori sampling: towards specialists in the field including architects and historians.

### 5.3.6 Methods of Analysis:

Statistical Package for the Social Sciences (SPSS) Software was used for analysis, with non-parametric techniques applied for data with nonnumerical interpretations, and regression techniques used for numerical interpretations. The analysis considered a number of factors including the occupant's number, age, and gender…etc. as discussed below.

### 5.3.7 Descriptive Analysis:

The below analysis is based on 40 questionnaires completed on each settlement (in total 80 questionnaires)

**A. Number and gender:**

Figure 5.1 shows the household size in both the case-study areas categorised into three groups. Overall, small households, comprising two to four members, represented 35% of households in Tafilelt and 30% in Beni Isguen. The majority of households had five to seven members, and these represented 55% of households in Tafilelt and 58% in Beni Isguen..

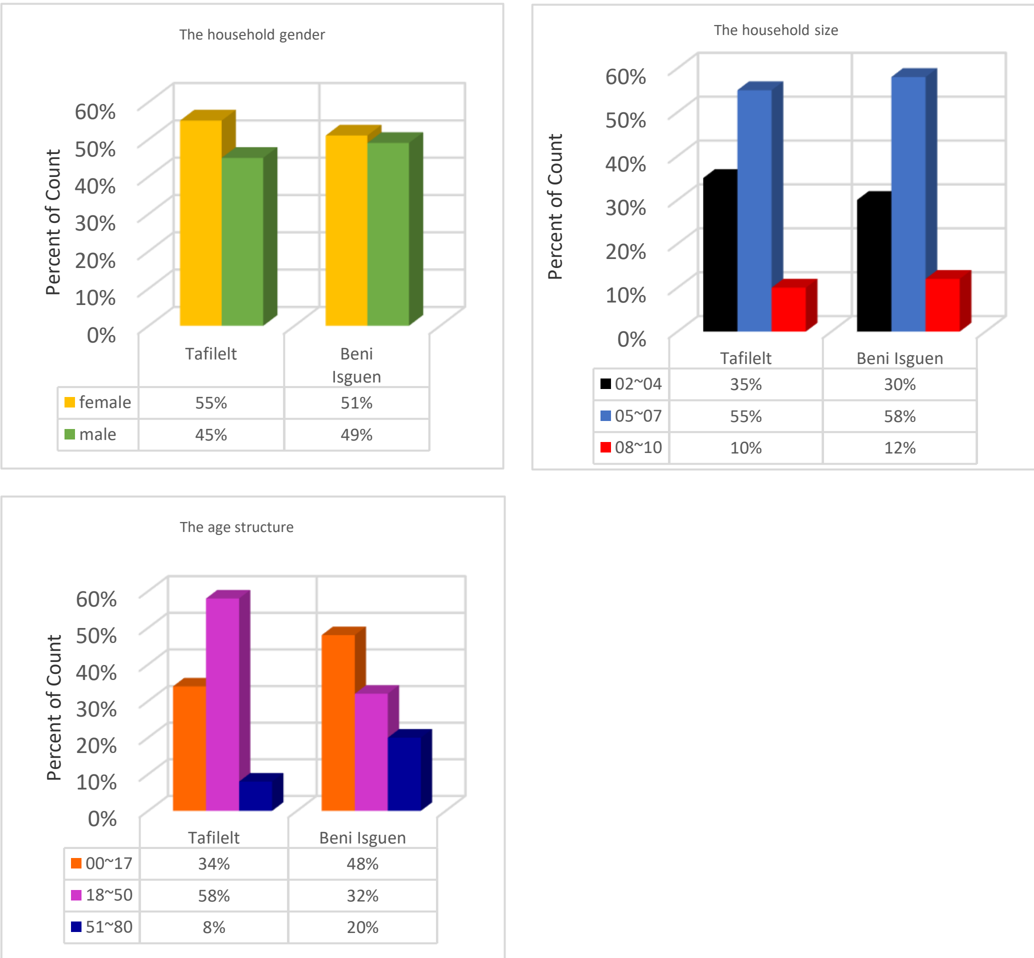



***Figure 5.1 Distribution of gender, number and age group of people living in the study areas.***

Larger households had between eight to ten members representing 10% and 12 % in Tafilelt and Beni Isguen, respectively. Further, most of the subjects were between the ages of 18 and 50, they accounted for 58% in Tafilelt. In contrast this age group is considered a youth community in Beni Isguen, and they represented 32% of the members. Next, those aged 51 to 80 represented 20% population in Beni Isguen and 8% in Tafilelt. Finally, those aged between 6 months and 17 years contributed to 34% in Tafilelt and 48% in Beni Isguen.

In terms of Gender, the percentage of female was higher than male in both settlements and there was no significant difference between the genders in each settlement in that female percentage was 55% and 51% in Tafilelt and Beni Isguen respectively; and 45 and 49% for male population respectively

**B. Activity (Metabolic Rate):**

The activities of the occupants were recorded for the last two hours before the interview such that the recorded information was used to estimate the metabolic rate of the respondents based on ANSI/ASHRAE Standard 55-1992R (Activity levels – Metabolic Rates for Typical Tasks).

From the questionnaire, the respondents indicated that most of the activities ranged between standing or sitting, which correlates to 1.2 met (70W/$m^2$), and medium to light movements which correlates to 2 met (116 W/$m^2$).

### 5.3.8 Analysis of Thermal Environment:

The main focus of this study was the thermal environment, which is a distinguishing factor from the other indoor conditions. Therefore, thermal performance was investigated to analyse the reasons for discomfort during the summer and winter seasons in the selected houses. The findings are discussed and presented in the following sub-sections:

**A. Natural ventilation:**

- **Summer:**

In both the areas, around 39% of the occupants used natural ventilation for cooling during the daytime and night-time, generally speaking it seems that the residents in Tafilelt tend to use more mechanical ventilation than natural. In Beni Isguen, the percentage of occupants using ceiling fans for cooling was estimated to be 75% during the day and night time, while in Tafilelt it was clearly observed that during the daytime the usage of mechanical cooling system was higher (see Figure 5.2).

- **Winter:**

The use of natural ventilation was minimal since all the openings were closed throughout early morning, evening and night. Around midday was the only point of time when natural ventilation was used (10:00 am to 01:00 pm). In Addition, in both settlements gas stoves were placed in the gathering places of the houses such that the warmth is somehow maintained (see Figure 5.2).

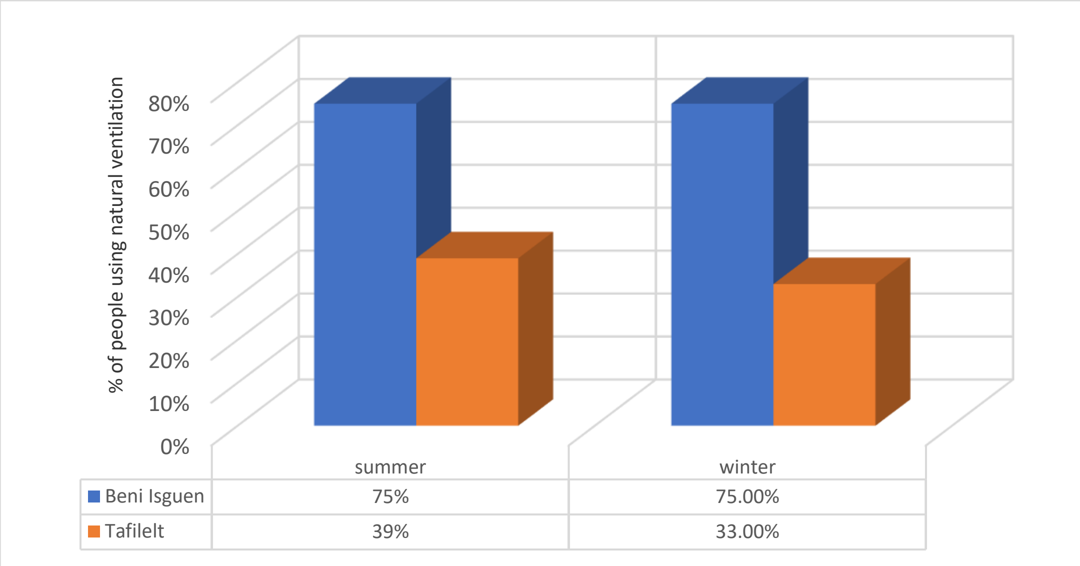



***Figure 5.2 Percentage distribution of people using natural ventilation***

**B. Mechanical cooling and heating:**

Depending on occupants' activities and their thermal comfort conditions, the houses on both the sites use ceiling fans and air conditioning for cooling during the summer months, and gas stoves are used during the winter.

- **Summer:**

With the outdoor temperature rising above 50°C, the use of air conditioning is inevitable if the building construction is not tolerant to the outdoor climate. Figure 5.3 shows that 61% of occupants use air conditioning in Tafilelt, while 39% use a mix of both natural ventilation and electric fans in the same. On the other hand, 25% use air conditioning in Beni Isguen, and 75% using natural ventilation and ceiling fans in Beni Isguen see Figure 5.3.

- **Winter:**

Both traditional and modern buildings use gas stoves during the morning and night. Natural ventilation is minimal, compared to the summer, since all the openings are closed throughout the night owing to the usage of the heating system during early mornings and evenings. Midday is when natural ventilation is primarily used (10:00 am to 01:00 pm).

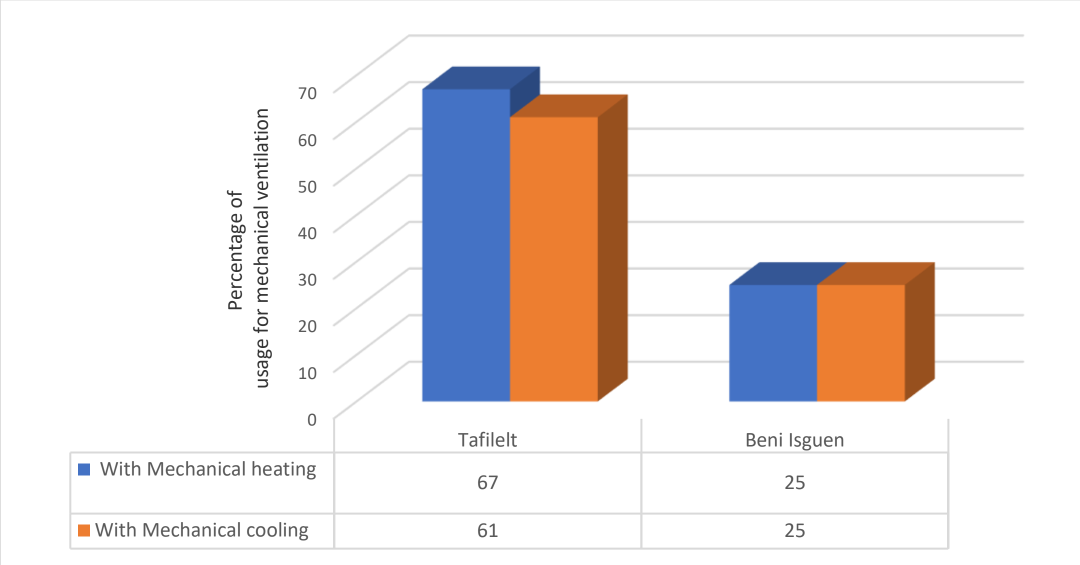



***Figure 5.3 Percentage distribution of population that using mechanical ventilation in the summer and the winter***

### 5.3.9 Analysis of Participants’ Thermal Response:

In Tafilelt, windows are designed small and directed for the exterior, for social-cultural reasons (opening/closing window or door), participants struggle to use the natural ventilation methods, which in turn have an impact on the occupant’s thermal comfort, encouraging the use of the air conditioning to help reduce the temperature. In Beni Isguen, the windows designed in different way in that windows are directed to the interior of the house (patios), which allows the occupants to use the natural ventilation methods while maintain the privacy of the household. People answered the questionnaire considering three intervals – morning, noon, and afternoon; this helped understand people’s thermal perception and use of the spaces throughout the day. All the respondents in this study were assumed to be at the steady state, and the results are based on this, which leads to the comparison with the predicted mean vote (PMV) model.

The predicted percentage of dissatisfied (PPD) thermal comfort index is based on the assumption that people voting the middle three categories (i.e., ‘slightly cool’ [–1], ‘neutral’ [0] and ‘slightly warm’ [+1]) of the 7-point thermal sensation scale are satisfied with their thermal environment. Extending the assumption to the AMV in this survey

Figure 5.4 shows that 15% of the participants in Tafilelt expressed their thermal sensation as ‘neutral’ while 12% in Beni Isguen stated the same during the summer.

In Tafilelt, more than 71% of the votes fell in the ‘warmer than neutral’ region (‘slightly warm’ [15%], ‘warm’ [32%] and ‘hot’ [35%]), while 9% fell in the ‘cooler than neutral’ region (‘slightly cool’ [5%], ‘cool=’ [3%] and ‘cold’ [1%]).

In Beni Isguen around 47% of the votes fell in the ‘warmer than neutral’ region (‘slightly warm’ [25%], ‘warm’ [11%] and ‘hot’ [11%]), while 41% fell in the ‘cooler than neutral’ region (‘slightly cool' [15%], 'cool' [18%] and 'cold' [8%]). In conclusion, 71% of the participants in Tafilelt during the summer were dissatisfied with the thermal conditions in their transitional spaces.

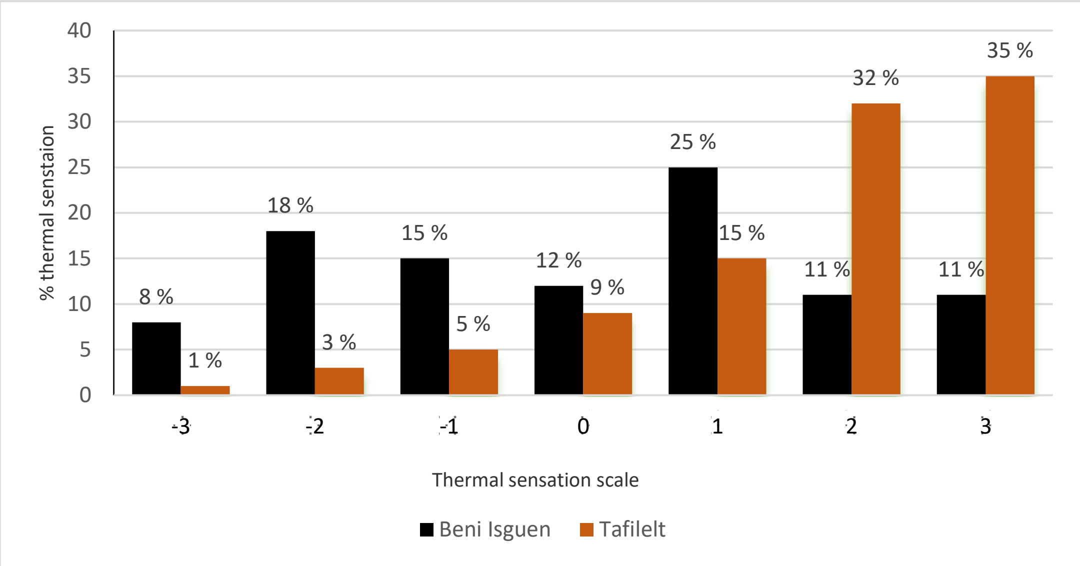



***Figure 5.4 Percentage distribution of Participants' Response to 7-point thermal sensation scale questions during summer***

In winter, as indicated in Figure 5.5, with regards to Tafilelt almost 57% of the votes fell in the 'cooler than neutral' region of the scale (which included 'cold' [25%], 'cool' [32%] and 'slightly cool' [15%]), while in Beni Isguen 39% of the votes fell in the 'cooler than neutral' region (included 'cold' [11%], 'cool' [14%] and 'slightly cool' [14%]).

This indicates that the transitional space of buildings in Tafilelt and Beni Isguen does not meet the industry-accepted minimum standard of 80% acceptability, as recommended by regulatory documents such as ASHRAE Standard 55.

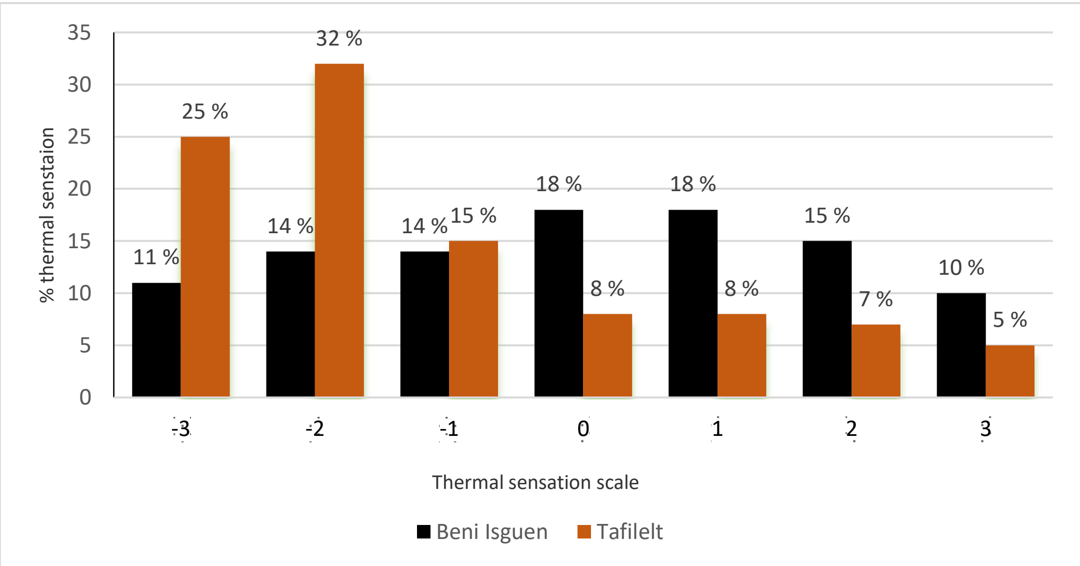



***Figure 5.5 Percentage distribution of Participants' Response to 7-point thermal sensation scale questions during winter***

While thermal acceptability, thermal sensation and thermal preference do overlap, they offer slightly different perspectives on people's relationship with a given thermal environment in that:

- Thermal acceptability determines whether the current thermal conditions are acceptable or not (poor, neutral or good).
- Thermal sensation assesses where a respondent's perception of current thermal conditions lies along an axis of 'hot' to 'cold'.
- Thermal preference determines if and how a subject would prefer the thermal conditions to change.

It is worth noting that the literature on thermal comfort (Fox et al. 1973; McIntyre 1980; de Dear and Brager 1997) shows that people can express satisfaction with the current conditions, select a neutral sensation and yet counter-intuitively express a preference for a different set of conditions. In terms of thermal unacceptability with Tafilelt, 89% participants in the winter and 73% in the summer found their thermal environment to be poor (unacceptable) (Figure 5.6). Regarding thermal sensation, in Tafilelt 78% and 80% of the participants in both winter and summer respectively were disappointed with the thermal conditions, according to the ASHRAE scale ('too cold' [–2, –3]) (Figure 5.6).

In Beni Isguen 55% and 45% of the participants in both winter and summer respectively were disappointed with the thermal conditions (thermal acceptancy). Regarding thermal preference in Tafilelt, only 17% participants preferred 'no change' during the summer, suggesting that they were not satisfied with the present conditions, while 10 % preferred 'no change' in Beni Isguen. Further, 39% participants preferred 'no change' during the Winter for Tafilelt, and 20 % preferred no change' during the Winter for Beni Isguen (Figure 5.6).

The results showed that thermal unacceptability and thermal sensation indicated a high level of thermal unsatisfaction (higher or lower, according to the ASHRAE Standard 55 recommended levels), while the thermal preferences indicated a significantly lower level of thermal dissatisfaction – about 20% during both winter and summer.

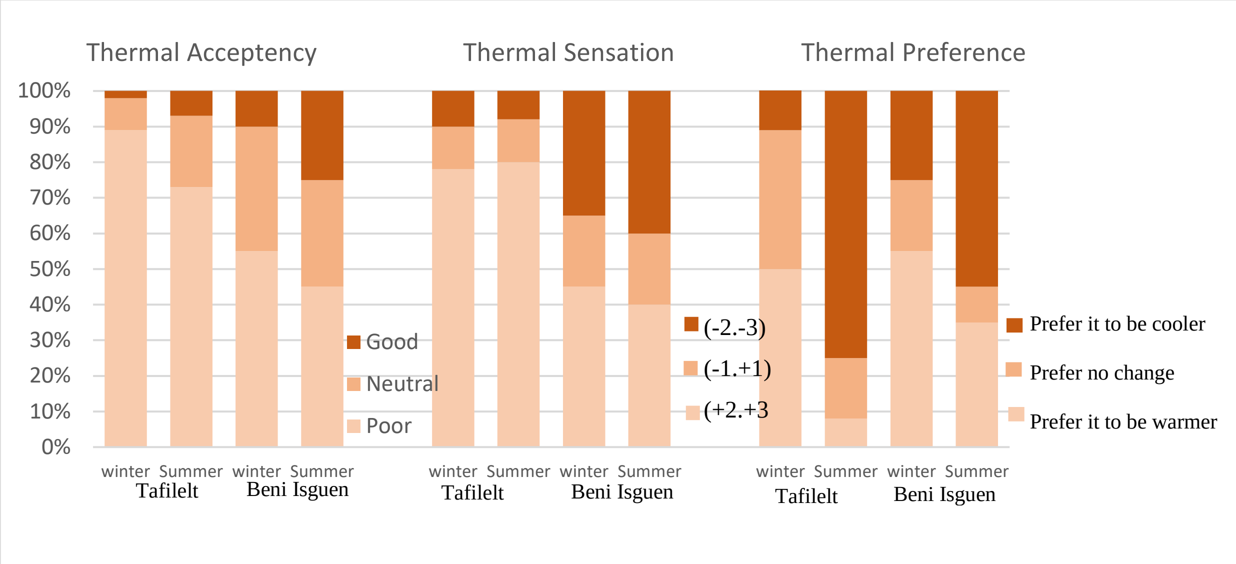



***Figure 5.6 A comparison of thermal satisfaction in terms of thermal acceptability, thermal sensation, and thermal preference in Tafilelt and Beni Isguen***

### 5.4 Summary:

According to the results of a field assessment, Tafilelt's residential buildings are uncomfortably cold in the winter and extremely hot in the summer. Without electric heaters in the winter and mechanical ventilation in the summer, these structures cannot provide a comfortable living environment. Nevertheless, based on the interviews conducted, all respondents felt that the traditional structures in the old city of Beni Isguen were more pleasant throughout the year. On the other hand, the people of Tafilelt no longer live permanently in the Beni Isguen, and all of the houses have been left empty. They have moved to the city, but they still keep their old houses in vernacular settlements as a place to relax and a sign of their family's uniqueness in Ghardaia.

As a result, comparing the thermal comfort of the two settlements was a question that many questionnaire respondents were not able to answer with accuracy. In the following chapter, a detailed comparison between two pairs (Modern house in Tafilelt and Traditional in Beni Isguen) at the same time during Summer and Winter is conducted and summarised in order to confirm the differences in thermal comfort considering temperature and humidity; with the intention of assisting architects and designers in the future to better design the upcoming settlements by using the herein results.

## 5.5 Fieldwork Introduction:

This section of the chapter will present an in-depth analysis and comparison of the thermal performance and indoor thermal conditions of a set of dwelling pairs during the summer (01st Au-gust to 30th August 2018) and winter (01st January to 30th January 2019). These include a pair of dwellings in Tafilelt and the traditional houses in Beni Isguen that were instrumented to compare environmental conditions including temperature and relative humidity. The assessed conditions range from temperature and humidity to the thermal performance of the buildings. The places that were studied include the building's immediate surrounds, the patio and living room on the ground floor, in addition to room 1 on the first floor. The outcomes of this comparative analysis can be used to develop strategies for enhancing thermal comfort. It intends to infer distinctions between the ancient and new buildings, particularly in terms of their technical aspects. Understanding these distinctions facilitates the development of computer-based models (as demonstrated in Chapter VII) that generate contextual and optimal plans for the upgrade of the residential building fabric in this region.

### 5.5.1 Modern House 1 (MH1):

***Figure 5.7 An aerial view of the MH1 location (Source: Apple maps)***

A new house (MH1) of less than 20 years of age was examined as the first case in this research. It is a two-storey (ground floor and first floor) self-build unit that was constructed in 2009 and is located in Tafilelt, around 1.5 km south of Beni Isguen (Figure 5.7). The MH1 is considered a medium-sized house with a roof terrace, a floor area of approximately 90 $m^2$, and a ceiling height of 3.3 m. It contains a patio behind it which is well connected to the social activity spaces. It is occupied by a working-class family of four (young parents with two children) whose average monthly income is around £500; that is considered a good income, compared to the general income in Algeria. The ground floor has a combined living room (accessed from the entrance for privacy reasons), and dining room, a guest room which is used occasionally, a kitchen that is connected to all the ground floor spaces and the patio. The first floor includes a living room as well, with a well-ventilated patio characterised by the large windows. Moreover, the building’s front has small windows to maintain social privacy. The house plan is described below to give an overview of the internal space organisation (see Figure 5.8).

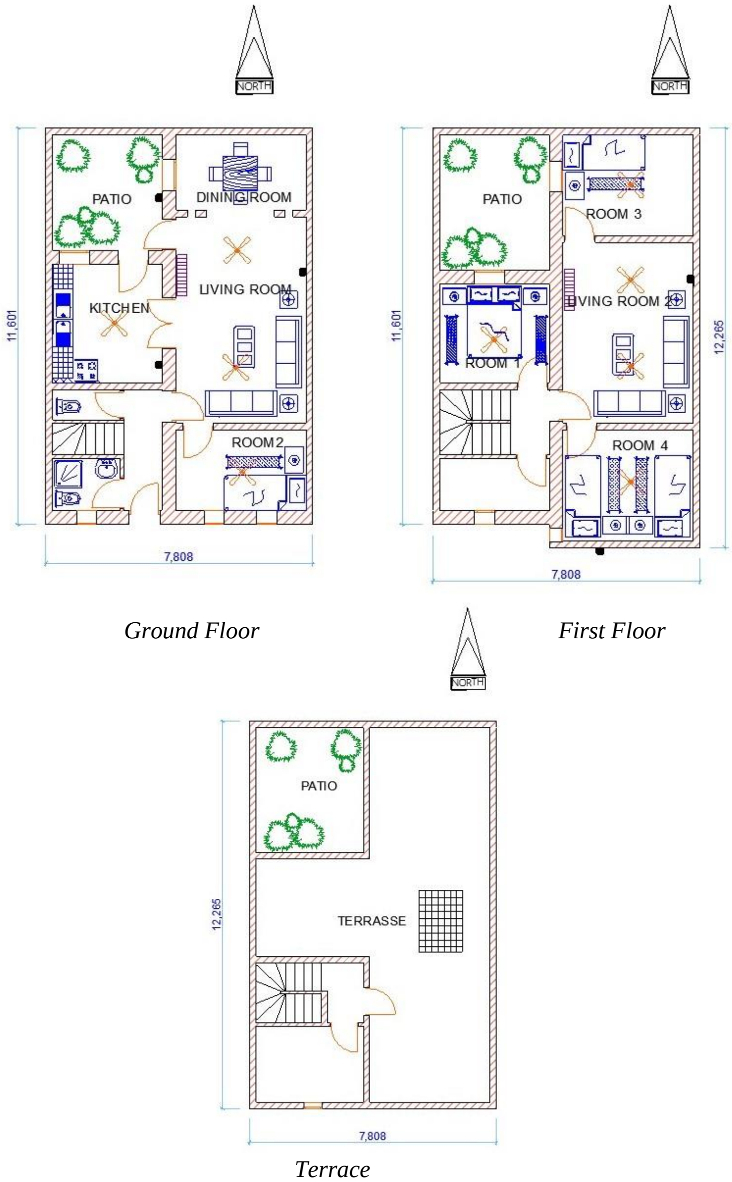



***Figure 5.8 The layout of the selected MH1 for the summer and winter measurements (source: by the Author).***

The ground floor is provided with small south facing casement windows, mainly in the combined living and dining area and the guest room, which is used occasionally during the summer period. Since the roads are narrow, the need for social privacy keeps the small windows that face the road closed, while preventing the hot air and sand from entering inside (see Figure 5.9). Most of the openings for ventilation and lighting are in the inner patio and regulate the indoor thermal environment to a great extent. For example, during summer nights, when the temperature inside the house is higher than the outside temperature, the ‘chebek’ i.e., the windows is often kept open all night to allow the fresh air into the house by removing overheating due to the solar or internal gains.

***Figure 5.9 picture showing the opening in the façade- House MH1 (source: by the Author).***

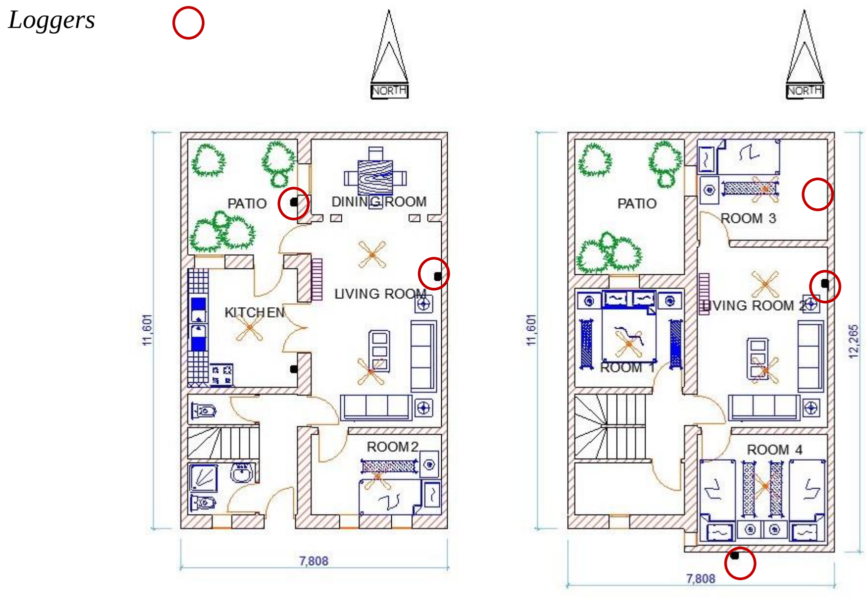
Given this context, MH1 functions freely without mechanical controls despite using ceiling fans regularly during summertime and a gas stove during the winter months. The electricity and gas supply is facilitated by the national grid (SONELGAZ) which is the case for the houses studied in this research. It is noteworthy that this region regularly experiences power cuts during the peak summer time when the air coolers are turned on in different businesses and buildings across the city creating a great pressure on the city’s main generators.

Table 5.1 describe the internal space within MH1, and the ventilation system used, which can be noted that in all the space, natural ventilation is used throughout the house.

***Table 5.1. Internal and the external spaces in MH1***

| **Internal Spaces** | | **Services: Cooling/Heating** |
|---|---|---|
| Ground floor | Entrance | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living Room | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Kitchen | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 1 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| First floor | Room 2 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 3 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 4 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Hall | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| **External Spaces** | | |
| Patio | | N/A |
| Roof Terrace | | N/A |

Figure 5.10 highlights the location of the loggers distributed in the two floors of the house.




*Ground Floor* *First Floor*

***Figure 5.10 The locations of the loggers in the habitable rooms and spaces of the MH1 for the summer and winter measurements (source: by the Author).***

The construction materials used at Tafilelt are locally available and do not require excessive energy during their production, transport or expenditure implementation which can otherwise generate pollution. The main idea is to use traditional materials, such as mud bricks, gypsum, lime, and palm branches for the construction of these buildings. However, the hipped roof that covers the first floor is constructed with concrete to ensure high thermal conductivity U-value (1.88W/m$^2$K); solid concrete blocks and reinforced concrete are used for floors and the flat roof respectively (see Figure 5.11). The external walls are only rendered with lime sand render (from the outside) and gypsum plaster (from the inside) with no insulation layer, resulting in a high U-value of 2.0W/m$^2$K which substantially influences the building's energy and thermal performance. On the other hand, the internal ones are rendered either with gypsum plaster or ceramic tiles, such as the ones used in the kitchen and bathroom.

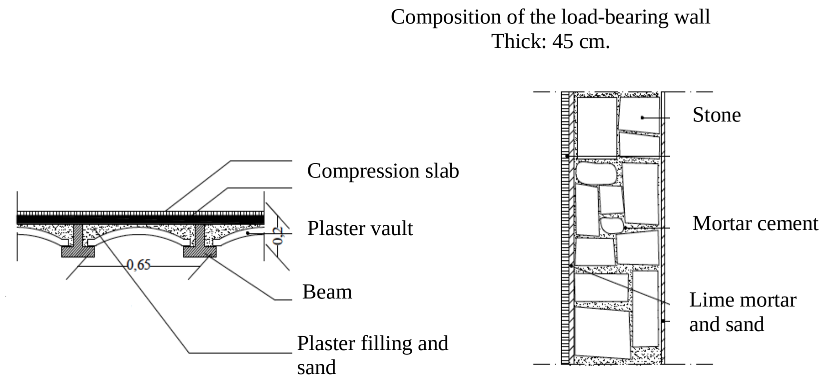



***Figure 5.11: Section of the wall and roof for MH1 (source: by the Author).***

As described in Figure 5.11, it can be noted that the 0.45 m thick stone walls support all the constructed structures of the house as well as all the walls in the front. The non-loadbearing walls are made in hollow blocks (concrete chipboard) of 0.30 m thickness. As for the exterior coating, the designers and builders of the project were inspired by the traditional techniques which comprise of lime mortar and sand (spread over the surface of the wall using a bunch of dates), the strong lime proportion, and the presence of fine sand that makes the mortar more malleable. The use of rough texture to provide shade to the wall, as shown in Figure 5.12, reduces the overheating of the walls.

***Figure 5.12: The texture for the façade and watering the roads in MH1 (source: by the Author).***

The use of stone, associated with local lime mortar, represents a heavy material with high thermal mass. Despite its poor thermal performance, the temperature fluctuations are attenuated because of the thickness of the load-bearing walls (45 cm). This is due to their thermal capacity, thus allowing heat to be stored during the day and be dissipated at night (high thermal mass) following the ventilation provided by the openings (in summer). Although high thermal mass is not beneficial during periods of high heat, the structure ends up being overheated and takes longer to dissipate the stored heat.

### 5.5.1.1 Occupant's Observations:

- **Summer**:

The questionnaires' responses revealed a variety of strategies used by occupants to cope with the summer heat which are quite similar to the ones followed in the old buildings of Beni Isguen. These include drinking a lot of liquids, showering to cool the body temperature, moving to the most comfortable space (usually the centre of the house which is far from the external walls and close to the patio), wearing comfortable clothes, removing carpets, turning on the cooling equipment (ceiling fans), and closing all the exterior windows to prevent thermal discomfort. As previously highlighted, the excessive consumption of energy in the city, especially in the summer, leads to continuous power cuts resulting in interruptions in using the ceiling fans during the peak time. It was noted for other residents in the area who happen to use  air conditioners, that during night-time, the situation is similar in at the residents sleep on the terrace even when the pressure on the city's electricity generator decreases as it was stated that '*We can say that sleeping with the A/C cooler on is better than sleeping on the roof which is extremely hot due to its exposure to the sun throughout the day , but we can't afford the electricity costs because the state applies discounts only in peak time'*. Before using the terrace at night-time, occupants usually pour water on the roof to cool it, saying '*the problem is the same, excessive consumption of water or electricity at the end is a waste of energy and money'*. Most of the time, the overheating during the night pushes the male occupants to sleep on the terrace (see Figure 5.13) after cooling the surface with water and sleep under the sky which is a well-known method used in hot areas.

***Figure 5.13: Occupants sleeping on the terrace during the hot weather (source: Google images).***

However, both the manual evaporative coolers, i.e., the indoor and outdoor one, cannot cool the indoor environment to a degree that the existing ACs would do which is why the mother and children, who spend most of their time in the house, are slightly dissatisfied with the thermal conditions, especially during daytime. Table 5.2 highlights that occupants use kitchen and living room for most of the day during the summer.

***Table 5.2. Summer occupation of internal and external spaces in MH1***

| **Summer** | **Morning** | **Lunch** | **Afternoon** | **Evening** |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **N/U** | **Eat** |
| Living room (ground floor) | **Eat** | **Socialise** | **Sleep** | **Socialise** |
| Hall (First floor) | **Sleep** | **Socialise** | **Sleep** | **Socialise** |
| Rooms (first floor) | **N/U** | **N/U** | **N/U** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **Socialise** | **N/U** | **N/U** | **Socialise** |
| Roof terrace | **N/U** | **N/U** | **N/U** | **Sleep** |

*Key: Never used (N/U), sometimes used, frequently used.*

- **Winter**:

Most of the roads in Tafilelt are east-west orientated, particularly service road, which are three metres wide, that can help to reduce the sun exposure throughout the day (see Figure 5.14). Since the main heat gain from the latter comes from diffused and reflected solar radiation, which by small interventions on the façade improve their relation to the temperature depends on the albedo of the surfaces.

***Table 5.3. Winter occupation of internal and external spaces in MH1***

| Winter | Morning | Lunch | Afternoon | Evening |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **N/U** | **Eat** |
| Living room (ground floor) | **Eat** | **Socialise** | **Socialise** | **Socialise** |
| Hall (first floor) | **N/U** | **Socialise** | **Socialise** | **Socialise** |
| Rooms (first floor) | **Sleep** | **N/U** | **Sleep** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **N/U** | **Socialise** | **Socialise** | **N/U** |
| Roof terrace | **N/U** | **Socialise** | **N/U** | **N/U** |

*Key: Never used (N/U), Sometimes used, frequently used.*

The use of indoor spaces in modern houses is frequently confined only to the kitchen and living room throughout the day during the winter (see Table 5.3). This is due to the placement of the gas stove which keeps these spaces warm during the night. Conversely, the horizontal wall–like surfaces of wide streets–is generally located at the edge of the settlement or close to the open spaces that are highly exposed to direct sunlight. So, as shown in Figure 5.15, the feeder streets-oriented east-west–considering the relatively high prospect–have a very low heat input in the winter. In summer, the horizontal street surfaces absorb a lot of heat, as shown in Figure 5.14, requiring masks or solar shades that can create shadows on the façades to decrease the heat input.

***Figure 5.14: Different Road widths in Tafilelt at midday (source: by the Author).***

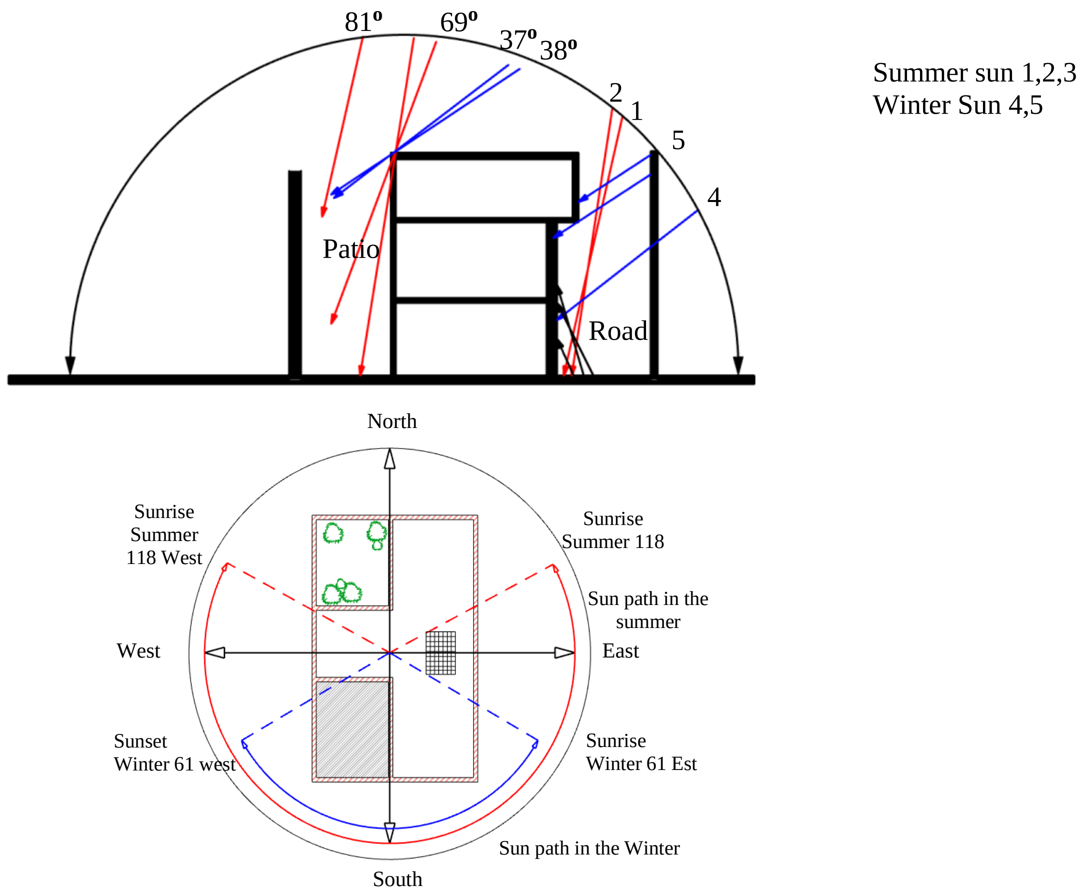



*Figure 5.15: Morphology of indoor spaces through the sun's path during summer and winter (source: by the Author)..*

The moving shadows continually adjust the temperature and pressure as draughts are created which can be refreshed by the proximity of water or vegetation. As for the primary streets with low prospects, the high rate of the solar radiation's reflection overheats the southern walls where vegetation is thought to be the preferable method of protection (Figure 5.16).

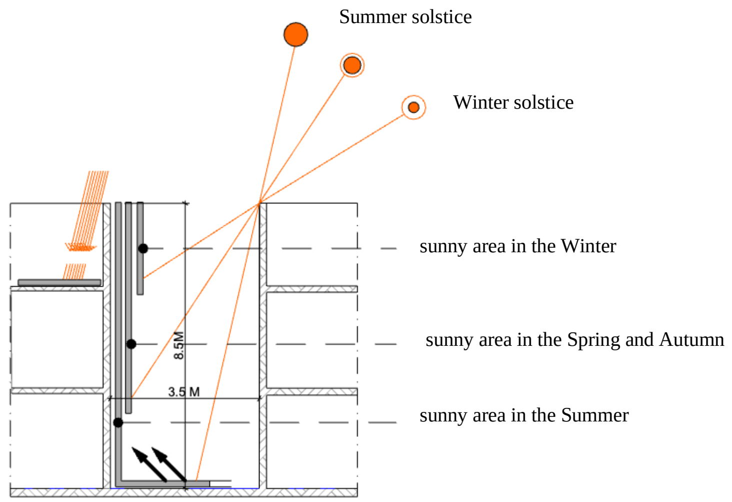



*Figure 5.16: The prospect in the streets of Tafilelt at midday (source: by the Author).*

In summer, the sun travels more than 240° in azimuth, according to Figure 5.16, and its passage through the southern direction is brief, unlike the east-west tracks where the shade depends mainly on the prospect (ratio between the height of the buildings and the width of the street). In these north-south streets, the façades facing eastern and western protect each other from sunshine.

**5.5.1.2. Summer Measurements in MH1 From 02/08/2018 to 09/08/2018:**

By following the research methods mentioned in Chapter 3, temperature and relative humidity data were collected from the assessed places (outdoor, patio, living room and first floor room) throughout the week. The results showed that the indoor/outdoor dry-bulb temperature rose quickly after dawn, recording a mean daily temperature ranged from 34.7°C to 35.8°C (table 5.4). While the running mean outdoor air temperature (Trm) for one week ranged from 27.2 °C to 42.2 °C (Table 5.4). The average daily sunshine duration in Tafilelt was about 12 hours; with a high level of solar radiation, this sometimes caused the occupants' thermal comfort to be higher or lower than the prescribed thermal comfort standard which actually failed to meet both the 90% and 80% acceptability limits of the ASHRAE Adaptive Comfort Criteria (see Figure 5.17).

*Table 5.4. Average, maximum, and minimum temperature of MH1.*

| MH1 Space | Temperature (°C) | | | |
|---|---|---|---|---|
| | Mean Temp | Daily Max | Daily Min | Mean Diurnal Range |
| Living room | 35.1 °C | 36.7 °C | 33.5 °C | 3.2 °C |
| Room 1 | 35.85 °C | 37.2 °C | 34.5 °C | 2.7 °C |
| Patio | 34.8 °C | 36.5 °C | 33.2 °C | 3.3 °C |
| Outdoor | 34.7 °C | 42.2 °C | 27.2 °C | 15.0 °C |

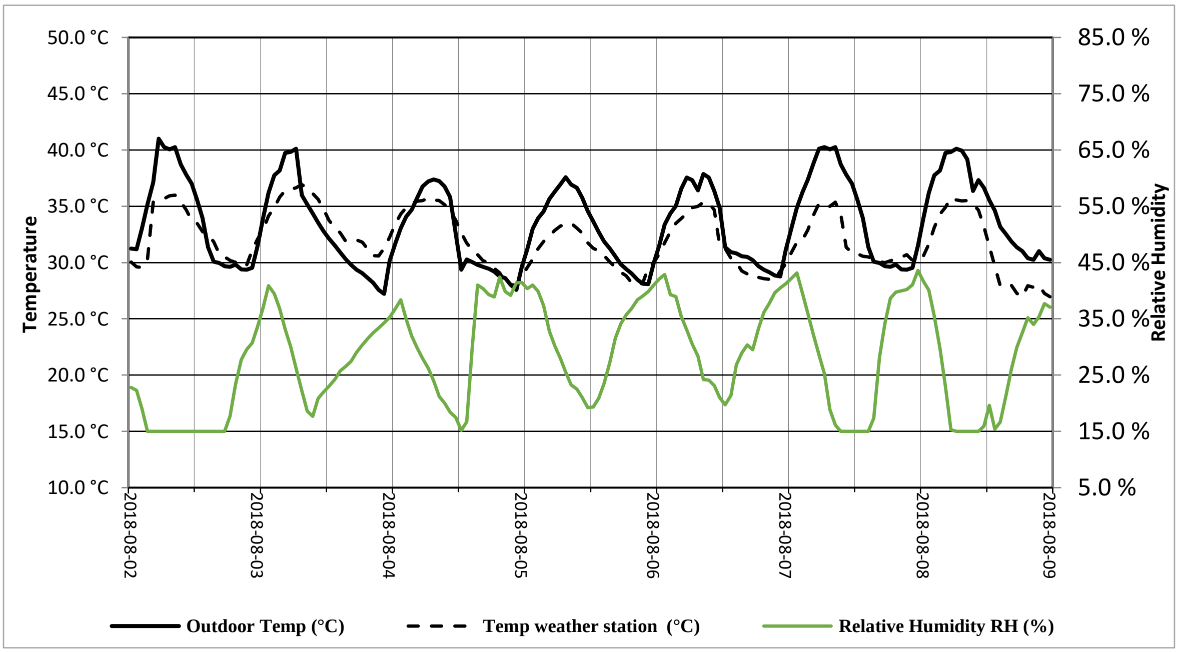



*Figure 5.17: The recorded outdoor dry-bulb temperature and relative humidity during the summer for MH1*

The MH1, on the other hand, is serviced by a natural ventilation system and ceiling fans, facilitating a higher thermal comfort for its occupants. Table 5.4 summarises the findings for the air temperature of MH1 during the monitoring period. The outdoor Mean Diurnal Range is found to be noticeable 15 K as an average and Mean Diurnal Range for the patio was about 3.3 K. During the interval, the data report that the Diurnal variations of outdoor relative humidity was on average 28% (see Figure. 5.17). It can be seen from Table 5.4 that the hottest temperatures are recorded in the outdoor spaces 42.2°C and 37.25°C of the room on the first floor (Room 1). The coldest temperatures were noted in the outdoor with a recorded temperature of 27.2°C and the patio (33.2°C) where the building sees an exchange of air. While all the internal spaces equally experience an average temperature remained within the range of 33.5 to 37.2°C, the lowest indoor temperature is recorded in the living room (33.5°C). Bedroom temperatures are very consistent with a range of approximately 3 K during this period (see Figure 5.18).

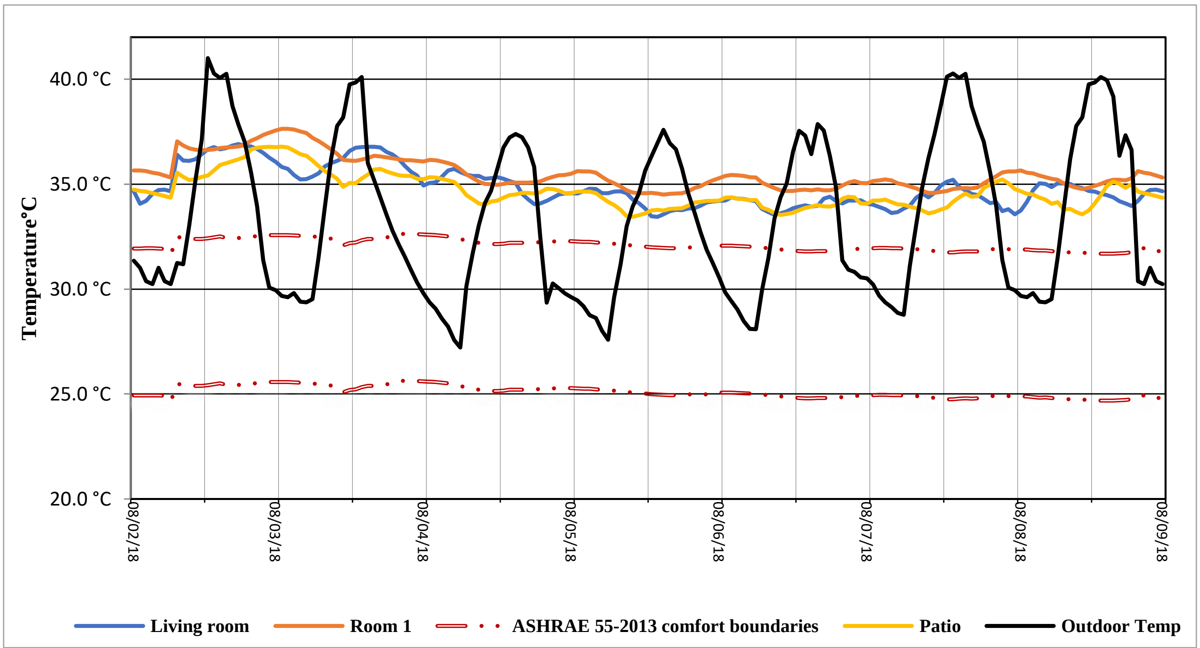



***Figure 5.18 Indoor and outdoor dry-bulb temperatures over a period of one week along with the comfort boundaries of ASHRAE for MH1***

The external space has better temperature compared with indoor spaces and semi external patio, which remained outside the acceptability range of ASHRAE adaptive comfort criteria (i.e., 80% acceptability limit). The indoor mean daily temperature ranged from 33.5°C to 37.2°C throughout the entire measurement period. A peak indoor temperature of 37.2°C was recorded at the first-floor room. It facilitated the heat transfer between the ground floor spaces through convection as the ceiling is characterised by high U Value 1.88 W/m2K leading to the conduction of heat over time from the ceiling to the first floor, consequently the heat transfers it to the ground floor contributing to the rise in temperature. On the other hand, the outdoor temperature exceeded the indoor temperature after midday, reaching a peak at 42°C around 13:00 hrs., as shown in Figure 5.18. Despite the outdoor space being the hottest area during the day, it can be noted that it is much cooler during the night with a recorded temperature of 27.0°C, compared to the other indoor spaces with a gradual decrease in temperature starting in the afternoons until after midnight to 6:00 am.

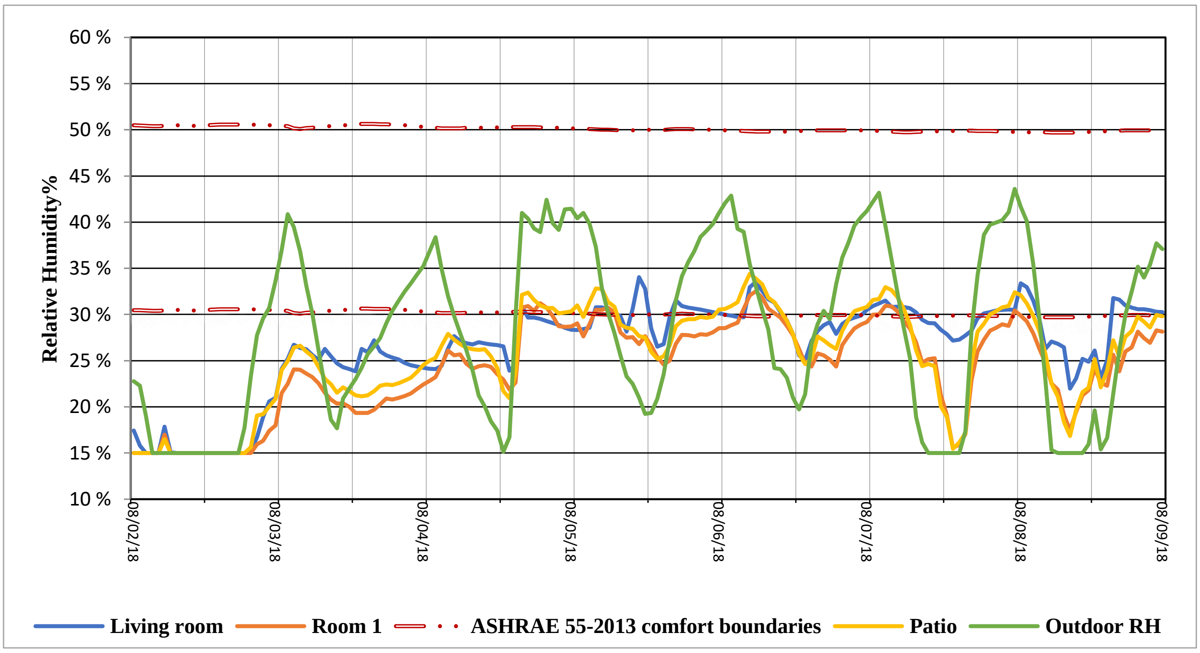



*Figure 5.19 Mean Relative Humidity over a period of one week with the comfort boundaries of ASHRAE for MH1*

Moreover, while the mean relative humidity was between 15% and 34% in all indoor spaces, it showed a greater range between 15% and 43% for outdoor spaces (see Figure 5.19), That's really just due to the very high temperatures in these rooms. This implies that for 40% of the measurement period, the average relative humidity remained within the adaptive thermal comfort range. Similarly, according to the thermal comfort criterion, 95% of the interior spaces have a thermal comfort range below the prescribed adaptive thermal comfort range (Figure 5.19). The lack of clouds and scarcity of vegetation contribute to the extremely hot climate at the site, causing the low relative humidity in the air. The relative humidity inside the building considered very low due to the narrow openings, high thermal mass, lack of vegetation, and the absence of water use inside the building (spraying, pouring etc.) (Figure 5.14).

#### 5.5.1.3 Winter Measurements in MH1 From 03/01/2019 to 10/01/2019:

It is important to note that the monitored houses (traditional and modern houses) studied in the previous section i.e., summer period were the same houses studied in the winter period. During Winter, the residents use different spaces; more specifically, they do not use open and ventilated spaces, such as the courtyard and the terrace during the night. The occupants use a different living room which is considered as a winter room, conducting the same activities during lunch when the temperature rises in the patio. It is to be noted that the MH1's occupants do use a Radiant Portable Gas Heater regularly for heating during the winter (see Figure 5.21).

*Table 5.5. Average, maximum, and minimum temperature of MH1 in Winter*

| MH1 Space | Temperature (Cº) | | | |
|---|---|---|---|---|
| | Mean Temp | Daily Max | Daily Min | Mean Diurnal Range |
| **Living room** | 17.5 ºC | 18.5 ºC | 16.4 ºC | 2.1 ºC |
| **Room 1** | 19.1 ºC | 20.1 ºC | 18.0 ºC | 2.1 ºC |
| **Patio** | 16.5 ºC | 23.5 ºC | 9.5 ºC | 14.0 ºC |
| **Outdoor** | 11.1 ºC | 18.6 ºC | 3.5 ºC | 15.1 ºC |

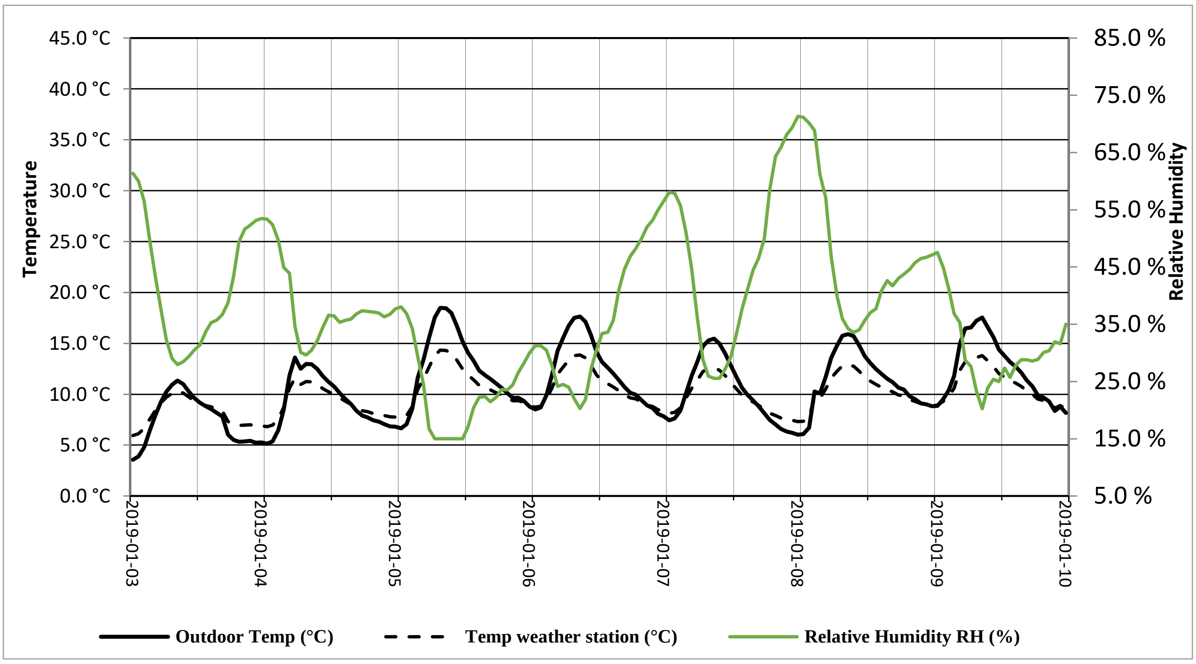



*Figure 5.20 The recorded outdoor dry-bulb temperature and relative humidity over a period of one week during winter for MH1*

*Figure 5.21 An example of the Radiant Portable Gas Heater used for heating (source: Google images).*

The outdoor mean daily temperature ranges from 3.5 °C to 18.6°C, which is considered very cold and failed to meet the acceptability limits of ASHRAE adaptive comfort criteria (i.e., 80% acceptability limit) (Figure 5.22). The indoor mean daily temperature ranged from 16.4°C to 20.1°C throughout the entire measurement period. A peak indoor temperature of 20.1°C was recorded at the first-floor room making it more comfortable to sit in as it meets the ASHRAE adaptive comfort criteria, since it relies on gas stove constantly throughout the day.

The lowest recorded temperatures were between midnight and early morning. Alternatively, the peak temperature in the patio was 23.5 °C at 14:00 hrs, despite the patio being considered a semi exposed part of the building and recorded a mean daily temperature of 16.5°C; 60 % of the measurement time, the patio's temperature failed to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria (see Figure 5.22).

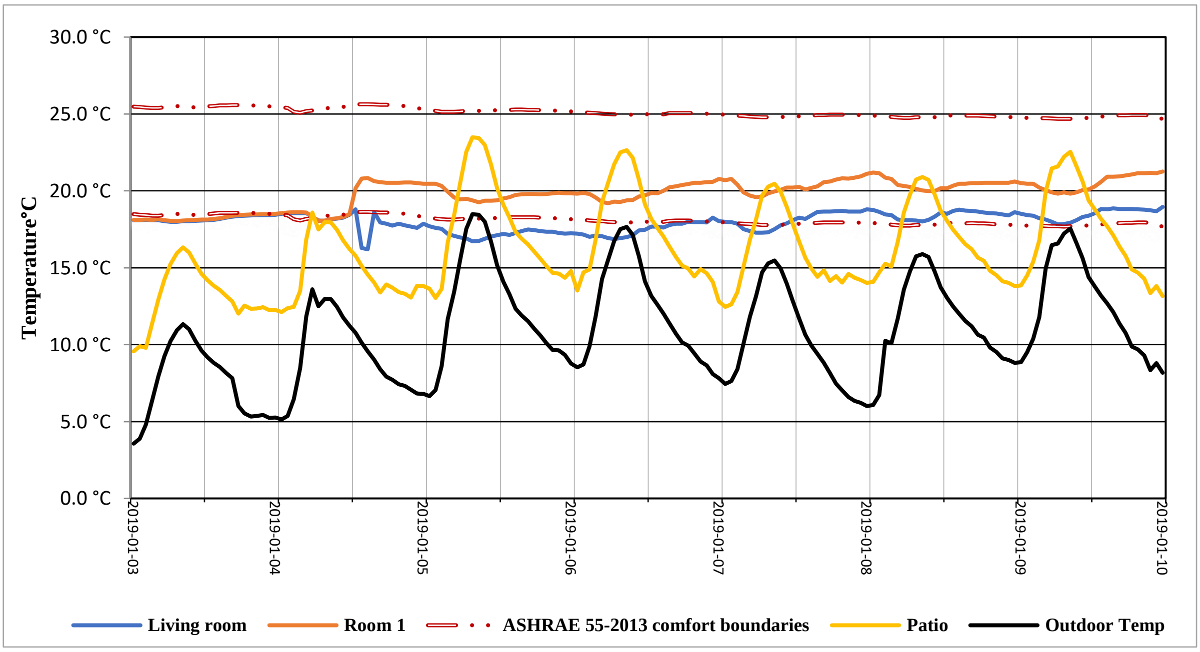



***Figure 5.22 Indoor dry-bulb temperature over a period of one week with the comfort boundaries of ASHRAE 55 for MH1.***

The living room on the first floor is one of the main habitable rooms due to the heater installed there. Needless to say, it becomes the family room during the winter season, and they had generally experience slightly as a warm place to gather which can notice from the figure 5.22, it remains steady during the monitoring record with mean daily temperature ranged from of 16.4°C to 18.5°C, and a range of the relative humidity is between 38% and 48% which considered within the comfort boundaries (Figure 5.23). The outdoor relative humidity range between 15% and 72%, and the patio with the first floor experienced a low relative humidity range of 25% to 38% and 23% to 35% respectively (Figure 5.23). According to the prescribed thermal comfort standard, 100% of the patio and outdoor spaces are not within the adaptive thermal comfort range. As per their diary entries, the occupants of MH1 spent most of their time in the living room, owing to the comfort provided by the heating (Table 5.3).

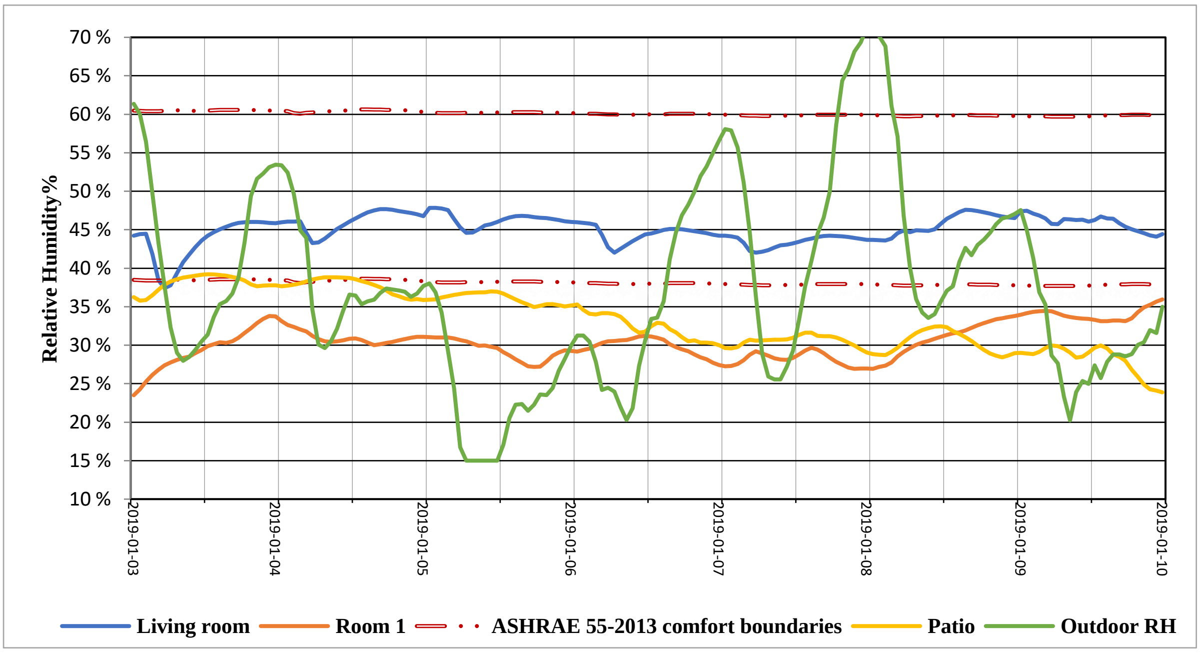



***Figure 5.23: Mean relative humidity over a period of one week the with comfort boundaries of ASHRAE 55 for MH1 during Winter.***

During the week of monitoring, the occupants kept their side windows open throughout morning and afternoon for lighting, while keeping the single glass windows closed. Despite the cold air blowing through the interior windows overlooking the patio, the heating in the living room ensured that their thermal environment was comfortable. However, despite the heating being distributed around their bedrooms as well, the occupants noted in their diaries that they felt uncomfortable sleeping at night due to the cold weather.

### 5.5.2 Traditional House (TH1):

*Figure 5.24 An aerial view showing the location of the house (Source: Apple maps)*

TH1 is a traditional house that is more than 900 years old and was used as the first traditional house in this case which is a double-storey self-build unit constructed in 1100 AD located at the heart of the historical city of Beni Isguen (Figure 5.24). TH1 is considered a medium-sized house with one façade that faces the narrow open alley with a width of nearly two metres; the other sides of the house are attached to the neighbouring houses, giving it an irregular shape. It comprises two storeys (ground floor and first floor) along with a roof terrace with a floor area of approximately 100 $m^2$ while the ceiling has a height of 3.3 m per floor (Figure 5.25).

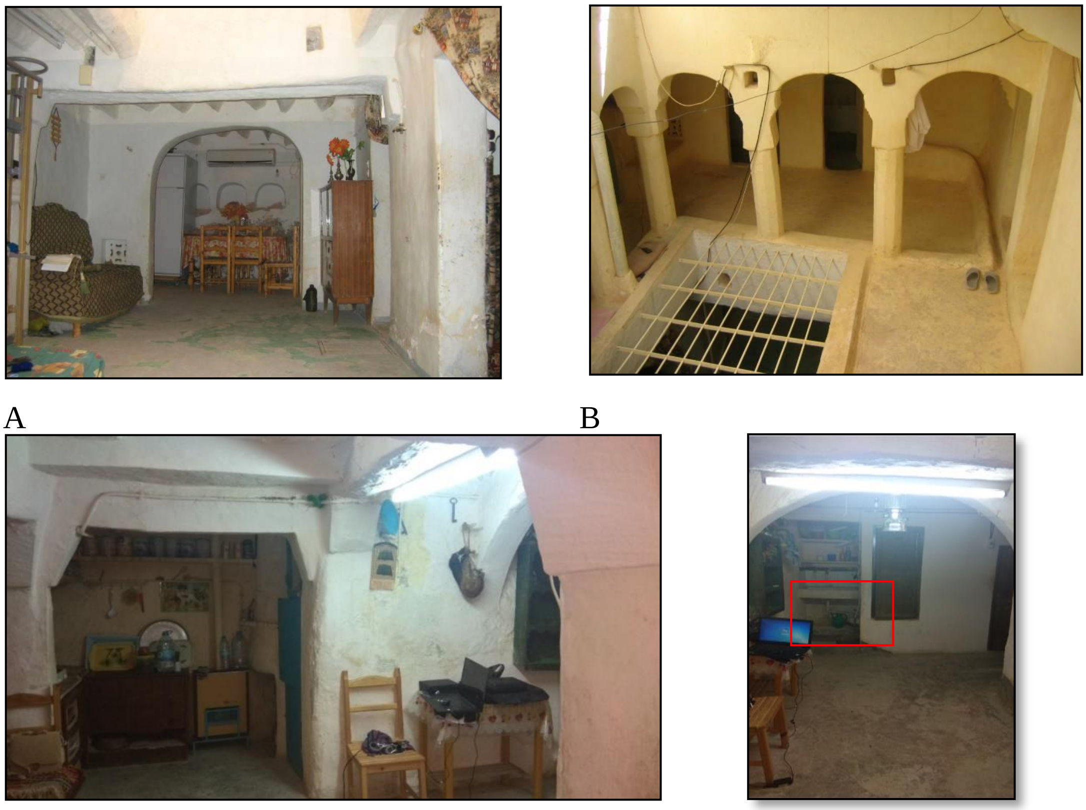
*Figure 5.25. A view of the house during summer (source: by the Author).*

The house has a patio located in the middle which is well connected to all the social activity spaces; the house is occupied by a working-class family of six (parents with four children) having an average monthly income of around £500. The father works in trading and the mother is a stay home mother and the four children attend school. The family is considered to have a good income, compared to the average income in Algeria. Figure 5.24 shows an aerial view of TH1, and Figure 5.25 provides a view of the house during summer. The first thing that is noticed at the entrance to the house is the threshold, which is a stone step that has a height of 10 cm. This threshold protects the house from sand, dust, rainwater, and harmful insects.


*Terrace*

***Figure 5.26 The layout of the habitable rooms and spaces in TH1 for the summer and winter measurements (source: by the Author).***

The entrance door usually remains open all day long; the privacy of the occupants is maintained despite the opened door as passers-by will not be able to see the interior of the house due to the entrance's design; a small hallway that ends with a wall so that the entrance to the centre of the house is a curve (Figure 5.26). When one passes the second entrance, they find themselves in a corridor called the shed, with a low stone bench built for sitting in front of the weaving loom during summer, along with a mill in one of the corners to grind grain. This entrance leads directly to the centre of the house which is lit by a window and connects the ground floor to the first floor. Windows, designed to be small and closed to the roof. The ventilation and the openings for light are designed in such a way that the occupants can benefit from the sunshine as long as possible see (figure 5.27), especially in winter. The women's reception room 'Tizfri' is considered the most appropriate location to sit around the centre of the house (Figure 5.27). This hall, which is almost be necessary in the Mozabites House, is a room with a somewhat wide entrance but without a door, facing towards the East and West to benefit more from the natural light.



A B C D

***Figure 5.27 Pictures showing the spaces in TH1. A: living room; B: Patio, C: Kitchen, D: Living Room (source: by the Author).***

The hall has two main roles primarily, it serves as a room for weaving brushes and woolen clothes and secondly, it is used for family's summer gathering and as the reception of the women. The kitchen (D) is an open space near one of the doors of the house and usually is the main gathering space during supper time. It consists of a stone stove connected to a ventilation hole to the roof, topped by shelves, pegs and some niches that are used for placing cooking supplies and utensils. On the sides of the house’s centre are the entrances to the private bedrooms of the house and next to them is usually a table built, under which are pots of fresh water and washing water (see figure 5.27 A, B, C, D).

***Figure 5.28. A view of TH1 and the narrow alley (source: by the Author).***

The irregularly shaped patio has good access to all the surrounding rooms, given its position in the centre of the building. It has one arched gallery on the first floor that creates extra shade on the wall that overlooks it. It provides access to the rooms on the upper floor as well, in addition to giving them good ventilation with a large windows and doors. For social privacy, all windows open on to the inner courtyard in the middle of the house (Figure 28 indicating no external windows), which is considered as private area and larger, compared to the one in MH1, and has windows with internal roller blinds. Each space on the ground floor is fitted with a ceiling fan which is used only during summer. The electricity and gas, as is the case with the other case studies, is provided by SONEL-GAZ. Table 5.6 describes the internal and external spaces within TH1.

***Table 5.6. Internal and the external spaces in TH1***

| **Internal Spaces** | | **Services: Cooling/Heating** |
|---|---|---|
| Ground floor | Entrance | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Hall | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living Room | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Kitchen | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 1 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| First floor | Room 2 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 3 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 4 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living Room <Tizfri> | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| **External Spaces** | | |
| Patio | | N/A |
| Roof Terrace | | N/A |

The building fabric is characterised by a thick wall (500mm) and roof (450mm) made from lime-stone which is used to reduce both heat gain and loss. Insulation also controls the average indoor radiant temperature by isolating interior surfaces from the influence of exterior conditions. It also reduces the droughts produced by temperature differences between the walls and the air. In hot weather, the insulation is placed on the outside face of the wall or roof, so that the thermal mass of the wall has a weak thermal contact with the external ambient (solar gain, direct wind) and is strongly coupled inside. Shading devices like overhangs windows on the patio, where canopies covered well the space during the sunny days to prevent sun rays reaching the space, moreover windows' shutters are well designed for solar control and can greatly reduce the impact of peak heat conditions. Moreover, they also improve the quality of natural lighting inside buildings.

Figure 5.29 highlights the location of the loggers distributed in the two floors of TH1.

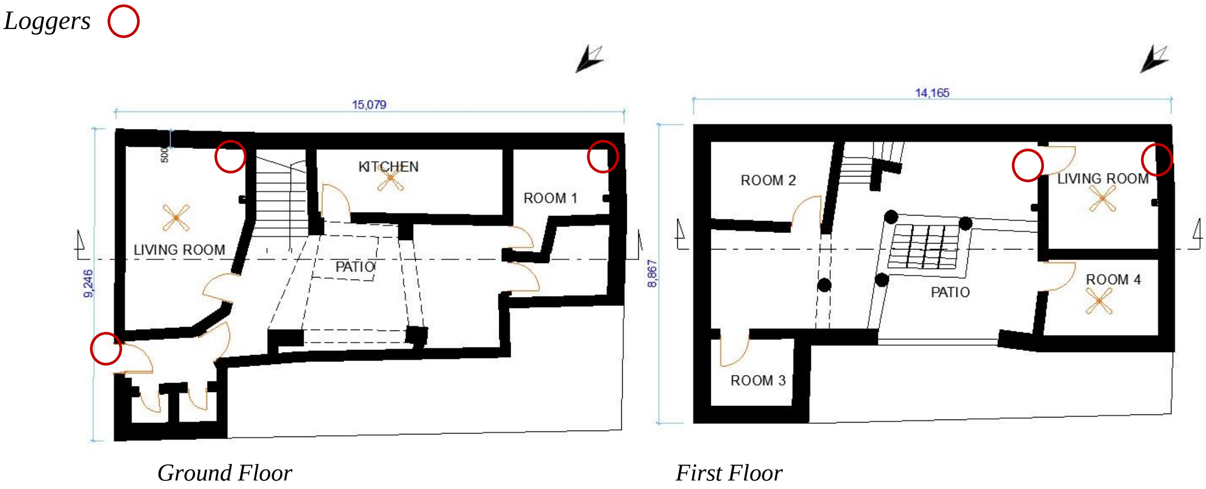



***Figure 5.29. The location of Hobo loggers in the habitable rooms and spaces of TH1 for the summer and winter measurements (source: by the Author).***

The construction materials used at Beni Isguen are those available locally , it is considered cheaper than the modern materials, which does not require at the stage of their production, and transport and even their expenditure implementation excessive energy that generates pollution harmful to health and the environment. Limestone bricks (400 mm) and lime sand render (50 mm) were mainly used for the internal and external walls, which resulted in a U-value of 2.00 W/m2 K. The roof also used the same materials but in four layers i.e., 20 mm of limestone on the outside and 20 mm of lime mortar on the inside using the palm branches to support the roof bottom, which resulted in a U-value of 1.88 W/m2 K, See Figure 5.30 and thought to substantially influences the building's energy and thermal performance.

On the other hand, the internal walls were rendered either by gypsum plaster or ceramic tiles, such as in the kitchen and bathroom. The stone walls are an essential element, with a thickness of about 0.50 m, made of stones linked together by lime mortar. All the walls inside the building bear the same characteristics and they are all (500mm) thick. As for the exterior coating, the designers and builders of the project were inspired by traditional techniques that use lime mortar and sand which are spread on the surface of the wall using palm branches and a lime mortar; the purpose of using the fine sand proportionately is believed to give a better flexibility to the mortar (Figure 5.31).

***Figure 5.30 A section for the wall and roof inTH1 (source: by the Author).***

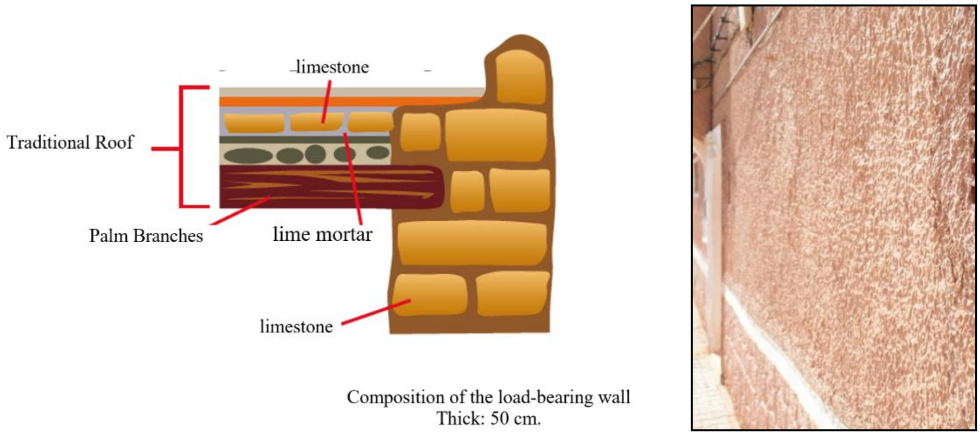



***Figure 5.31. The texture of the façade in TH1 (source: by the Author).***

A coarse texture, as shown in Figure 5.31, is used to provide shade to the walls and prevent excessive overheating (Rapoport 1972). The use of stone in this building, with regards to heat control, has the same benefits and characteristics as MH1.

### 5.5.2.1. Occupant's Observations:

- **Summer**:

From the questionnaire, it is clear that residents of TH1 indicated that all the traditional buildings had better thermal performance, compared to the new buildings in Tafilelt. Of all the spaces in TH1, the participants said that they felt particularly comfortable in the patio. In old buildings like TH1, there are a variety of adaptive strategies that can be taken to ensure better cooling techniques and thermal comfort including pouring water around the patio and floors, moving to the most comfortable space which is usually in the centre of the house that is far from the external walls and close to the patio, adjusting clothes, removing carpets, turning on cooling equipment (ceiling fans), and closing all exterior windows to prevent thermal discomfort. The alleyways (see Figure 5.28) in Beni Isguen kept pedestrians safe and comfortable from severe winds, sandstorms, and direct solar radiation.

***Table 5.7. Space usage in TH1 during the summer***

| **Summer** | **Morning** | **Lunch** | **Afternoon** | **Evening** |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | Eat | Eat | Eat | N/U |
| Living room (ground floor) | Eat | Socialise | Sleep | Socialise |
| Hall (First floor) | Socialise | Socialise | Sleep | Sleep |
| Rooms (first floor) | N/U | N/U | N/U | Sleep |
| External Spaces | | | | |
| Patio | Socialise | N/U | N/U | Sleep |
| Roof terrace | N/U | N/U | N/U | Sleep |

*Key: Never used (N/U), Sometimes used, frequently used.*

From Table 5.7, it can be noticed that usage of spaces in TH1 are almost similar to that in MH1. During the morning, the patio (or courtyard) is mostly used for socialising, as the sun is still low, and the open-air courtyard is better protected from solar radiation. As the sun rises higher, the rooms around the courtyard become the epicentre of household activities as they are protected from solar radiation (although the courtyard is not), with the external temperature reaching its peak at 39°C around midday. The rooms around the courtyard have wide windows, compared to those found on the main façade of the dwelling. During early morning and evening, the cool air comes into the rooms through the windows, and after it becomes warmer inside, it flows to the courtyard through the upper parts of the windows which creates a stack ventilation.

- **Winter**:

The spatial arrangement of the house was influenced by the family's needs during the winter; the kitchen, living room and the first-floor room are essential aspects of the house's spatial arrangement, where daily activities such as cooking eating and housework are usually done (Table 5.8). However, the occupants stated that they felt uncomfortable occupying the patio and so they occasionally use it during midday due to the cold conditions (14~15°C) compared to the other spaces; in addition to its smaller size that limits the exposure to solar radiation making it not within the comfort boundaries of ASHRAE 55. According to Table 5.10, the average indoor temperature during daytime fluctuates between 12°C ~ 15°C, while the average outdoor temperature remains as low as 6°C. The relative humidity average fluctuates between 60 and 15%, increasing at night and decreasing during day.

***Table 5.8. Internal and external spaces occupied during the winter in TH1***

| Winter | Morning | Lunch | Afternoon | Evening |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **Eat** | **N/U** |
| Living room (ground floor) | **Eat** | **Socialise** | **Socialise** | **N/U** |
| Hall (first floor) | **Socialise** | **Socialise** | **Socialise** | **Socialise** |
| Rooms (first floor) | **Sleep** | **Socialise** | **Sleep** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **N/U** | **Socialise** | **Socialise** | **N/U** |
| Roof terrace | **N/U** | **N/U** | **N/U** | **N/U** |

*Key: Never used (N/U), Sometimes used, Frequently used.*

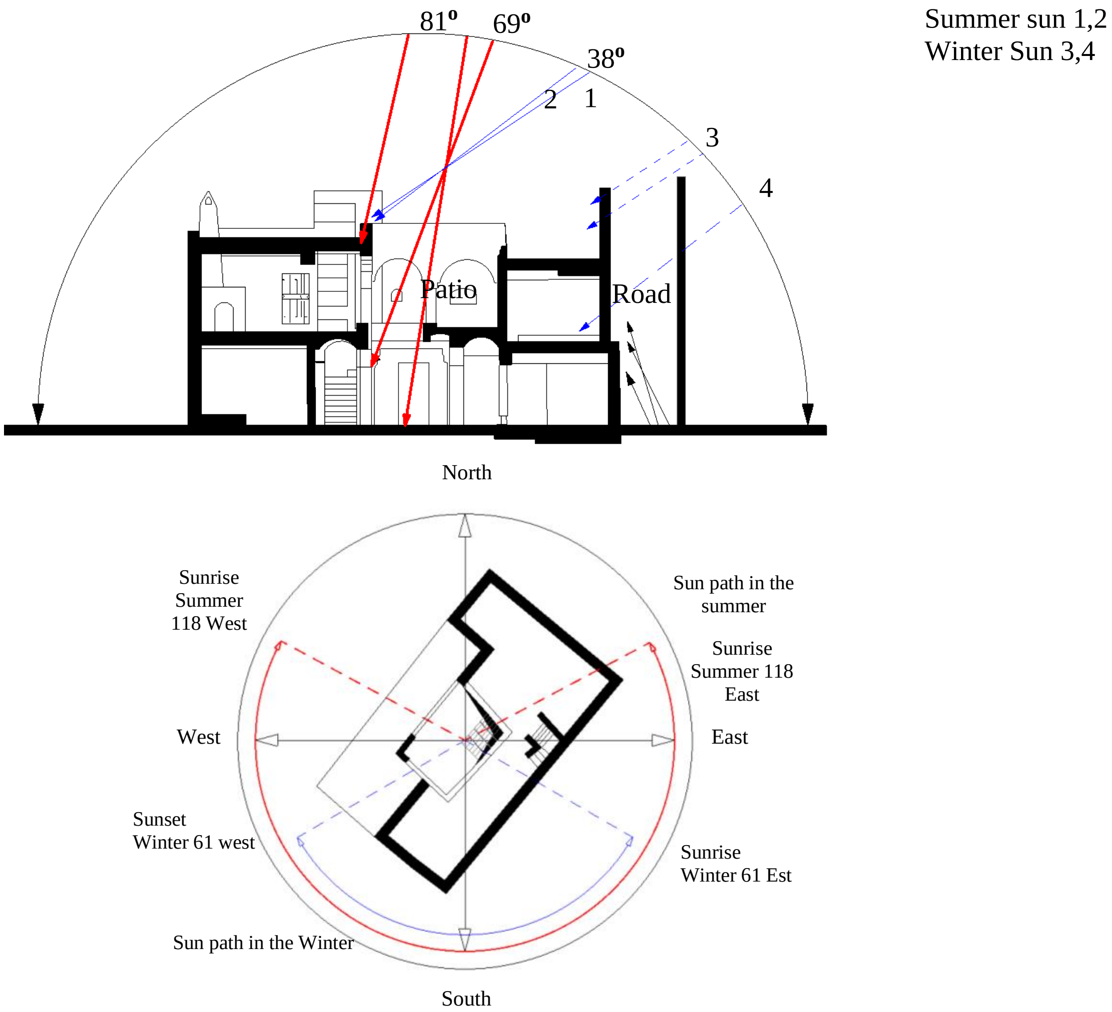



***Figure 5.32. Morphology of the sun's path through the indoor spaces during summer and winter (source: by the Author).***

All the courtyard houses are surrounded by built rooms with thick walls 6.5 m high with an average thickness of 50 cm within a compact urban texture. They were built to protect the inhabitants from the extreme summer heat. Moreover, the main roads in Beni Isguen are east-west orientated for the primary roads (3 m depth), while the secondary roads are north-south oriented (less than 2 m depth). The roads are planned and built this way so as to block sunlight during the summer while allowing it in winter, which linked to the geometric H / W ratio of the street and the dimensions of the galleries (height and width). Consequently, the façades are insulated from solar radiations as well (Figure 5.32) which reduces heat gain and heat loss. It can be seen that traditional houses use more insulation (more than 3cm of gypsum) on the building envelope's exterior and use the rough surface on buildings texture figure 5.31. This helps control the average indoor radiant temperature by isolating the interior surfaces from the influence of exterior conditions, in addition to reducing the draughts produced by temperature differences between the walls and the air (Figure 5.33). Furthermore, the natural shading of the compact tissue, either as parts of a building or separately placed on the façade, significantly reduce the peak heat conditions, enhance the cooling, and improves the quality of natural lighting inside buildings (Figure 5.34).


*Figure 5.33: Different Road widths and same orientation in Beni Isguen (source: by the Author).*

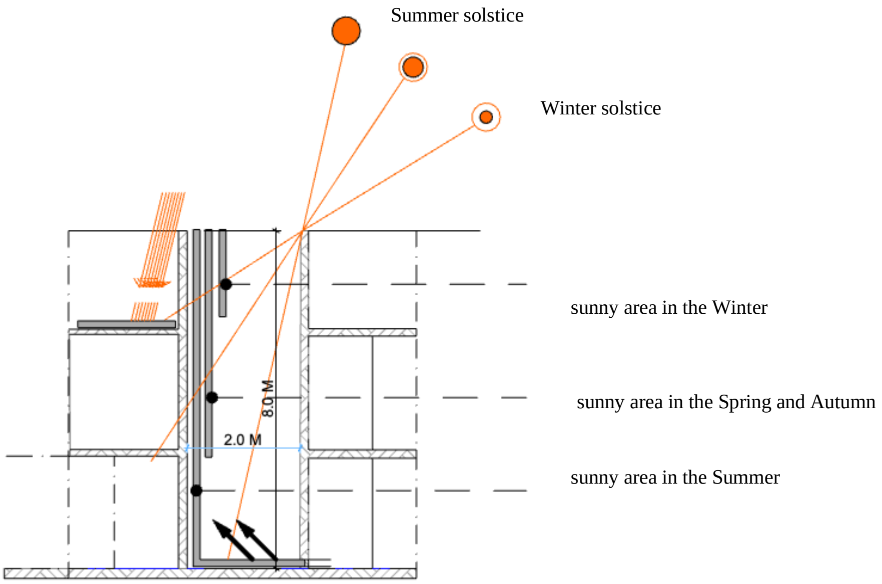



*Figure 5.34 The prospects in Beni Isguen at midday (source: by the Author).*

### 5.5.2.2 Summer Measurements in TH1 From 02/08/2018 to 09/08/2018:

The thermal conditions during the summer season are quite important, as this is the period when it is most affected by solar radiation. The internal mean daily air temperature ranged from 30°C to 36.5°C for the living room and the first floor while the recorded outdoor mean daily temperature varied from 23.5°C to 39.2°C.

During the morning the occupants stated that they feel between normal and slightly warmer at early afternoon time. They also stated that they experience cooler climate during night time, where most of them sleep on the terrace and on the open patio. In contrast to the occupants of new houses like MH1 who said that they experienced discomfort during midday and evening, the occupants of TH1 indicated that they feel cool and pleasant during such times of the day during the summer season. Table 5.9 summarises the recorded temperatures in TH1 during the monitoring period. It worth remembering that TH1 does not have any kind of air-cooling system in any of its spaces; it uses only ceiling fans.

***Table 5.9. Average, maximum and minimum relative humidity of TH1 during the summer***

| TH1 Space | Temperature (ºC) | | | |
|---|---|---|---|---|
| | Mean Temp | Daily Max | Daily Min | Mean Diurnal Range |
| **Living room** | 30.1 ºC | 30.8 ºC | 29.5 ºC | 1.3 ºC |
| **Room 1** | 35.0 ºC | 36.5 ºC | 33.5 ºC | 3.0 ºC |
| **Patio** | 32.3 ºC | 33.3 ºC | 31.3 ºC | 2.0 ºC |
| **Outdoor** | 31.5 ºC | 39.2 ºC | 23.5 ºC | 15.7 ºC |

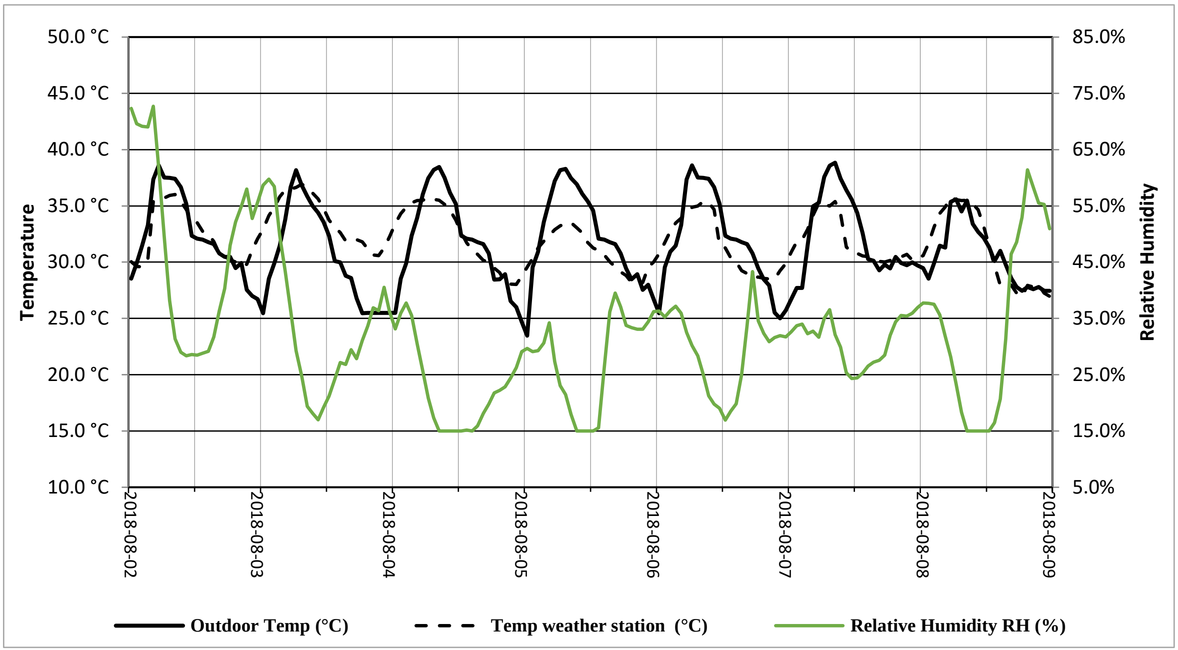



***Figure 5.35 The recorded outdoor dry-bulb temperature and relative humidity during the summer for TH1.***

Figure 5.35 shows the recorded outdoor dry-bulb temperature and relative humidity for the first week of August 2018 starting from then 2nd August to 9th August. The average daily sunshine duration in Beni Isguen was about 12 hours, it can be noticed from the table 5.9, the lowest recorded indoor temperature was 29.5°C in living room, and the the highest recorded temperature was recorded in the first-floor room 36.5°C. Additionally, the running mean outdoor air temperature (Trm) ranged from 23.5°C to 39.2°C with diurnal temperature variation about 15.7 K as an average. During the first two days at noon, a noted high RH was recorded at 70% compared to other days owed to pouring the water during the evening aiming to cool down and achieve high air moisture. For the rest of the days, generally the RH was less than 30%, which reflects the very hot and dry climate. For TH1, a very steady temperature was surprisingly recorded during the measurement period. The data logger’s setup and operation were investigated for any flaws. But it was found that all the devices were working normally when used outside the building.

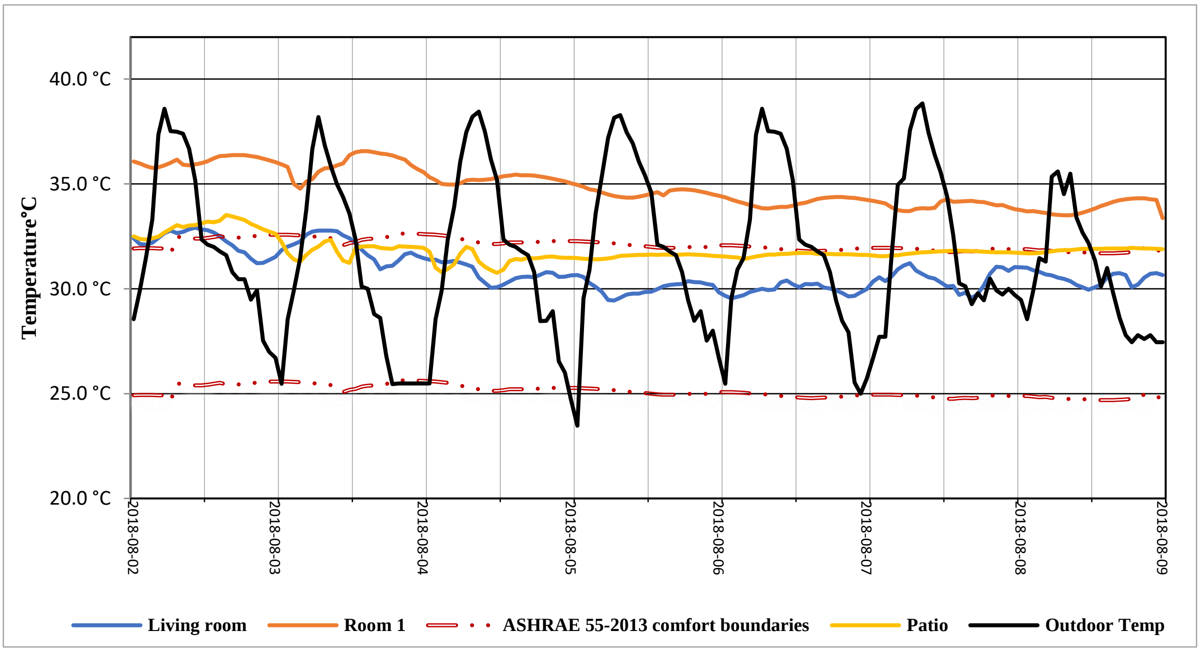



*Figure 5.37. Indoor dry-bulb temperature over a period of one week with the comfort boundaries of ASHRAE 55 for TH1.*

As shown in Table 5.7, all occupants use natural ventilation in the patio from late night till morning (8:00 pm – 9:00 am) which has a temperature range of 31.3 °C to 33.3 °C as shown in Figure 5.37. During the morning, all activities are centered around the patio. However, it was also found to be the hottest place during the midday when the sun is perpendicular at the space, with the temperature going as high as 39.2°C at 15:00 hrs. Moreover, the first floor, which recorded a temperature fluctuation between 33.5°C and 36.5°C during the measurement period, failed to meet the acceptability limits of the ASHRAE adaptive comfort criteria.

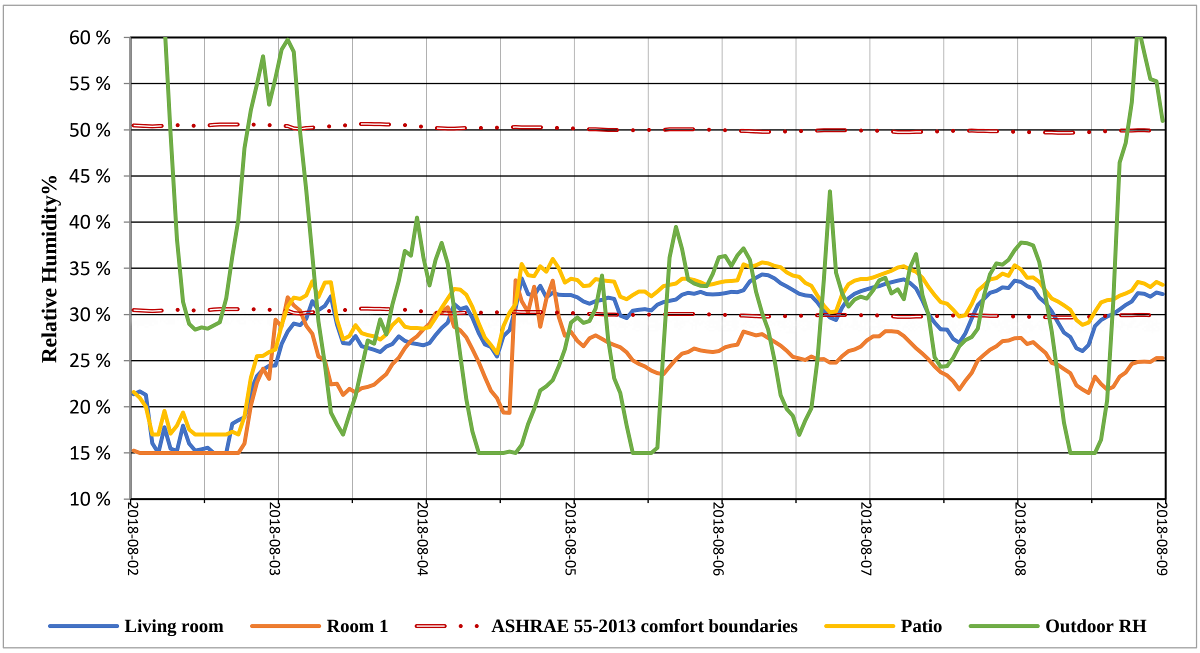



*Figure 5.38. Mean relative humidity over a period of one week the with comfort boundaries of ASHRAE 55 for TH1.*

The reason is due to the lack of air conditioning and constant exposure to the sun. In contrast, the living room maintains a steady range of 29.5°C to 32°C, successfully meeting the acceptability limits of

ASHRAE 55 (Figure 5.37). The chance of the indoor temperature exceeding the outdoor temperature is significant after mid-night, this is due to heat storage during the day and allowing the heat exchange increased to constantly occur by convection during the nighttime. The mean outdoor temperature has a remarkable effect on occupants' thermal preference vote during the summer in terms of using natural ventilation. Most occupants feel uncomfortable outdoor during midday when the air temperature reaches 39.2°C. However, they start to feel slightly cooler and more comfortable during the hours between midnight and early morning (06:00 am) since the temperature comes down to 23.5°C.

During the first two days of the measurement period, the relative humidity was very low in TH1 due to the weather characteristics and the lack of vegetation cover. On the third day, there was a significant increase in humidity, after referring to the residents, their answer was that it was the result of pouring water into the patio, which gave a cooling effect. Doing this increased the relative humidity to 15%, while helping to decreasing the temperature. In contrast, the mean relative humidity outdoors is 25% higher than that of indoors, that for 40% of the measurement period, the average relative humidity was within the adaptive thermal comfort range. Note that the patio maintains a high humidity and low temperature compared to the other indoor spaces, which makes it the best place to be in (Figure 5.38).

#### 5.5.2.3. Winter Measurement in TH1 From 03/01/2019 to 10/01/2019:

Over the first week of January, data recorded outdoor and indoor thermal environment for the living room on the ground floor, the Patio, and the first floor room1. The room 1 was chosen as it is open to the patio and its roof is exposed to sunlight. The occupants use stoves regularly as heating systems during the winter.

The lowest indoor monitored temperature was experienced in the patio (12°C), and recorded a mean daily temperature ranged from 12.0°C to 22.0°C, which failed to meet both 90% and 80% acceptability limits of ASHRAE adaptive comfort criteria (see figure 5.39 and figure 5.40).

The living room on the first floor is one of the main habitable rooms due to the heater installed there; it remains steady during the monitoring record with mean daily temperature ranged from of 20.0°C to 22.5°C (table 5.10 and figure 5.40), and a range of the relative humidity is between 38% and 48% which considered with-in the comfort boundaries (Figure 5.41).

***Table 5.10 Average, maximum and minimum temperature of TH1***

| **TH1 Space** | **Temperature (ºC)** | | | |
|---|---|---|---|---|
| | **Mean Temp** | **Daily Max** | **Daily Min** | **Mean Diurnal Range** |
| **Living room** | 21.2 ºC | 22.5 ºC | 20.0 ºC | 2.5 ºC |
| **Room 1** | 20.0 ºC | 21.5 ºC | 18.5 ºC | 3.0 ºC |
| **Patio** | 14.0 ºC | 22.0 ºC | 12.0 ºC | 10.0 ºC |
| **Outdoor** | 11.5 ºC | 16.5 ºC | 06.5 ºC | 10.0 ºC |

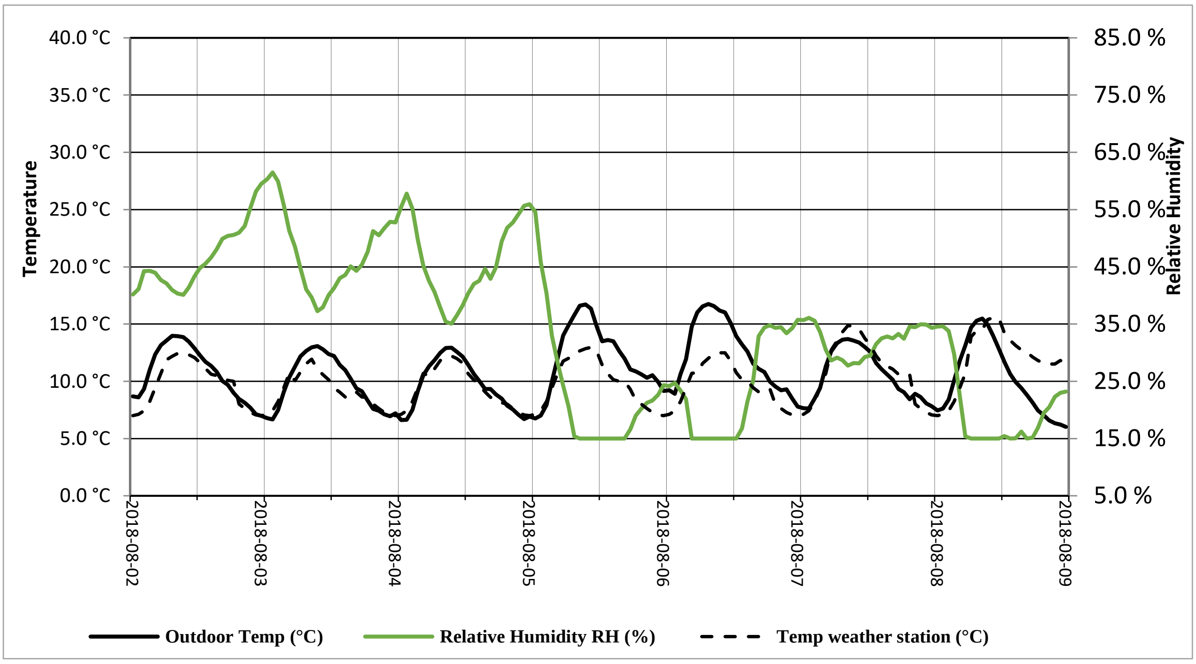



*Figure 5.39. The recorded outdoor dry-bulb temperature and relative humidity during the winter for TH1.*

Table 5.10 summarised of TH1's temperatures during this period and as figure 5.40 shows the monitoring period of the four spaces of the traditional house in Beni Isguen TH1. The outdoor mean daily temperature ranges from 6.5 °C to 16.5°C, which was considered very cold and failed to meet the acceptability limits of ASHRAE adaptive comfort criteria (i.e., 80% acceptability limit), The lowest temperature was recorded between midnight and early morning (6.5 °C). The peak outdoor temperature was found to be 16.5°C at 14:30 hrs.

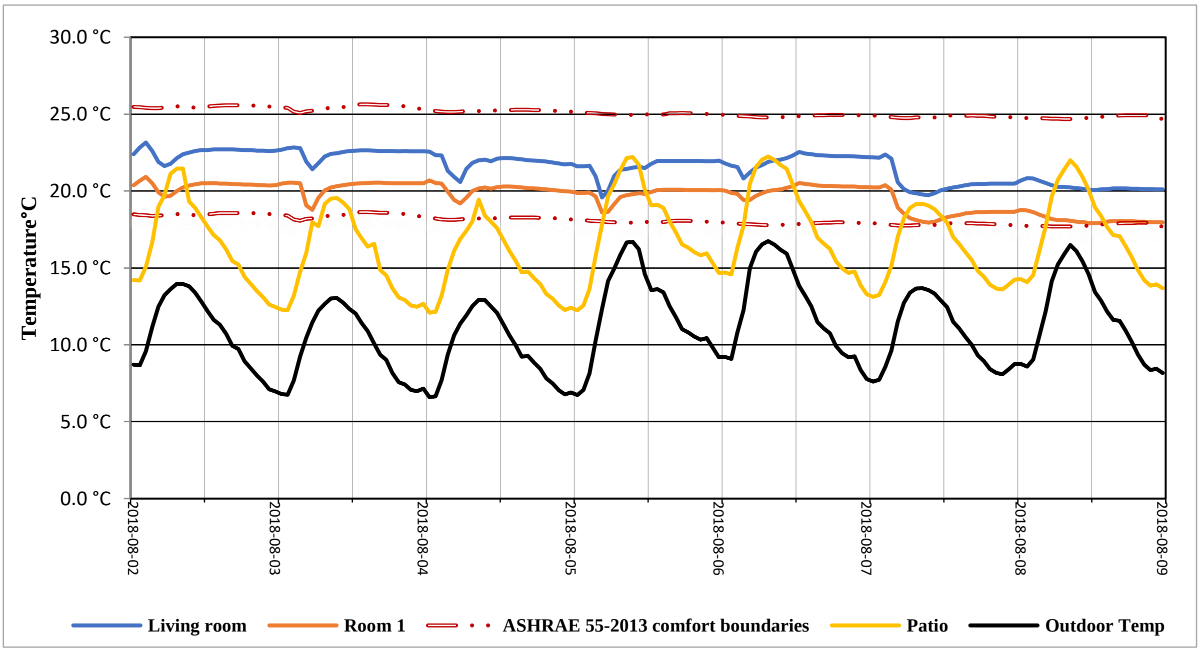



*Figure 5.40. Indoor dry-bulb temperature over a period of one week with the comfort boundaries of ASHRAE 55 for TH1.*

In addition, it was observed that the recorded temperature at the patio was clearly different to the outdoor temperature, which has an effect on the surrounding areas, such as the living room and the rooms, this is what prompted the occupants to the use of the stove heaters during the cold days. Interestingly, the occupants utilise different spaces during winter. In fact, the centre of all activities gets transferred from the patio to the hall on the ground floor, thus making it a winter room or in other words, it becomes the family room, thanks in part due to the heater installed in the room which distributes heat the surrounding rooms as well.

The relative humidity ranged from below 15% to 61% and in the patio which was normally occupied from 8 am until 04 pm where the relative humidity was ranged from below 30% to 47%, making it similar and very consistent living room and first floor room on the first three days of the measurements (Figure 5.41). This indicates that all the indoor and outdoor spaces were well within the adaptive thermal comfort range during the measurement period.

The patio and the living room showed different values from the third day of the measurement period. The occupants stayed in the hall throughout the day. According to their diary responses, this is due to the comfort provided by the heating in the living room. The occupants kept the door and windows closed in the morning and afternoon to avoid the cold air from the patio or outdoor spaces. This was also when the heating operated. The thermal environmental conditions prevailing in the living room were comfortable during this period of time. The distributed heating from the living room also helped the residents to use their bedrooms during the night.

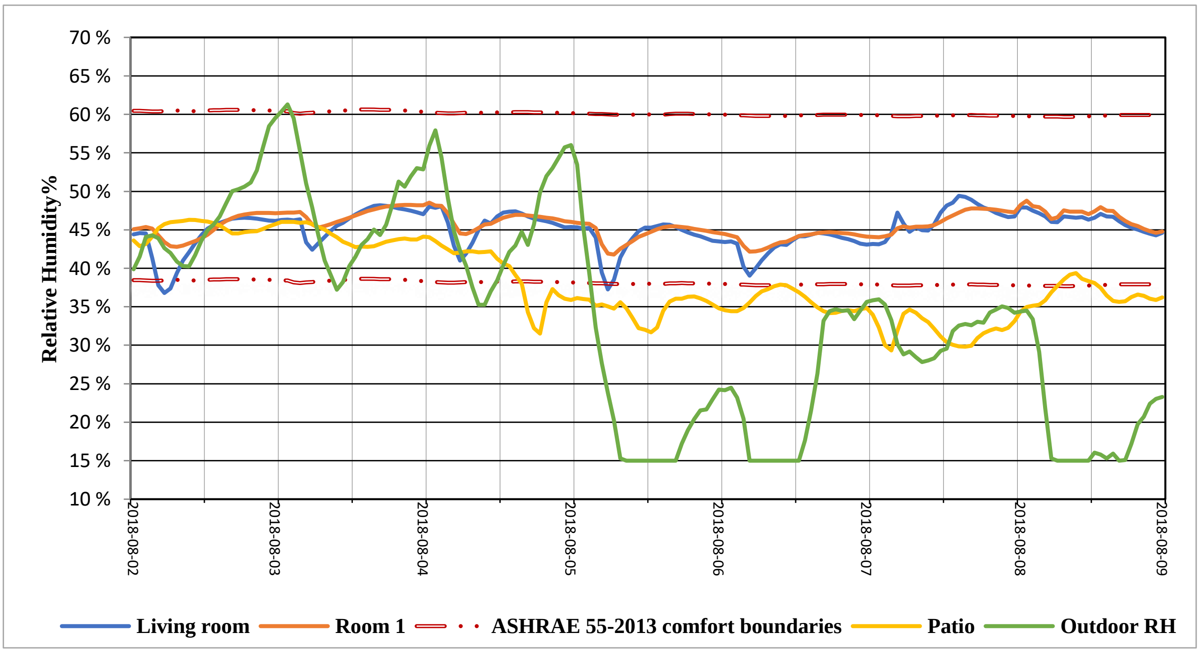



***Figure 5.41 Mean relative humidity over a period of one week the with comfort boundaries of ASHRAE 55 for TH1.***

### 5.6 Comparison between MH1 and TH1:

This section analyses the aforementioned findings together with an analytical comparison of the thermal performance of TH1 and MH1 for one week during the summer and for another week during the winter to understand the current occupants’ comfort, satisfaction, and perception of the thermal performance of these houses. The measurements will present the air temperature and the RH values (average, maximum and minimum) graphically for four spaces (outdoors, patio, living room, and room 1) for both houses, in addition to the dairy entries and thermal monitoring.

**5.6.1 Summer Measurements From 02/08/2018 to 09/08/2018:**

- **Outdoors:**

Significantly, the flow of data has the same curve pattern with small variations, which could have an impact on the indoor temperatures, the outdoor mean daily temperatures readings show in MH1 within range of 27 to 41 °C at midday, whilst for TH1, it was the mean daily temperatures ranged from 23°C to 39°C (Figures 5.42). The diurnal temperature variation is found to be noticeable between the MH1/TH1 up to 6 k during the daytime and lowest during the night-time up 2 k. The road widths in Beni Isguen played a substantial role as well as the building heights, the narrow passageways of the city and the light wells provided natural ventilation, creating different pressure zones which caused air movements to move from high-pressure zones to low pressure zones, where the hot air is replaced with cooler and humid air in the shaded passageways. Additionally, in MH1, the high solar exposure on the exterior walls created a temperature gradient allowing heat exchange to constantly occur by radiation and also caused a high indoor temperature by convection.

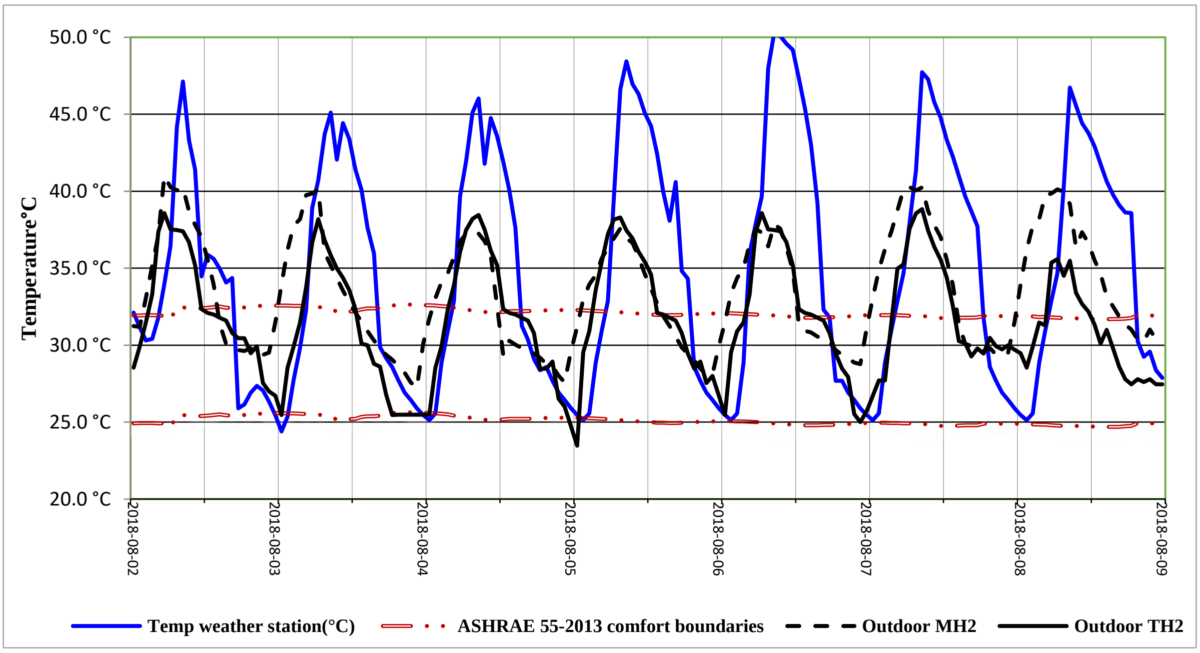



*Figure 5.42. Comparison of the outdoor summer temperatures for one week.*

It is generally observed the recorded RH frequently outside the ASHRAE range which is considered as very dry climate especially on the MH1, where noted that the RH less than TH1 which is below the recommended criteria of thermal comfort and the average air temperatures. The variation between the daily minimum and maximum relative humidity is shown to be different between both building MH1/TH1, this is due to the residents of the TH1, were using the watering and irrigation process, which makes big and flash differences.

It was also noted that on at the start of the week and the, the occupants poured water on the narrow roads to cool the air which, in turn, increased the humidity, as seen in the graph (Figure 5.43).

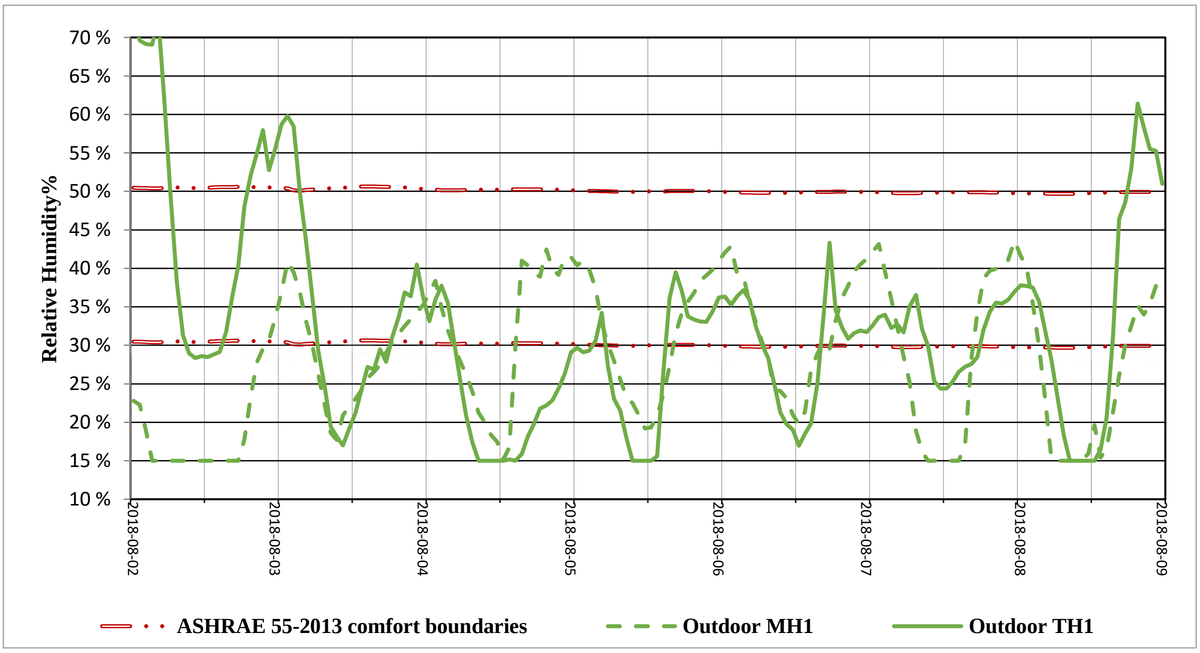



*Figure 5.43 Comparison of the relative humidity during for one week during the summer.*

- **Living rooms:**

The mean daily temperature for TH1 range of 29°C to 32°C, which is within the recommended criteria of thermal comfort and the acceptability range ASHRAE 55.

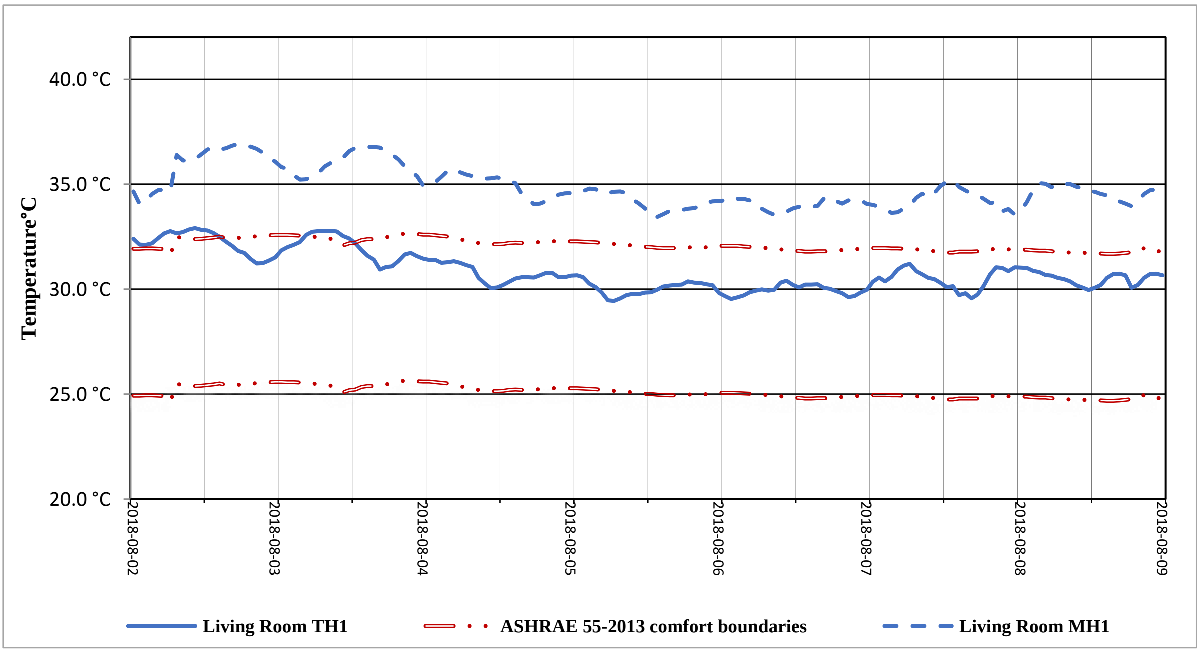



*Figure 5.44. Comparison of the living room temperatures during a week in the summer.*

The lowest indoor temperature (29°C) was possibly due to the advantage of a north-west oriented opening faces the patio as the temperature started to increase from 12:00 hrs as the solar radiation reached the ground floor through the patio. Meanwhile, on MH1 the air temperatures fluctuated between 34°C and 37°C (Figure 5.44) which is about 5°C higher than that of TH1.

Furthermore, the mean daily RH remained within the range of 15% to 34% (Figure 5.45), which seems to take a similar pattern in both buildings.

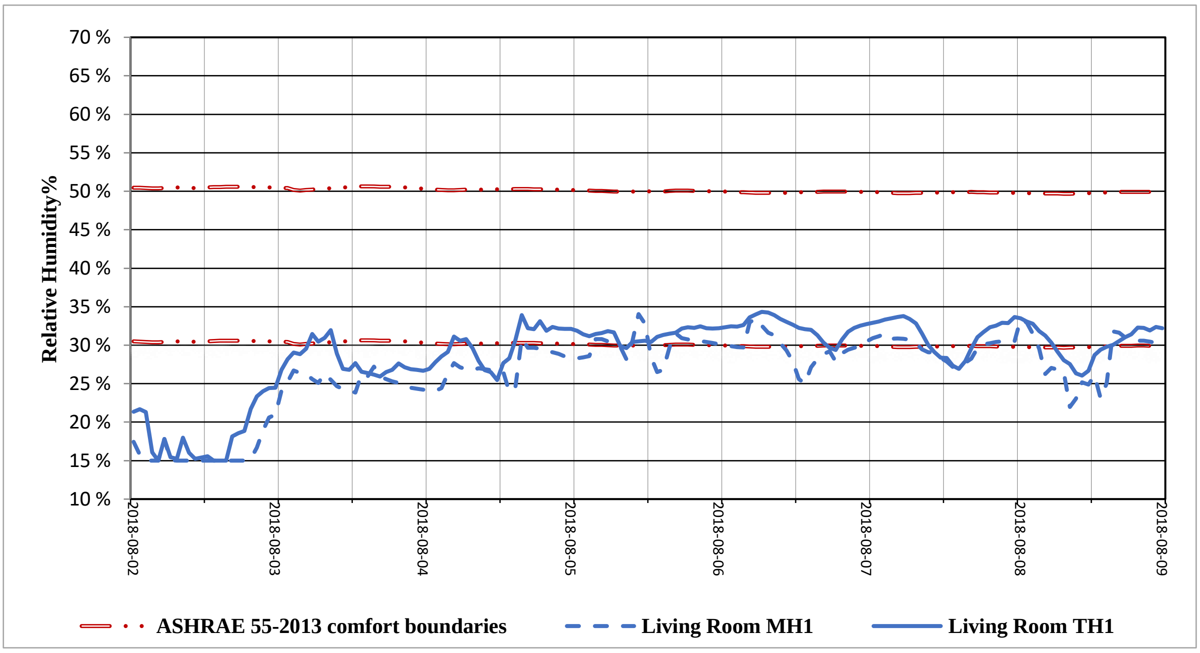



***Figure 5.45. Comparison of Living Room relative humidity during the summertime for one week.***

The MH1's temperature was above the recommended criteria of thermal comfort and the average air temperature values during the whole week, despite both building has same characteristics, the fact that the thermal mass in MH1 influences the amount of excess heat accumulated during the day, which is sorted in the mass and then released the night, leading to rise of the indoor temperature, and making the living room environment as uncomfortable. The living room on MH1 is almost unventilated and far from the patio, its windows remain closed during the summer due to privacy reasons and out of respect for the occupants' beliefs. Overall, however, occupants were not satisfied with their thermal environment during the summer.

- **Room:**

Both first floor rooms at (TH1 and MH1) showed the same fluctuation pattern with different temperatures. This is a result of their location on the top floor. From Figure 5.46, the readings show that the mean daily air temperatures for TH1 and MH1 ranged between 33 to 35°C and 33.5 to 37°C respectively, which is above the recommended criteria of thermal comfort and the average air temperatures prescribed by ASHRAE 55. Both rooms were most affected by the outdoor temperature due to their direct connection to the external envelope through the roof and the patio opening.

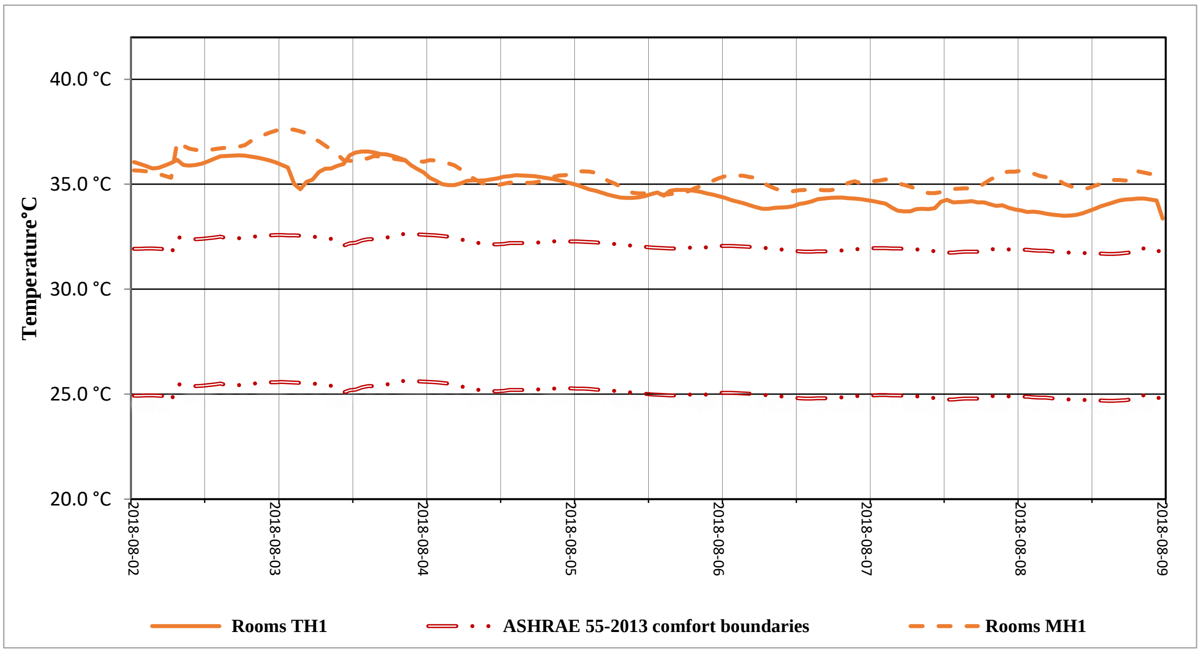



***Figure 5.46 Comparison of room temperatures during the summertime.***

The reason for the high temperature can be attributed to the roof which is the part of a building that receives the greatest solar radiation in both cases. The thermal performance depends, to a great extent, on its shape which is flat even though most successful roof design in hot arid climate was the dome roof , it is identified that the spaces with curved roofs have lower indoor temperature and lower heat gain compared with the spaces with flat roofs (Yaghoubi M, et al 2017) , based on his research on hot arid climate he pointed dome achievements the less heat flux per unit area, because the large self-shaded area and dissipate more heat than other flat roofs where it fully exposed to the sun  and leads that provide a sun protection surface better than the flat roofing.

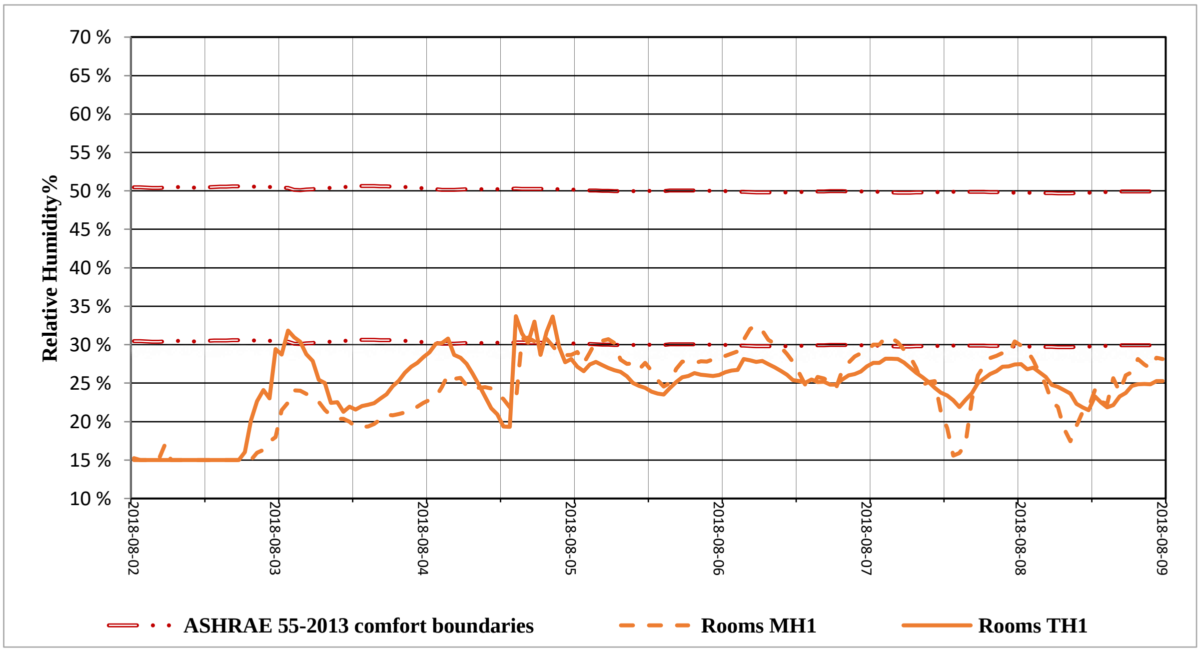



***Figure 5.47 Comparison of relative humidity during the summer.***

Meanwhile, the data reveals that the diurnal fluctuation of RH at TH1 was from 15% to 34%; on the other hand  the diurnal fluctuation of RH at MH1 fluctuated between 15% and 33%. This reflects the higher temperature reached in MH1 Figure 5.47.Likewise, the high and solid parapet walls along the edge of the roof can provide daytime shade and privacy but can also have the disadvantage of creating an undesired stagnant pool of hot air, which cannot float away because the small size of the windows and the ceilings height.

The major function of the roof in this case is to serve as a radiation shield by blocking off solar radiation. Effectively ventilating the attic in summer should not lead one to believe that heat gain to the building through the attic is greatly reduced. This is because most of the heat transfer through the attic is by radiation. despite the thickness of the roof, still the exposed to the sun for all day, which lead to function to serve as a radiation shield by blocking off solar radiation during the day and after transferred from the roof and walls by conduction to the inside building, which leads to rise the indoor temperature during the night.

- **Patios:**

Figure 5.48 indicates that the flow of outdoor temperature data in the patio for MH1 has the same curve pattern as TH1 patio temperature. For 70% of this period, TH1 patio's temperature was in the range 28°C ~ 33°C which is within the range of ASHRAE 55. It should be noted that the peaks and cooling loads for TH1 were nearly similar to the outdoor temperature during the week.

Meanwhile, the temperature in MH1 varied diurnally much less, showing only a slight fluctuation between 34.5 and 38°C which was out of the comfort boundaries of ASHRAE 55 throughout the whole measurement period, the period when the occupants being uncomfortable to use the patio. The relative humidity levels for MH1 and TH1 were slightly different and showed fluctuation ranges of 15% ~ 34% and 17% ~ 36%, respectively.

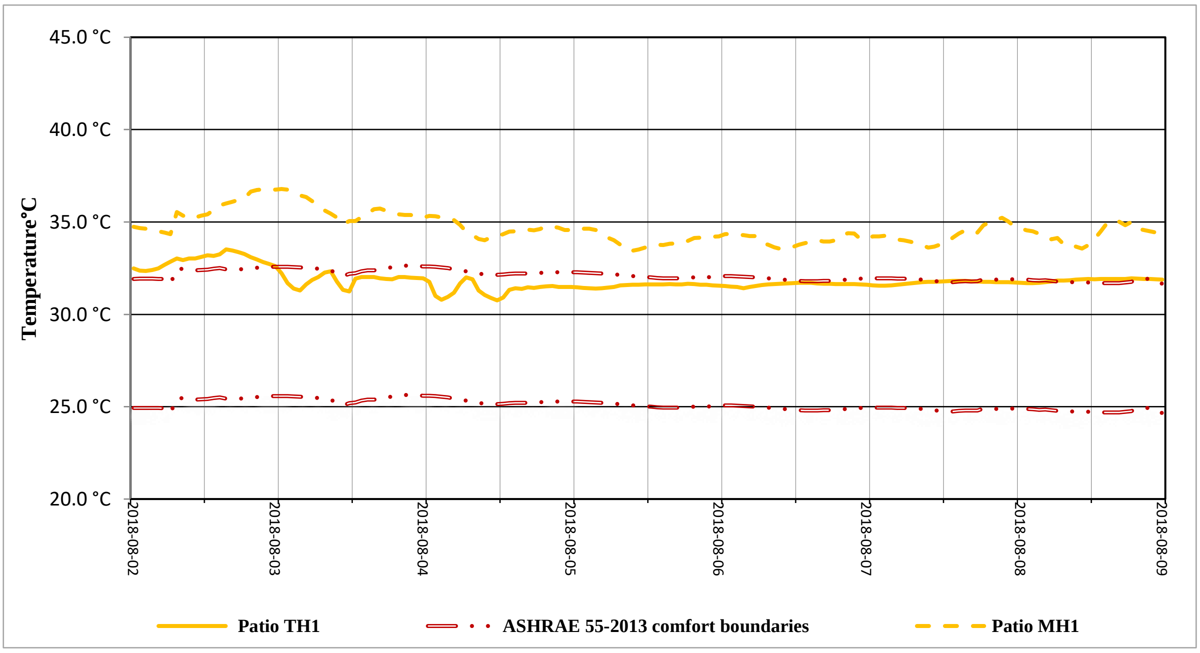



*Figure 5.48 Comparison of room temperature during the summer.*

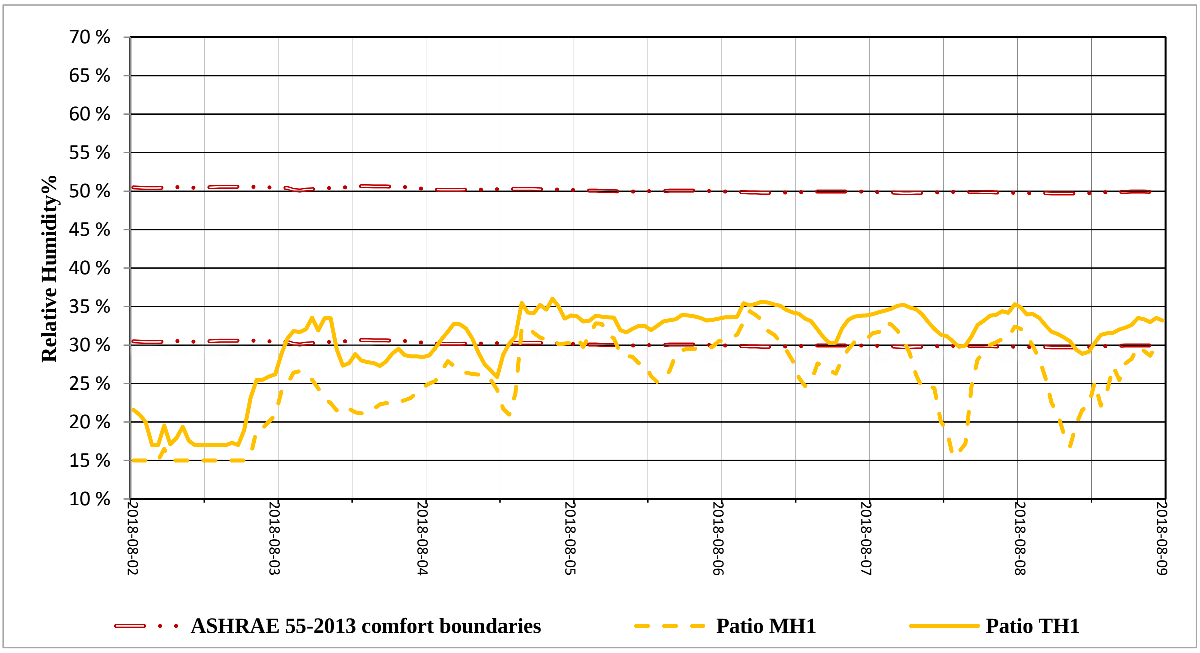



*Figure 5.49 Comparison of relative humidity during the summertime for one week.*

### 5.6.2 Winter Measurement From 03/01/2019 to 10/01/2019:

- **Outdoors:**

From Figure 5.50, it can be observed that the outdoor spaces in both TH1 and MH1 had generally the same fluctuation pattern but offset by 1~2°C. Based on the below figures, the air temperatures for TH1 and MH1 ranged between 6 and 16°C and 3 and 18°C, respectively which is below the recommended criteria for ASHRAE 55.

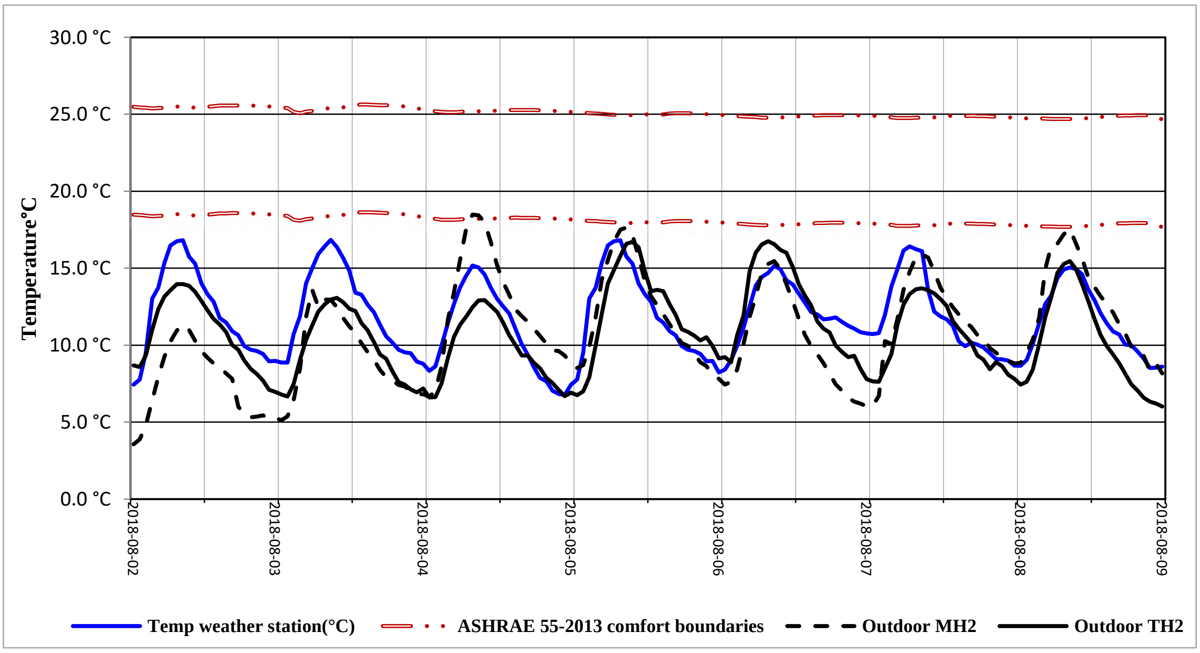



*Figure 5.50. Comparison of room temperature during the winter*

The recorded temperatures in MH1 reached about 18°C around midday and 6°C between midnight and early morning, this is due to the wideness of the roads in Tafilelt, which helps to expose the sun's rays on the walls and floor, making it warmer. Based on the urban morphology and to the compact urban fabric, it is noticeable that during the winter time, the only part that is exposed to external elements is the roof. Almost all external walls (parts) in the house are adjacent to a neighbouring house, exposed to external weather factors and the low temperature explains those figures to some extent. The relative humidity for TH1 was 100% within the ASHRAE range for the first three days, although it was only 60% for MH1, implying a dry climate (Figure 5.51); which could potentially be due to the cloudy days and the fact that it rained slightly during the first three days. In addition, MH1 is located in higher level compared to TH1 which is thought to influence the second half of the week.

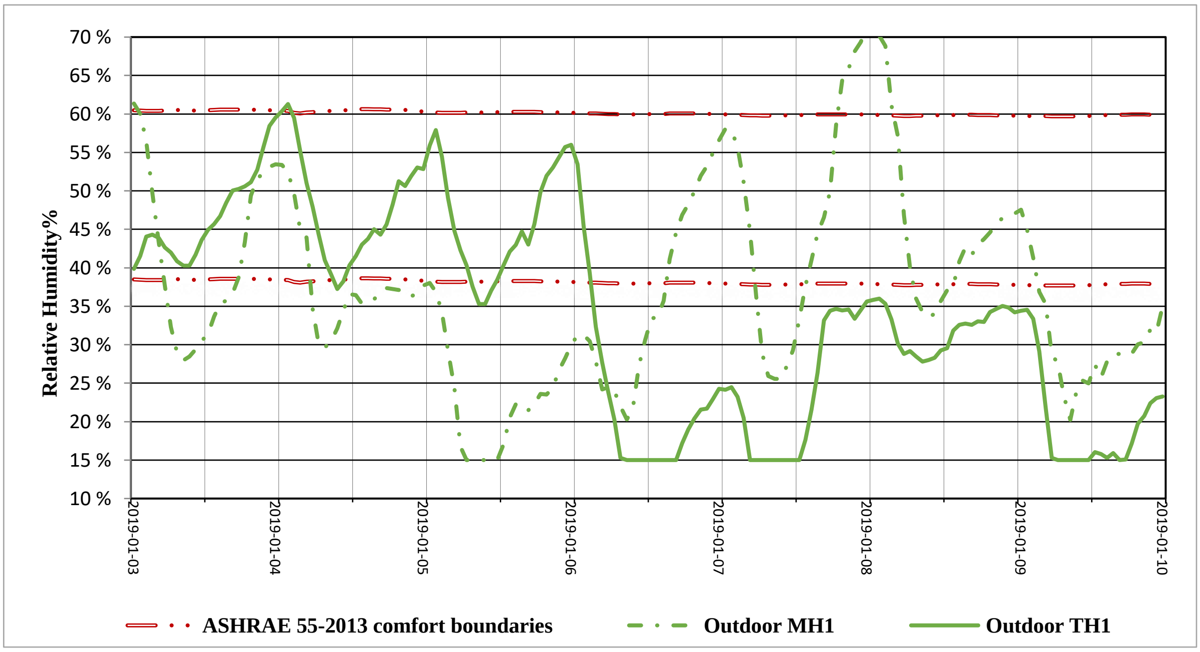



*Figure 5.51 Comparison of the relative humidity during winter*

- **Living Room:**

The readings show that the mean daily temperatures for TH1 ranged between 19°C and 22°C, remaining generally steady throughout the week and well within the recommended range of criteria ASHRAE 55. The household was generally satisfied with the warm indoor thermal condition, this is due to the use of stoves during cold days (Figure 5.52). It can also be connected to the casual heat gains, ventilation, and rate of infiltration.

The mean daily temperatures for MH1 ranged between 16.5°C and 18.5°C, with variation between the daily minimum and maximum dry-bulb temperature up to 2 K. Despite the extensive use of the gas stove to keep the temperature inside the living room warm, temperatures had slightly fallen below the lower margin of acceptability limits of ASHRAE adaptive comfort criteria. Moreover, the living room environment is slightly uncomfortable based on the occupants questionnaire, which was normally occupied from 8 am until 10 pm.

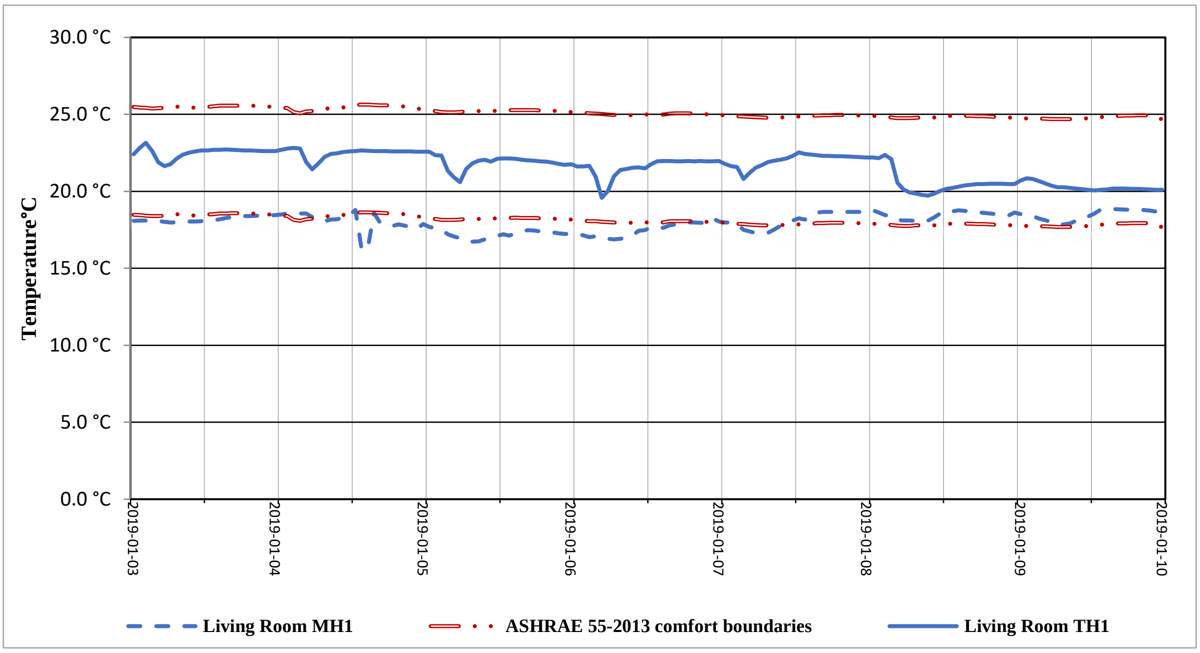



*Figure 5.52. Comparison of living room temperatures during winter (MH1/TH1)*

The mean daily Relative Humidity remained within the range of 36%–49% for which is 100% within the recommended range of ASHRAE 55 (Figure 5.53). Using this comparison shows that the living room air temperature was within the comfort zone during the winter period when a heat source was used regularly, indicating that TH1/MH1 does not have a good thermal performance during this season without the use of gas heaters.

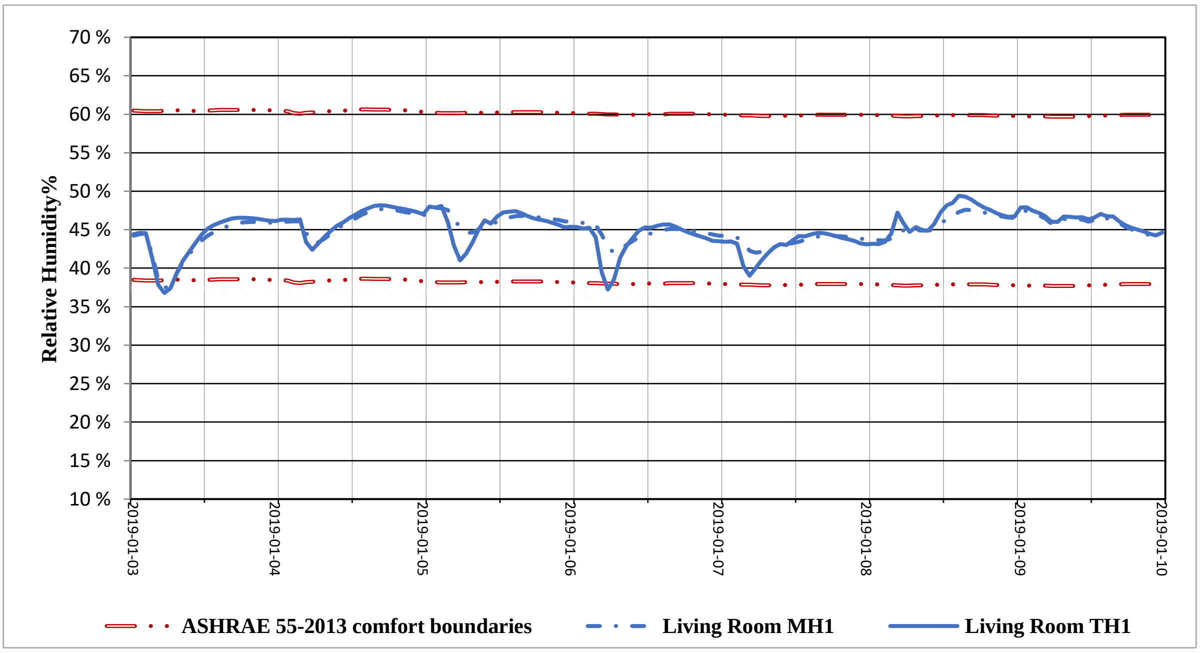



*Figure 5.53. Comparison of relative humidity during winter (MH1/TH1)*

- **First Floor Rooms:**

Over the period of the monitoring, the mean daily temperature for TH1 had been between 18°C and 20°C, indicating that the area was generally warm, wet, and well within the range of ASHRAE 55. Looking closely at the results, aside from the consistent improvement of thermal comfort for the rooms of both the houses, Figures 5.54 and 5.55 hint at much better thermal conditions in the top floor's rooms all the time. the diurnal temperature variation for MH1 is found to be around 3 k, with a lowest record of 18 °C. The comparison shows that the air temperature of the rooms upstairs was well within the comfort zone during winter since they regularly used a heating source.

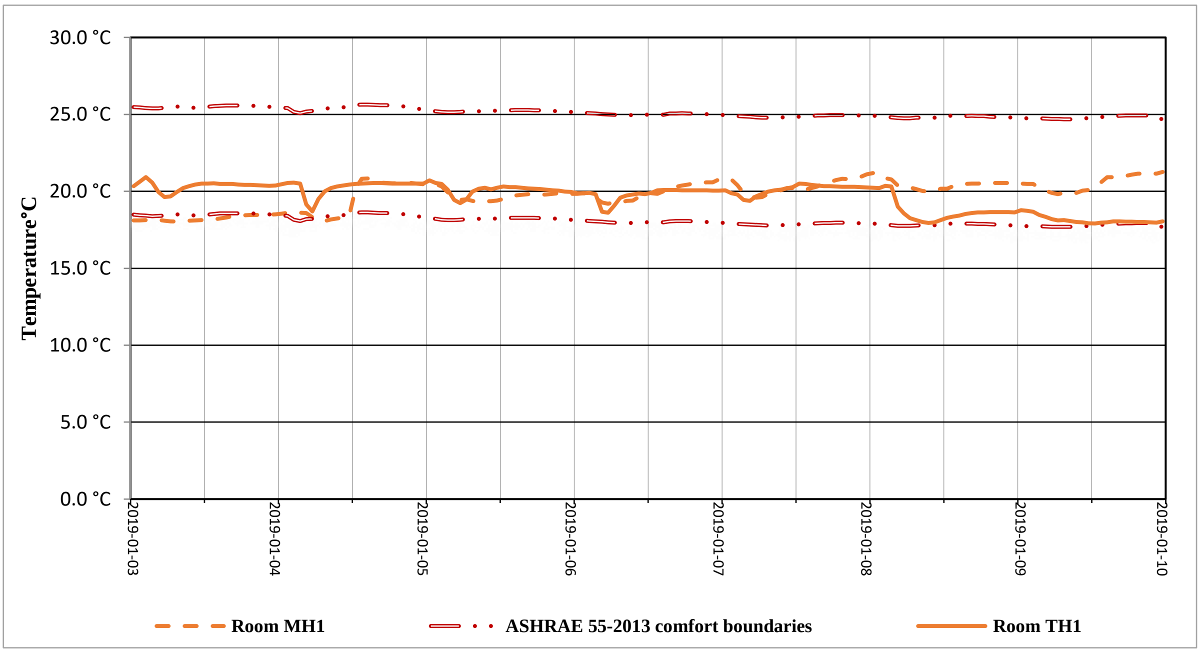



*Figure 5.54. Comparison of room temperatures during winter (MH1/TH1)*

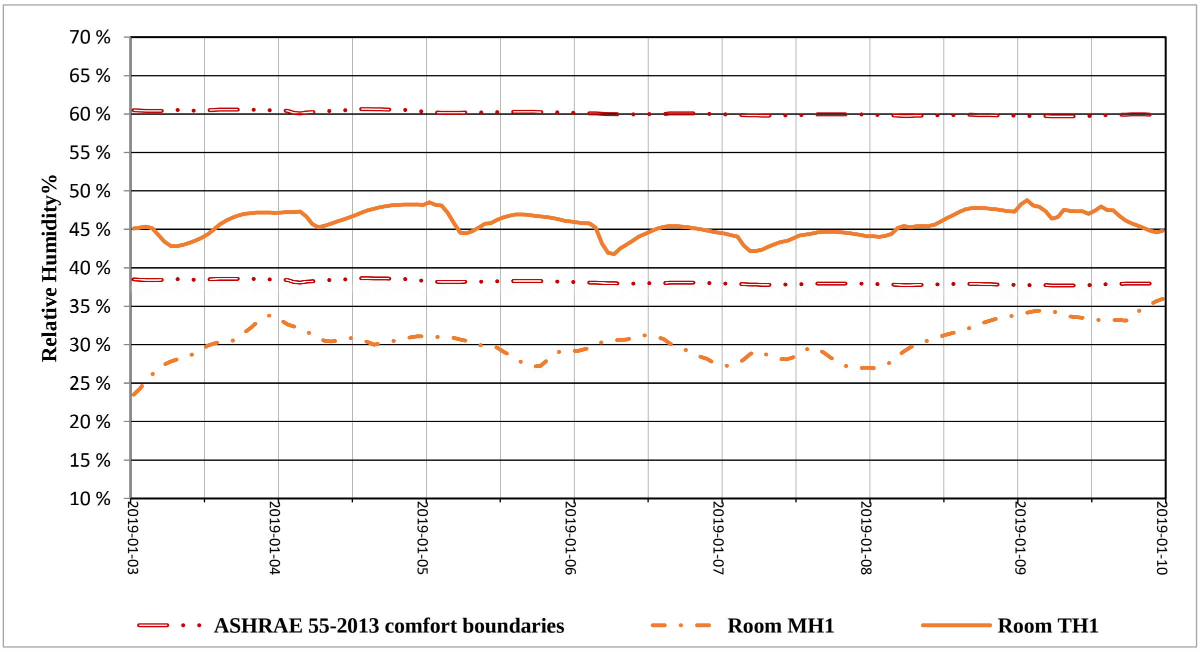



*Figure 5.55 Comparison of the rooms' relative humidity during winter (MH1/TH1)*

The relative humidity ranges are 41–47% for TH1 which is within the recommended range of ASHRAE 55%; it was recorded to be 23–35% for MH1 which is well below the recommended range of ASHRAE 55% (Figure 5.55). This indicates the thermal comfort considering both parameters examined that TH1 room 1 on the first floor is within the thermal comfort required during this season.

- **Patios:**

Both MH1 and TH1 had a similar curve pattern with small variations, which could have an impact on the indoor temperatures; TH1 had mean daily temperatures readings, which shows a range of 12°C to 22°C, with noticeable diurnal temperature variation 10 k, whilst for MH1, it was recorded to be 9.5°C to 23.5°C (Figures 5.56) estimating the diurnal temperature variation to be 14k. The patio in both location TH1/MH1 played a substantial role by being used in occupant's daily lives which the temperature started to increase from 10:30am as the solar rays reached the ground floor through the patio, which leads to rise the indoor temperature, as a result considered the patio environment as being comfortable during the midday.  It can generally be observed the recorded RH frequently inside the ASHRAE range for the first three days (for both houses) and by then the mean daily RH dropped below the recommended range (Figure 5.57). It can be summarised that TH1 behaved within the ASHRAE comfort boundaries compared to MH1 in that it demonstrated that living room and the patio are best places of the house for the occupants to use during the hot summer; the living room was again a comfortable place within TH1 to use during the winter months and partly the patio in addition to the bedroom on the first floor.

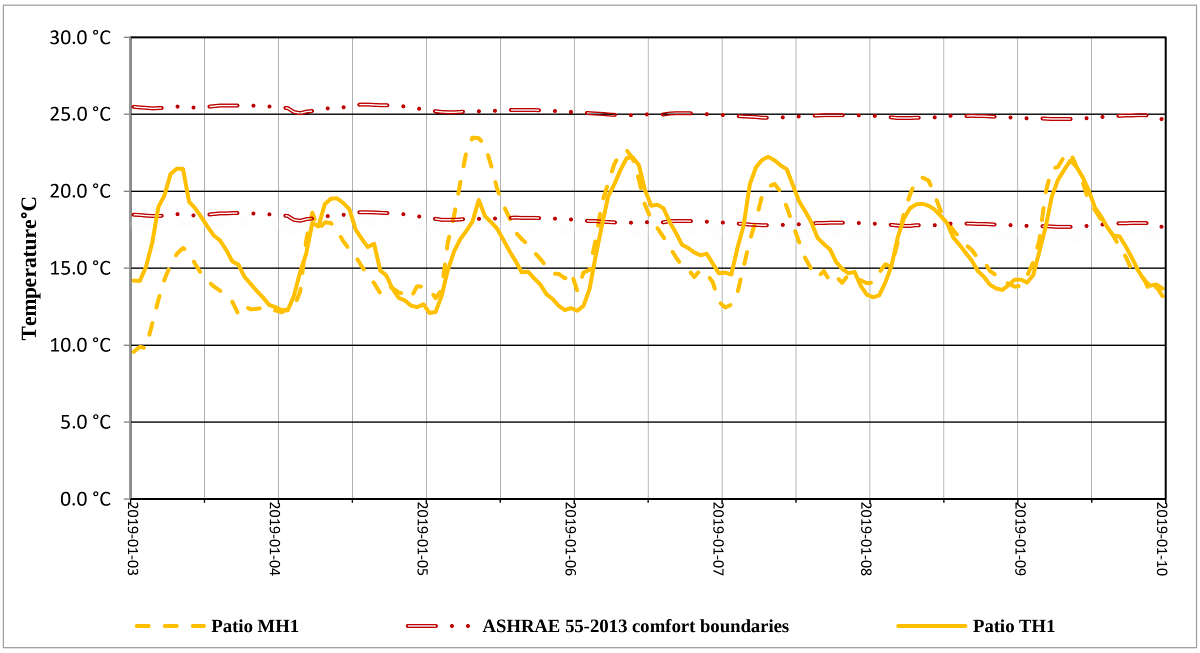



*Figure 5.56. Comparison of the patio's air temperatures during wintertime.*

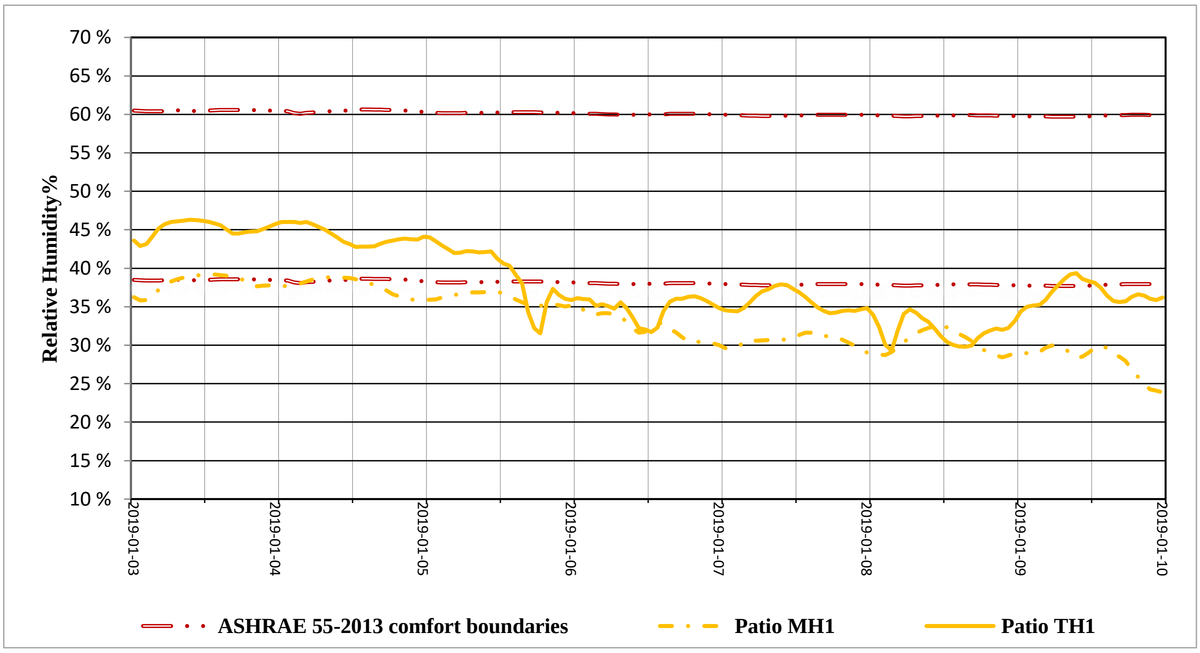



*Figure 5.57 Comparison of the patio's relative humidity (MH1/TH1) during winter*

## 5.7 Traditional House (TH2):

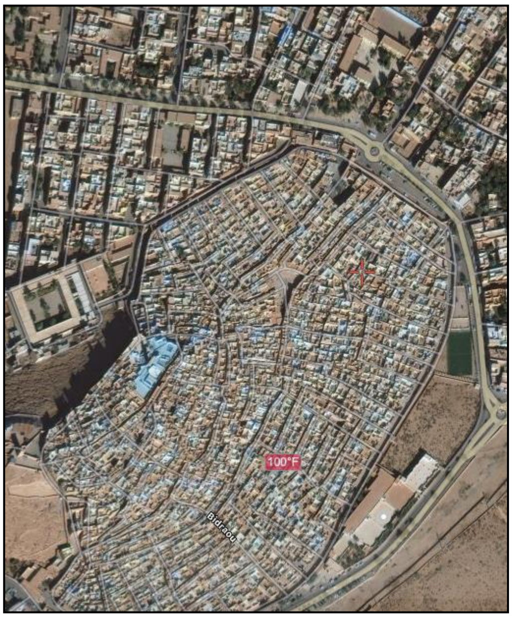
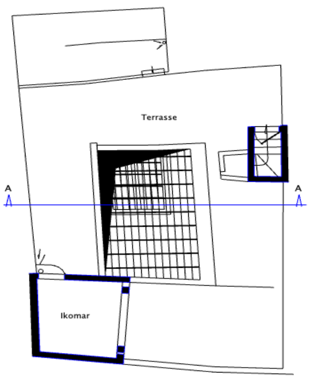


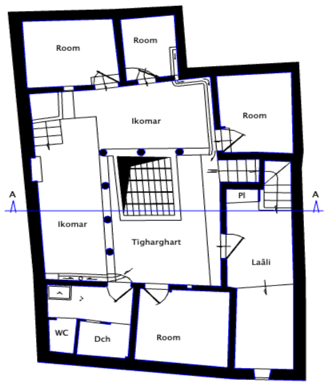
*Figure 5.58. An aerial view showing the location of the house TH2 ((source: Apple maps )*

TH2 is considered to be more than 400 years old and is a medium-sized double-storey (ground floor and first floor) house that has a roof terrace and basement. It comprises eight rooms and a lot of other spaces which is not surprising, covering an area of approximately 170 m$^2$ and a ceiling height of 3.3 m. The ground floor, the house incorporates a courtyard which is located in the centre of the house with a good connectivity to the activities' spaces including a living room and four bedrooms along with two other gathering spaces that are located around the courtyard including a colonnaded gallery which opens into the courtyard. The first floor comprises a living room (the main family space) and four similarly designed medium-sized rooms which are located around the patio. The basement floor comprises one room and some storage spaces which is used for keeping the food and other household items. The terrace is an open space that provides free movement and an opportunity for gatherings. Its external walls guarantee safety and privacy, (especially for women), which is considered, it is suitable for sleeping and hanging the laundry (Ghardaia State Report, 1985). However, unlike other traditional houses in Beni Isguen, TH2 is not equipped with a cooling or heating system, see figure 5.59 that describes the layout of TH2. In addition, figure 5.60 highlights a view of the house during the summer.

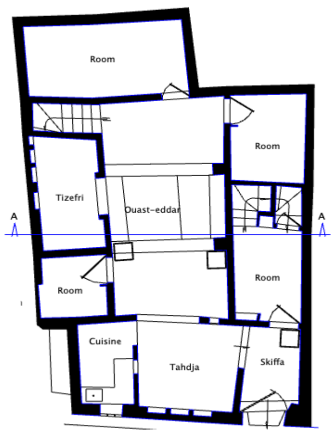
A working-class family of eight with an average monthly income of around £600 resides here. The father works in trading while the mother is a stay home mum. There are two other female adults who stay at home, and two male adults who attend university and two children who attend school. The family's income level is considered to better than the general income level of the people of Algeria. In general, the occupants of all the traditional houses in Beni Isguen use their house the same way throughout all seasons, except for the patio, which is used more during the summer, and almost all have the same activities during day time.




*a. Terrace*




*b. First floor*

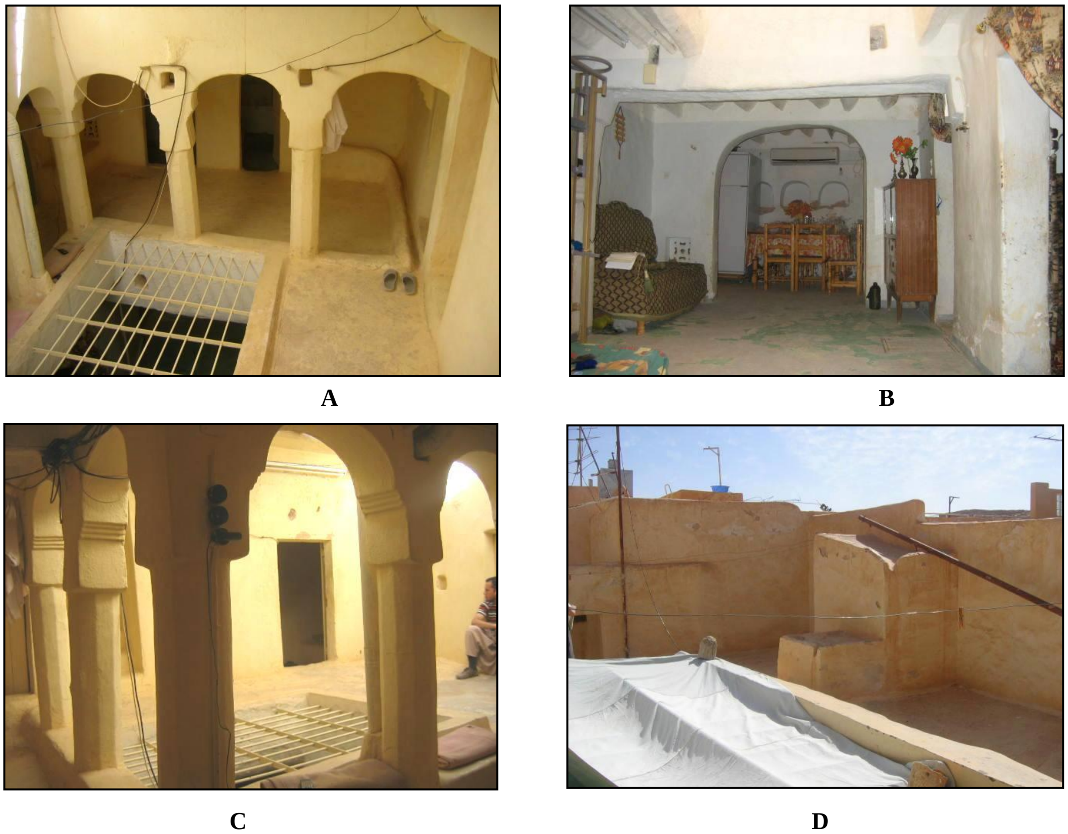



*b. Ground floor*

***Figure 5.59. The plans of the habitable rooms and spaces of TH2 for the summer and winter measurements (source: by the Author).***

In general, the inhabitants of TH2 use these spaces according to the climate conditions of each season.

*Figure 5.60: A view of the house during the summer (source: by the Author).*



A B C D

*Figure5.61. The interior spaces in TH2 (source: by the Author).*

Generally, all the openings for ventilation and lighting are open towards the patio (the centre of the house) which is considered a private area used just by the occupants (Figure5.61). TH2, as a whole, functions freely with no mechanical controls to modify or regulate the indoor environment during winter and summer as highlighted in table 5.11. Each space on the ground floor is fitted with a ceiling fan which is used only during the summer. The electricity and gas supply is ensured by SONELGAZ.

***Table 5.11. The internal and the external spaces in TH2***

| **Internal Spaces** | | **Services: Cooling/Heating** |
|---|---|---|
| Ground floor | Entrance | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living Room 1/ Living Room 2 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Kitchen | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 1/Room 2/Room 3/Room 4 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| First floor | Room 5/Room 6/Room7/Room8 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living room 1 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Stock room | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Hall | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| **External Spaces** | | |
| Patio | | N/A |
| Roof Terrace | | N/A |

Figure 5.62 indicates where the loggers are located in TH2 for the summer/ winter measurements. The location of loggers were selected based on the residents occupation table 5.11.

*Loggers*

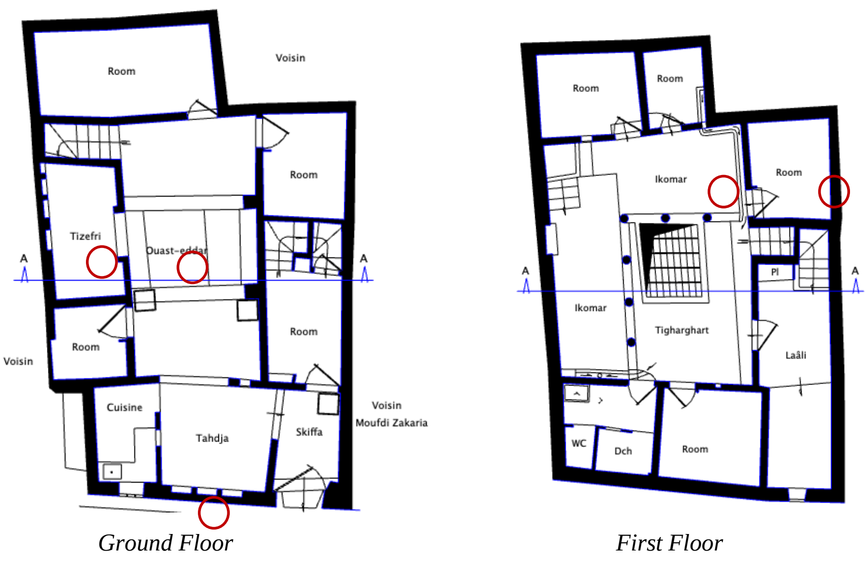
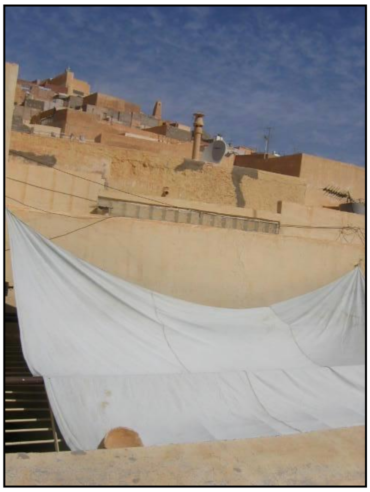



***Figure 5.62. The locations of the loggers in the habitable rooms and spaces of TH2 (source: by the Author).***

The building is thickly insulated by limestone on the exterior to reduce heat gain and loss, it employs the same materials and construction methodology as TH1 see figure 5.65 that describes the texture of the façade. Furthermore, the occupants covered the patio with wet tissues during midday to prevent the accumulation of heat (see figure 5.63) which were removed only after midday to improve the ventilation and prevent the rise of peak heat conditions throughout the summer.

*A*



*B*

***Figure 5.63. Patio covered during the summer (TH2) (source: by the Author).***

The patio or the roof window mainly functions to allow natural lighting and air pass through the building. Given this, it was necessary to cover it to prevent the summer heat from touching the ground floor and all the other rooms (Figure 5.64). The absence of green spaces was also a limiting factor as it contributed to the prevalence of dry climate. Due to this, an oasis-like concentration of plant and grass-covered areas was desirable, where the vegetation is nearly not existing in the populated places, one of the occupants said, *'Most of the occupants move to orchards and fields during the summer where it is colder due to the presence of palm forests. However, not all occupants have summer houses (houses with palm trees outside the ksar)*.

***Figure 5.64. A view of the patio from the terrace (TH2) (source: by the Author).***

***Figure 5.65. The texture for the façade (TH2) (source: by the Author).***

### 5.7.1. Occupant's Observations:

- **Summer:**

The occupants use the ground floor more than the first floor due to the latter being generally hotter due to the direct solar exposure. The ground floor offers a lot of respite in this regard due to the coolness from the basement, making it the coldest place in the house and, therefore, the best place to store the food. Moreover, as indicated in table 5.12, the occupants tend to use the patio during the mornings, afternoons, and evenings for their daily social activities, (e.g., having meals, doing the washing, or cooking etc.), owing it to its connection to indoor spaces. The living room, on the other hand, is mostly used for gatherings or having the afternoon siesta.

At night, the occupants sleep on the roof terrace since it is more open and less stuffy. In addition to this, it provides complete privacy from neighbours.

***Table 5.12. Summer occupation of internal and external spaces in TH2***

| **Summer** | **Morning** | **Lunch** | **Afternoon** | **Evening** |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **Eat** | **N/U** |
| Living room (ground floor) | **Eat** | **Socialise** | **Sleep** | **Socialise** |
| Hall (First floor) | **Socialise** | **Socialise** | **N/U** | **Sleep** |
| Rooms (first floor) | **N/U** | **N/U** | **N/U** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **Socialise** | **N/U** | **Socialise** | **Socialise** |
| Roof terrace | **N/U** | **N/U** | **N/U** | **Sleep** |

*Key: Never used (N/U), Sometimes used, frequently used.*

The patio, particularly, is used more on the warmer days for having breakfast and, sometimes, lunch. The roof is used only for drying the laundry while sleeping is limited to rooms on the ground and first floors, instead of the terrace. The living rooms on both the floors are used to receive guests, have lunch, or sit and watch TV, as it is considered the warmest area in the house due to the presence of the gas stove.

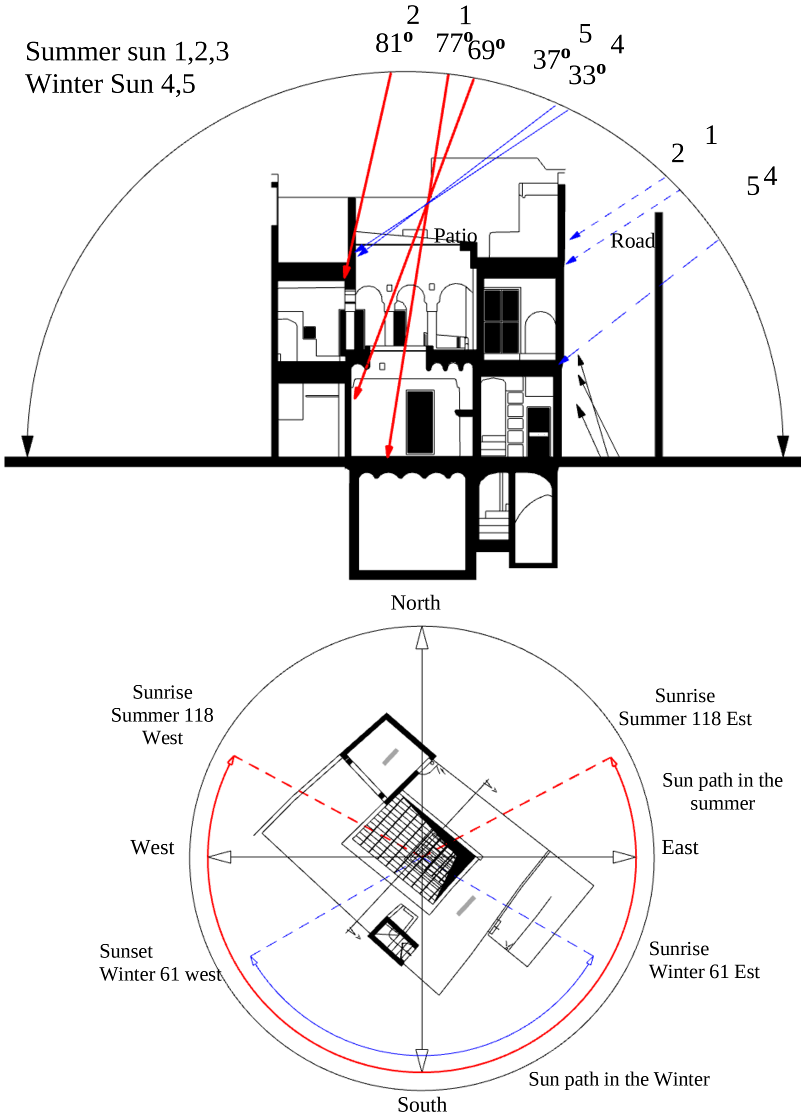



*Figure 5.66. Morphology of the sun's path through indoor spaces during summer and winter (source: by the Author)..*

*Table 5.13. Winter occupation of internal and external spaces in TH2*

| Winter | Morning | Lunch | Afternoon | Evening |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **Eat** | **N/U** |
| Living room (ground floor) | **Socialise** | **Socialise** | **N/U** | **N/U** |
| Hall (First floor) | **N/U** | **Socialise** | **Socialise** | **Socialise** |
| Rooms(first floor) | **Sleep** | **N/U** | **Sleep** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **N/U** | **Socialise** | **Socialise** | **N/U** |
| Roof terrace | **N/U** | **N/U** | **N/U** | **N/U** |

*Key: Never used (N/U), Sometimes used at this time, frequently used at this time.*

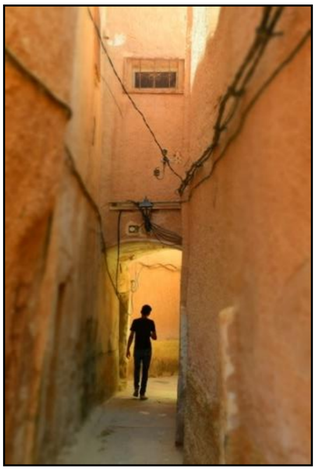


*Figure 5.67. Different road widths in Beni Isguen (source: by the Author).*

The narrow road outside the house is oriented east-west, which is considered a secondary road, compared to the main road which is oriented north-south, making the façade protected from the sun gain compared to the roof which is fully exposed all day long (figure 5.67/ 5.68).

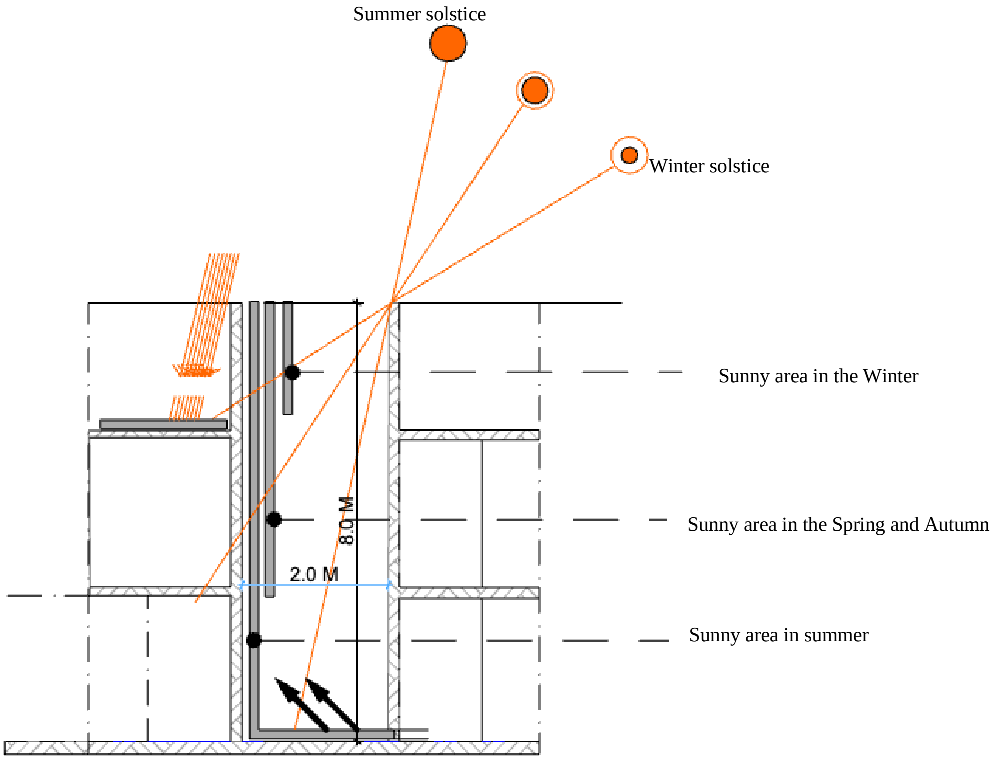



*Figure 5.68. The prospect in the Beni Isguen (source: by the Author).*

### 5.7.2 Summer Measurements in TH2 From 23/08/2018 to 30/08/2018:

The occupants used the patio during the morning, afternoon, and evening; they stated that they feel between normal and slightly cool while they feel warmer at early afternoon time, the patio was covered during the daytime, which lead to well thermal environmental conditions caused by the shade. The outdoor temperatures simultaneously increased and reached a peak after midday (39.5°C) and decreased to 27.5°C between night time and early morning (21:00– to 6:00 hrs) (Figure 5.69). Over the period of the measurements the roof was exposed directly to the sun, where allowing the heat exchange to constantly occur by convection, which reacted similarly to the outdoor temperature, caused the increasing of the temperature which continued to impact on the thermal behaviour of the occupants; obliging to use the ground floor, where the indoor recorded data showed a clear difference between the taken record in the ground floor spaces (living room) and the those taken on the first floor space ( room1).

Starting from 21:00 to 9:00 hrs and then continuing from 12:00 to 21:00 hrs, the temperature was beyond the prescribed range by ASHRAE 55 which implies that the occupants used ceiling fans and watered the floors to reduce the heat. The following table summarises the outdoor temperatures for TH2 during the monitoring period (table 5.14).

***Table 5.14. Average, maximum and minimum relative humidity (TH2)***

| TH2 Space | Temperature (C°) | | | |
|---|---|---|---|---|
| | Mean Temp | Daily Max | Daily Min | Mean Diurnal Range |
| **Living room** | 29.3 °C | 31.3 °C | 27.3 °C | 4.0 °C |
| **Room 1** | 37.7 °C | 36.0 °C | 31.5 °C | 4.5 °C |
| **Patio** | 31.0 °C | 33.0 °C | 30.0 °C | 3.0 °C |
| **Outdoor** | 33.5 °C | 39.5 °C | 27.5 °C | 12.1 °C |

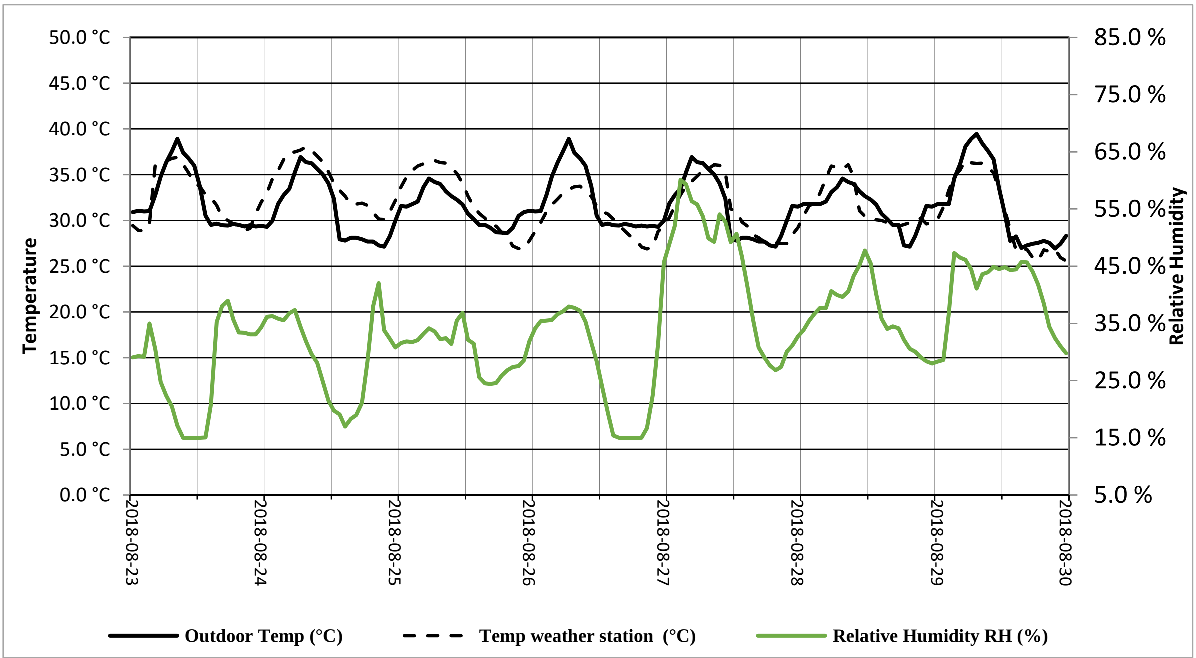



***Figure 5.69 The recorded outdoor dry-bulb temperature and relative humidity***

The variation between the daily minimum and maximum temperature for the first-floor room 1's was up to 5 K, warmer than the living room with maximum of +7°C at midday. However, it was found to have the lowest temperature 27.5°C after midnight on the outdoor measurements. With no doubt, the roof being more exposed to direct sunlight for more than 12 hrs, which provoke the temperatures to exceeded 39.5 °C (Table 5.14). This is sure to be influenced by the fact that they occupy the living room more than the bedroom, more specifically, on the ground floor, the occupants mostly use the living room all day (7:00 to 22:00). Meanwhile the living room was found to be the coolest monitored space in the house with mean daily temperature ranged from 27.3 °C to 31 °C, during the recorded hours, the temperature remained within the acceptability range of ASHRAE 55 adaptive comfort criteria. On the other hand, the patio remains covered during the day time, which helps to reduce the temperature to 30.0°C with diurnal temperature variation is found to be around 3K during all the measurements period. It is understandable that patio was obviously affected by the cover, which made the atmosphere less vulnerable to solar radiation having an effect on the surrounding spaces, which is already affected by the heat coming from the roof (figure 5.70).

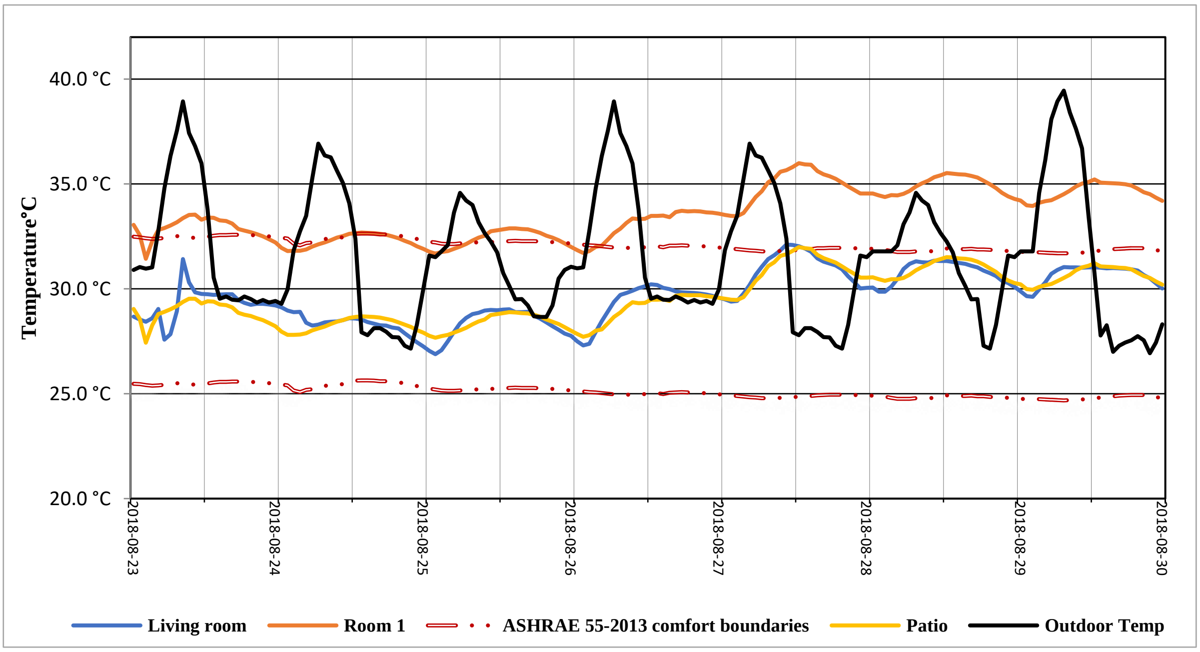



***Figure 5.70 Indoor temperatures with the comfort boundaries of ASHRAE 55 (80% acceptability)***

The relative humidity operates in a good way, especially on the patio where the mean daily RH is found ranging from 25% to 45%, which remained within the margin of ASHRAE adaptive comfort band width on all the period this made the place more attractive for the occupants to use mostly (Figure 5.71).

Although the relative humidity for the living room and first floor room (room 1) as shown in the figure 5.71 was close to the patio and maintain inside the within the margin of ASHRAE adaptive comfort for the first three days, day four and five were different compared to the patio where they watering the floor which created microclimate and good atmosphere for gathering, the mean daily RH is found ranging from 15% to 42% where 15% was recorded because the minimum value for the data logger was 15%. However, given the completely hot and dry climate, it was evident that it was even lesser than that.

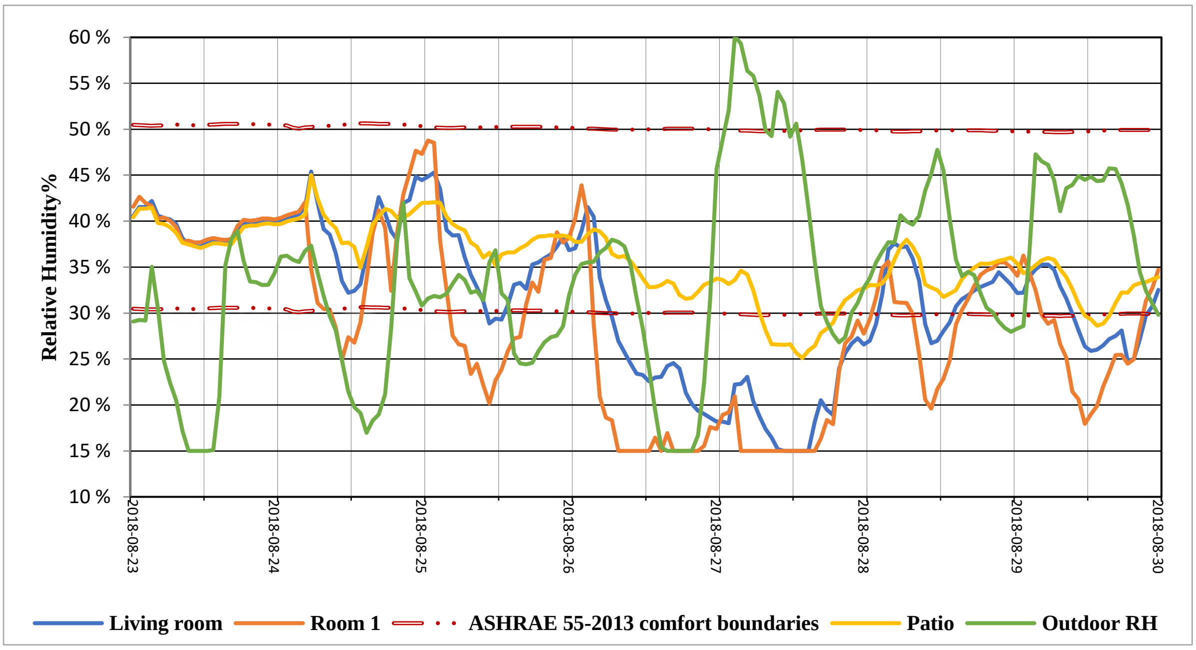



***Figure 5.71 Mean relative humidity with the comfort boundaries of ASHRAE 55 (80% acceptability)***

Compared to the results indoors, living room and the patio were generally better result and complaisant to the comfort zone, where can clearly showing up to 7 K lower temperatures when compared to the first floor bedroom, which the mean daily RH is ranging from 15% to 45.5% (see Figure 5.71), over three quarters of the readings the mean RH was below the average the adaptive thermal comfort range, however in the living room and the patio shows that 65% of measurement period, the average relative humidity within the adaptive thermal comfort range. Similarly, according to the thermal comfort criterion, 95% of the patio was well within the prescribed range of ASHRAE 55, underlining the reason why most of the activities were based in the patio (see Figure 5.70). Furthermore, all occupants benefit from the natural ventilation here, especially between 20:00 and 9:00 hrs. From 11:00 to 18:00 hrs. the mean daytime temperature fluctuated in the range 27 ~ 32°C in the living room whereas the mean daily temperature was very hot, fluctuating between 31 ~ 36°C in room 1 for the first floor. Most of the occupants would feel slightly warm and uncomfortable during midday. In the first two days, the humidity was very low due to the narrow openings and the lack of vegetation cover. From the third day, the use of water inside the building provided some moisture and cooling, increasing the relative humidity by 15% and decreasing the temperature to around 3 k.

### 5.9.4 Winter Measurements in TH2 From 10/01/2019 to 17/01/2019:

This section will present the collected data during the winter for TH2, as highlighted in the previous case, occupants of TH2 also used gas stoves, particularly in the living room, and most of the bedrooms, as the heating system, during the cold period, like the majority of the houses in Ghardaia region the heat system operating frequently.

*Table 5.15. The average, maximum and minimum temperature of TH2*

| TH2 Space | Temperature (C°) | | | |
|---|---|---|---|---|
| | Mean Temp | Daily Max | Daily Min | Mean Diurnal Range |
| **Living room** | 17.5 **°C** | 18.5 **°C** | 16.5 **°C** | 2.0 **°C** |
| **Room 1** | 19.1 **°C** | 16.5 **°C** | 16.0 **°C** | 0.5 **°C** |
| **Patio** | 16.5 **°C** | 14.0 **°C** | 12.0 **°C** | 2.0 **°C** |
| **Outdoor** | 11.7 **°C** | 16.5 **°C** | 7.0 **°C** | 9.5 **°C** |

Table 5.15 summarised TH2's temperature measurements in four spaces: Living room, Bedroom (first floor room 1), Patio, and Outdoor during the monitoring period. It can be clearly observed from the outdoor readings, the space was generally cold and dry. The mean daily temperature ranged from 7.0 °C to 16.5 °C (figure 5.72), the diurnal temperature variation is found to be around 9.5 K. In relation to the indoor readings, the living room and the first floor Room 1, were the mean daily temperature ranged from 16.0 °C to 18.5 °C, all readings remained close to the lower margin of ASHRAE adaptive comfort see figure 5.73, generally observed that all the occupants activities were based on the places where the gas heating was being operated. It is worth noting that the occupants of TH2 use a living on the ground floor, as opposed to the patio during summer time, while in the winter where they concentrate all their activities within there, it is also known as the winter room. The patio is one of the main habitable rooms which is used as a family room during the winter and has a heater that distributes warmth to the surrounding rooms as well.

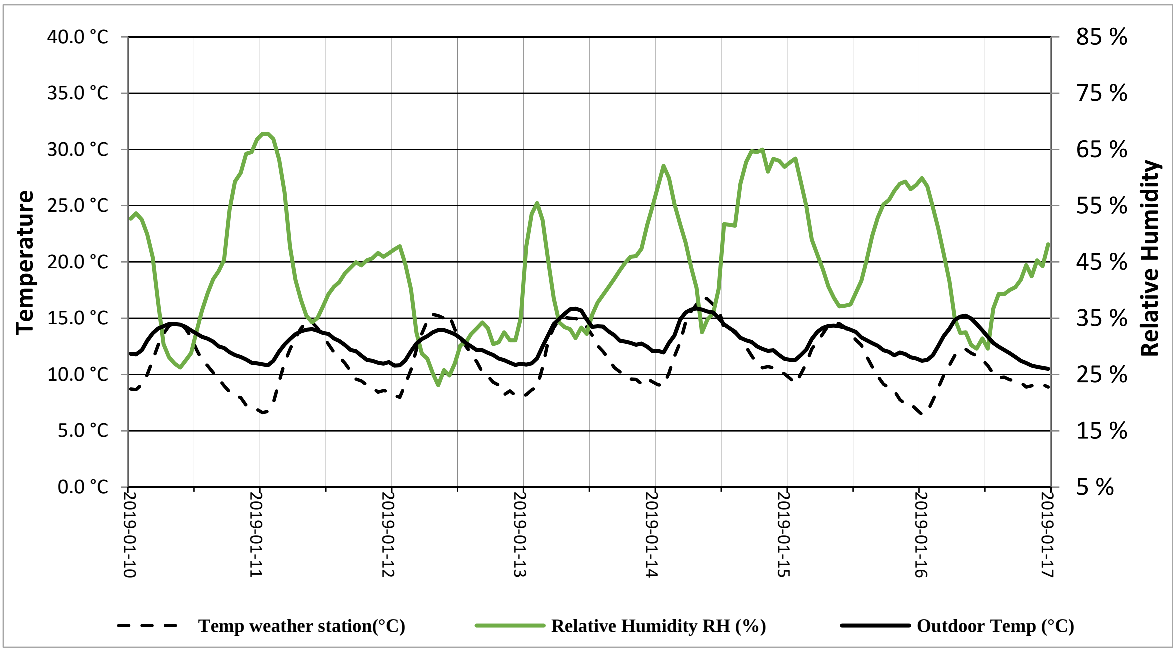



*Figure 5.72 The recorded outdoor dry bulb temperature and relative humidity during the winter*

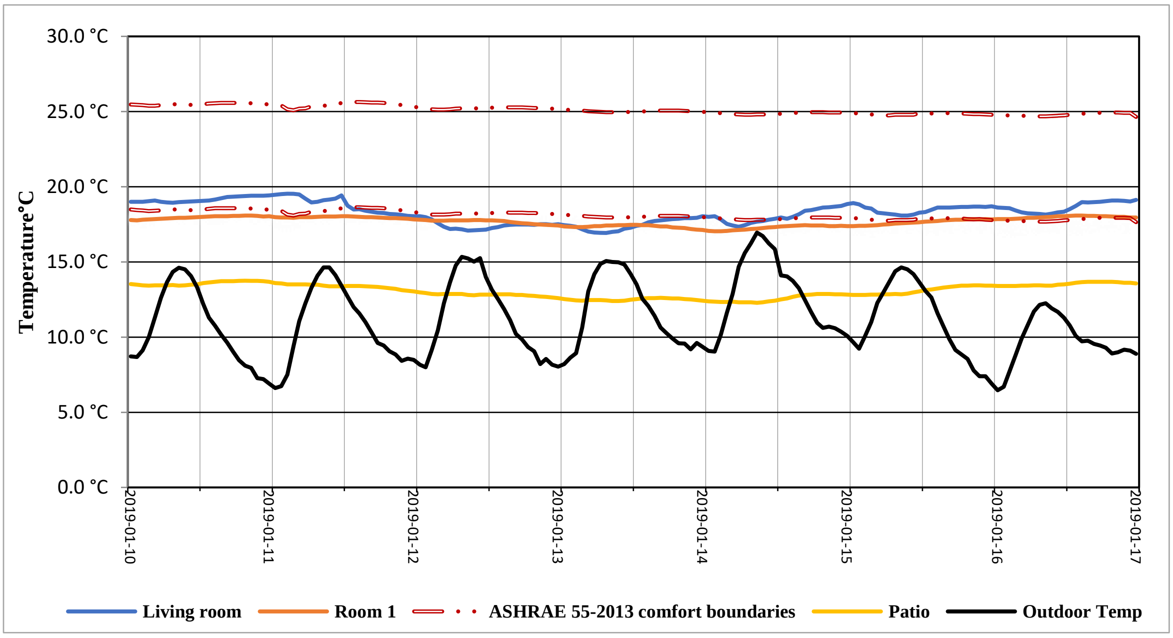



***Figure 5.73. Indoor and outdoor temperatures with comfort boundaries of ASHRAE 55 (80% acceptability)***

The mean daily RH is found to be relatively similar across the monitored areas ranging from 24% to 67%. The outdoor mean relative humidity was remained within the range 24% to 67%. As shown in figure 5.74, all indoor (living room, room1, patio) relative humidity readings remained within the margin of ASHRAE adaptive comfort bandwidth. However, from the third day, the patio started showing different values, it was remained within the range 29.5% to 39% for the remaining four days and considered below the lower margin of ASHRAE adaptive comfort bandwidth.  The occupants used the living room and the rooms more often throughout the day. According to their diary entries, they felt comfortable in the hall due to the heating there. In this regard, the prevailing thermal conditions in the living room were also comfortable due to the distribution of the heating. Moreover, it helped the occupants to sleep comfortably at night.

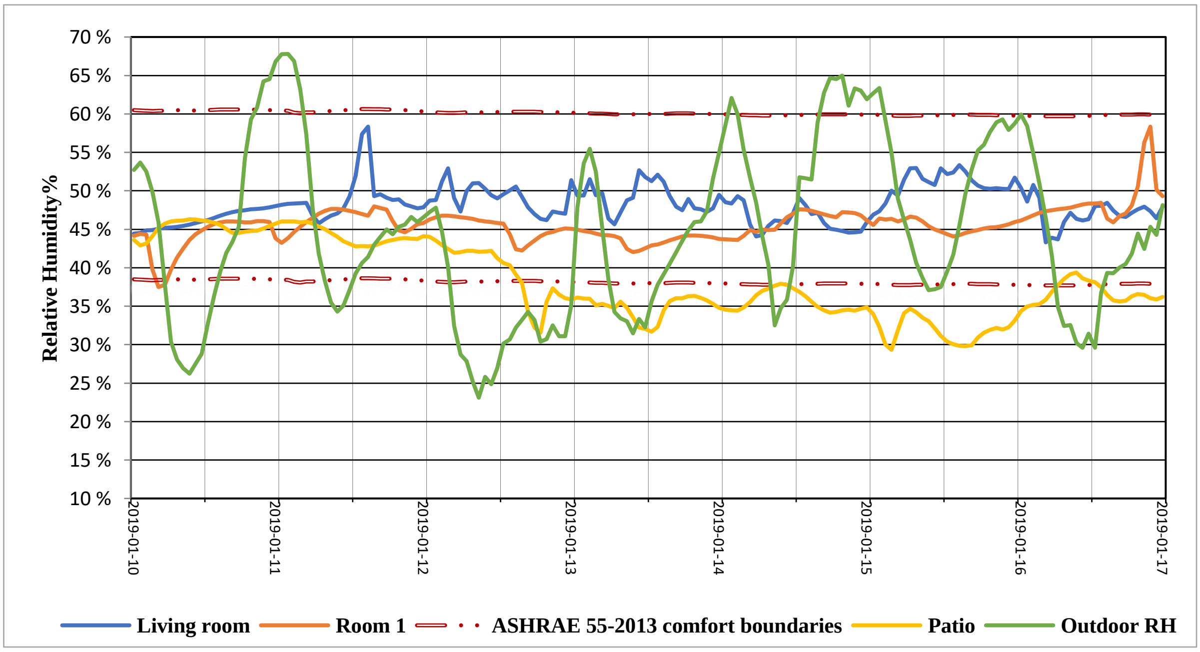


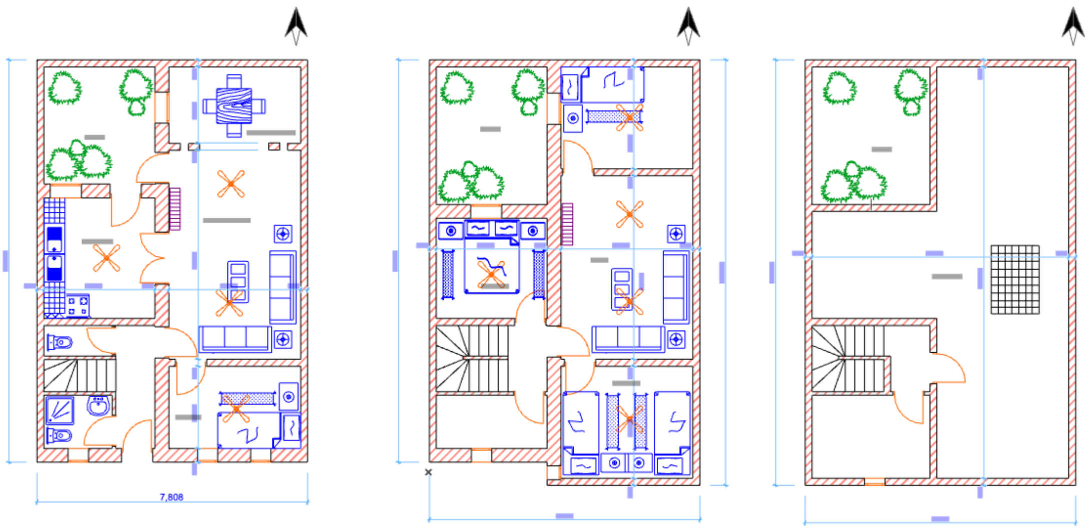

***Figure 5.74. Indoor temperatures with the comfort boundaries of ASHRAE 55 (80% acceptability)***

### 5.10.1 Modern House 2 (MH2)

*Figure 5.75. An aerial view showing the location of the modern house MH2 (source: Apple maps)*

MH2 is a new house that is less than 10 years old (figure 5.75). It is a medium-sized two-storey self-built unit constructed in 2009 in Tafilelt, located 1.5 km south of Beni Isguen, with a ground floor, first floor and a roof terrace; the building has a floor area of approximately 90 m$^2$ and a ceiling height of 3.3 m. It contains a patio which is located behind the building and well-connected to the activity spaces. A working-class family of three (young parents with one child) with an average monthly income of around £400 resided here. Their income level is good, compared to the general income level of Algeria. The ground floor combines a living room that has access from the entrance for privacy reasons, a dining room, a guest room which is used occasionally, and a kitchen with good connectivity to all the ground floor spaces and the patio. The first floor incorporates all the living rooms with the patio, along with large windows to provide good ventilation. The front of the house is equipped with small windows have been used to maintain social privacy (Figure 5.76, Figure 5.78).

*Figure 5.76. A view of the house during the summer (source: by the Author).*




A-Ground Floor B-First Floor C-Terrace

***Figure 5.77. The layout of the habitable rooms and spaces of MH2 for the summer and winter measurements (source: by the Author).***

The ground floor is provided with small south facing windows at the façade, and the large windows opened at the patio on the north facing of the building in the summer, where is faced to cold winter wind during the winter (Figure 5.77). The small windows at the façade are mainly used for privacy reasons as well as for preventing the hot air from entering inside. The other openings for ventilation and lighting are opened towards the inner patio, which is a private area, while the windows are provided with internal roller blinds.

***Figure 5.78. The opening in the façade (source: by the Author).***

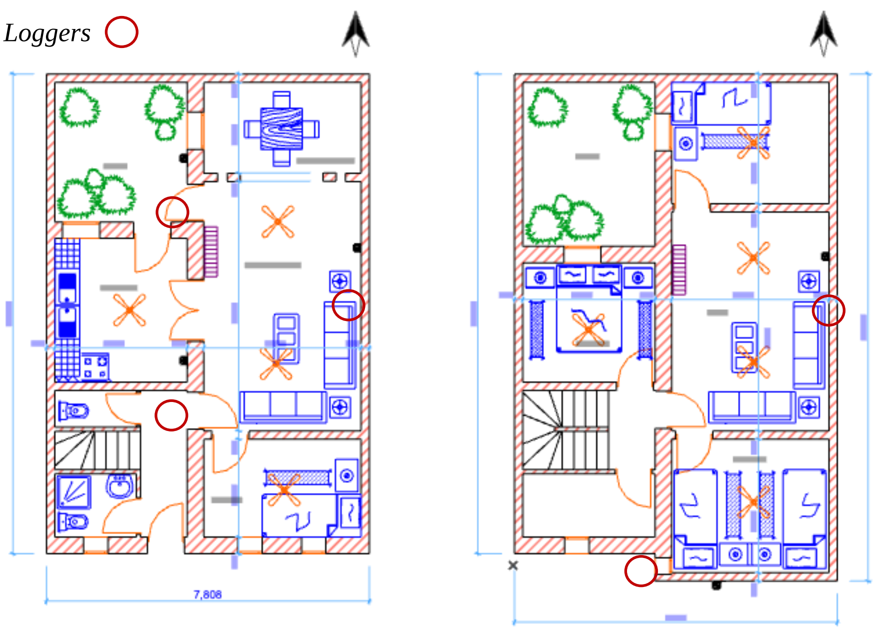
MH2 does not have any mechanical controls to regulate the indoor environment during both the seasons. Each space on the ground floor is fitted with a ceiling fan which is used only during the summer (table 5.16).

Figure 5.79 highlights where the loggers are placed in MH2 for the summer and winter measurements, the location of loggers were selected based on the use by the occupants on each period (see table 5.17).

*Table 5.16. The internal and external spaces of MH2*

| **Internal Spaces** | | **Services: Cooling/Heating** |
|---|---|---|
| Ground floor | Entrance | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Living Room | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Kitchen | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 1 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| First floor | Room 2 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 3 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Room 4 | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| | Hall | **Cooling:** Natural ventilation<br>**Heating:** N/A |
| **External Spaces** | | |
| Patio | | N/A |
| Roof Terrace | | N/A |

The inner patio on the north east part of the building, which is a constant feature of vernacular architecture in most of the local desert regions, is considered as the main element in MH2 and is built using different materials. The house is manufactured by private sector using materials that are sourced locally, these materilas are thought not to cause harm to environment, and do not require major expenses. The following materials were used to build MH2: mud bricks, gypsum, lime, and palm branches. However, the hipped roof that covers the first floor was constructed with concrete to ensure high thermal conductivity. Solid concrete blocks and reinforced concrete were used for floors and the flat roof, respectively.




*Ground Floor* *First Floor*

***Figure 5.79 The location of the loggers in the habitable rooms and spaces of MH2 for the summer and winter measurements (source: by the Author).***

The external walls were only rendered with lime sand (from the outside) and gypsum plaster (from the inside) with no insulation layer, resulting in a high thermal transmittance U-value (2.15W/m2K). This allows heat transaction through conductivity which substantially influences the building's energy and thermal performance. The internal spaces were rendered either by gypsum plaster or ceramic tiles, such as in the kitchen and bathroom

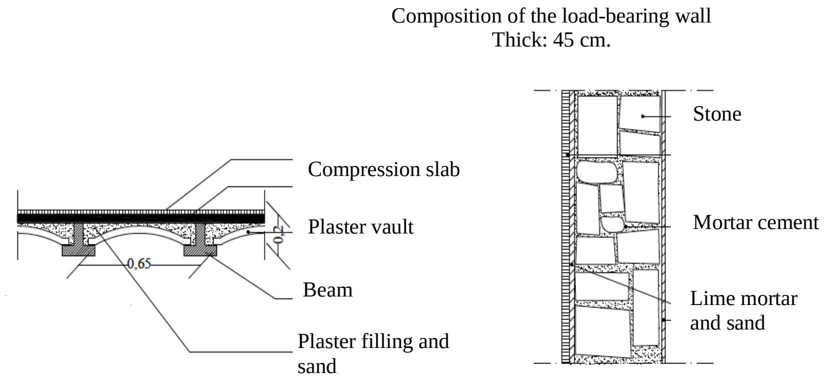



***Figure 5.80 A section of the wall and roof (MH2) (source: by the Author).***

The structure of this building consists of figure 5.80. The 0.45 m thick stone walls support all the constructive structures of the house as well as all the walls on the front. Non-loadbearing walls are made also from stone that are 0.30 m thick. The exterior coating comprised of lime mortar and sand that were spread all over the surface of the exterior wall  using a bunch of dates , the designers and builders of the project adopted these traditional techniques with an aim to protect the wall from the direct sun radiation which prevents over heating of the wall surface, this is thought to be due to the presence the fine sand which makes the mortar more malleable which subsequently provide shade to the wall (figure 5.81).

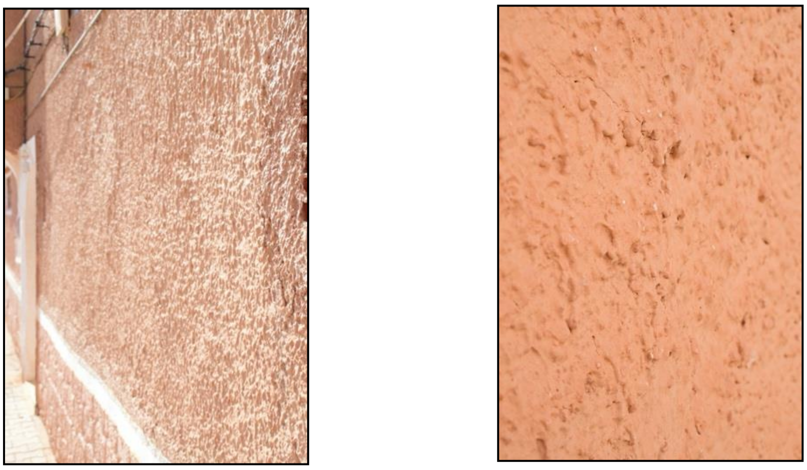


***Figure 5.81. The texture of the façade in MH2 (source: by the Author).***

The use of stone, associated with local lime mortar, represents a heavy material with high thermal mass. Despite its poor thermal performance, the temperature fluctuations were attenuated because of the thickness of the load-bearing walls (45 cm). This is the effect of thermal resistance, thus allowing heat to be stored during the day and dissipated at night (beneficial in winter). This dissipation also serves well as ventilation during the summer. But even if the high thermal mass is beneficial, in periods of high heat, the structure ends up being loaded with heat and takes longer to empty itself of the stored overheating.

On a side note, the traditional and modern houses are constructed, most of the time, by relatives who have enough experience and expertise in this matter.

### 5.10.2 Occupant's Observations:

- **Summer**:

The occupants' strategies to deal with the summer heat was gauged based on their questionnaire responses, social interactions and hours spent inside the house. As is with other case studies, the strategies comprised of drinking a lot of liquids, showering to reduce the body temperature, moving to the most comfortable space (usually the centre of the house which is far from the external walls and close to the patio), adjusting clothes, removing carpets, turning on cooling equipment (ceiling fans), and closing all the exterior windows to prevent thermal discomfort. The front part of the house is the entrance, where the guest room represents a private zone, and the interior zone represents the family space. Most of the spaces open onto the internal courtyard where most of the daily activities took place, where windows and openings mostly open onto the courtyard as well.

- **Winter:**

The occupants rarely used the patio due to the low air temperature and relative humidity. Sometimes, however, they would occupy it during midday on warmer days. The living room on the ground floor was used more frequently by the occupants throughout the day for social activities e.g., Watching TV, receiving visitors, and holding social gatherings. The bedrooms on the first floor were used for sleeping and because of the cold weather, the roof terrace was not used by the occupants.

The herein represented case study, MH2 is surrounded by 10m height buildings, with East-West façade orientated and 3m road width (Figure 5.82), which acts as external shading preventing the solar gains especially during the summer.

***Figure 5.82 A view of the secondary road at Tafilelt (source: by the Author).***

Conversely, horizontal walls, such as the surfaces of wide streets, are highly exposed to direct sunlight, as shown in Figure 5.83, the feeder streets-oriented east-west considering the relatively high prospect—have a very low heat input in winter figure 5.83. In summer, according to Tables 17 and 18, the horizontal surfaces naturally receive the heat by intercepting 94% of the solar radiation. Due to this, masks or solar shades that create shadows on the façades are required to decrease the amount of energy being received.

*Figure 5.83 Different Road widths in Tafilelt (source: by the Author).*

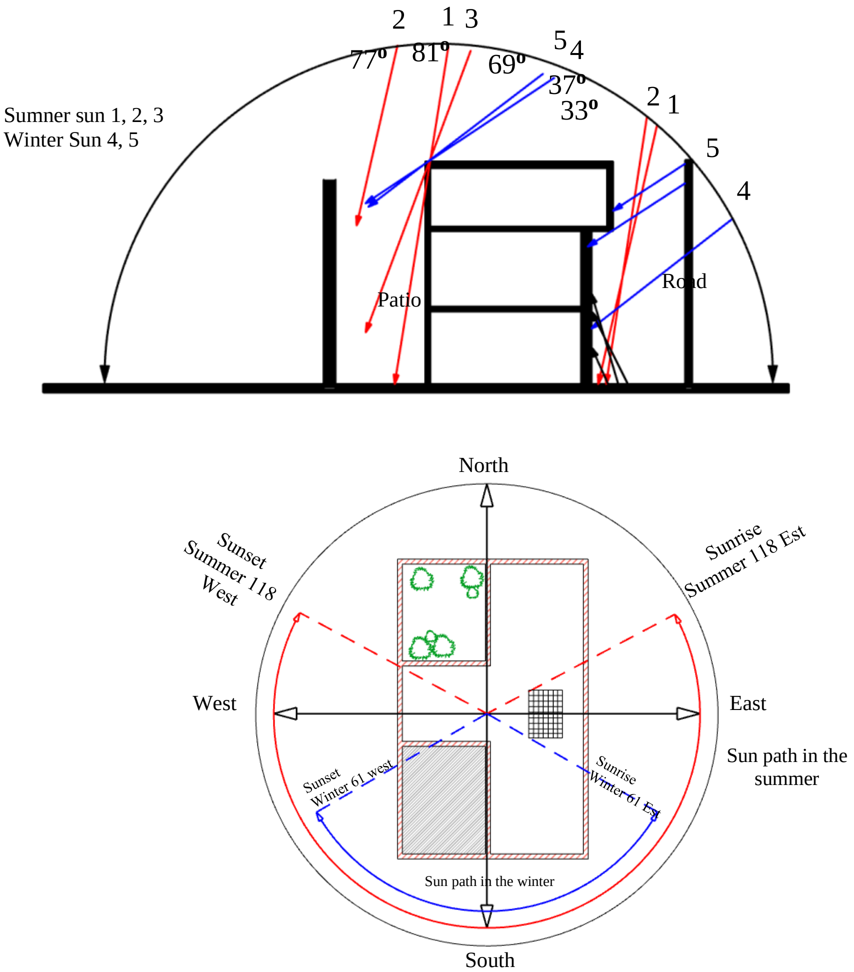



*Figure 5.84 Morphology of the sun's path through the indoor spaces during summer and winter (source: by the Author)..*

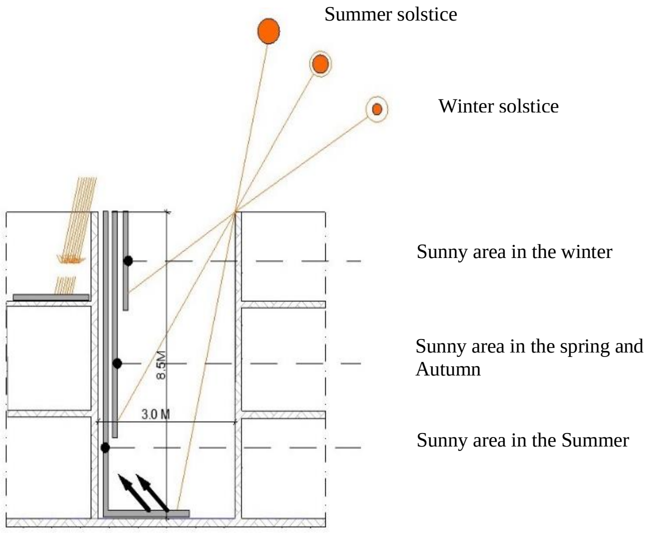
The movement of shadows means that there is always a constant re-evaluation of the temperature and pressure. which creates a draft that can be refreshed by the proximity of water and vegetation.

As for the primary streets with low prospect, the high reflection rate of the solar radiations generates overheating of the southern walls, when vegetation is the preferred solution to protect from this. In summer, the outdoor temperature reached more than 45°C, according to figure 5.84/Figure 5.85, and its passage.

in the southern direction is brief, unlike the east-west tracks where the shade depends mainly on the prospect (the ratio between the height of the buildings and the width of the street). In these north-south oriented streets, the east and west facing façades protect each other from sunshine, which have a significant impact on the facades and the conduction of heat into the buildings

*Figure 5.85 The prospect in Tafilelt*

*(source: by the Author).*




### 5.10.3 Summer Measurements in MH2 From 23/08/2018 to 30/08/2018:

Table 5.17 describes the pattern of occupants and the use of internal and external spaces in MH2 based on the conducted questionnaire. It's worth noting that the living room and the first floor are the spaces most frequently used during the summer due to its cooler nature compared to other spaces

*Table 5.17. Summer occupation of internal and external spaces in MH2*

| Summer Period | Morning | Lunch | Afternoon | Evening |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| Kitchen | **Eat** | **Eat** | **N/U** | **Eat** |
| Living room (ground floor) | **Eat** | **Socialise** | **Sleep** | **Socialise** |
| Hall (First floor) | **Sleep** | **Socialise** | **Sleep** | **Socialise** |
| Rooms (first floor) | **N/U** | **N/U** | **N/U** | **Sleep** |
| **External Spaces** | | | | |
| Patio | **Socialise** | **N/U** | **N/U** | **Socialise** |
| Roof terrace | **N/U** | **N/U** | **N/U** | **Sleep** |

*Key: Never used (N/U), Sometimes used, frequently used at this time.*

The occupants use the same rooms and spaces during summer and winter for the same activities. This is because these spaces have been designed in a similar manner to each other. Of all the spaces, the patio has been used more significantly, especially during early mornings and late evenings in the summer when the weather becomes really hot.

***Table 5.18. The average, maximum and minimum temperatures of MH2***

| MH2 Space | Temperature (C°) | | | |
|---|---|---|---|---|
| | **Mean Temp** | **Daily Max** | **Daily Min** | **Mean Diurnal Range** |
| **Living room** | 35.0 °C | 37.5 °C | 32.5 °C | 5.0 °C |
| **Room 1** | 34.7 °C | 37.0 °C | 32.5 °C | 4.5 °C |
| **Patio** | 33.5 °C | 39.0 °C | 28.0 °C | 11.0 °C |
| **Outdoor** | 36.0 °C | 46.5 °C | 25.5 °C | 21.0 °C |

It can be seen from Table 5.18 that the hottest temperatures are measured outdoors. During the week, the temperature rises quickly after dawn, reaching the maximum mean temperature of 46.5°C. Given that MH2 uses natural ventilation, a noticeable diurnal temperature variation is found (21K as an average) for the outdoor. Meanwhile, the data reveals that the diurnal fluctuation of the relative humidity is from be ranging from 15 to 47% (Figure 5.87).

Moreover, from Figure 5.87, the patio allows heat transfer to occur among the ground floor spaces and the first floor through an air exchange, especially during the hot period when the recorded temperature at the patio fluctuates between 28°C and 39°C.

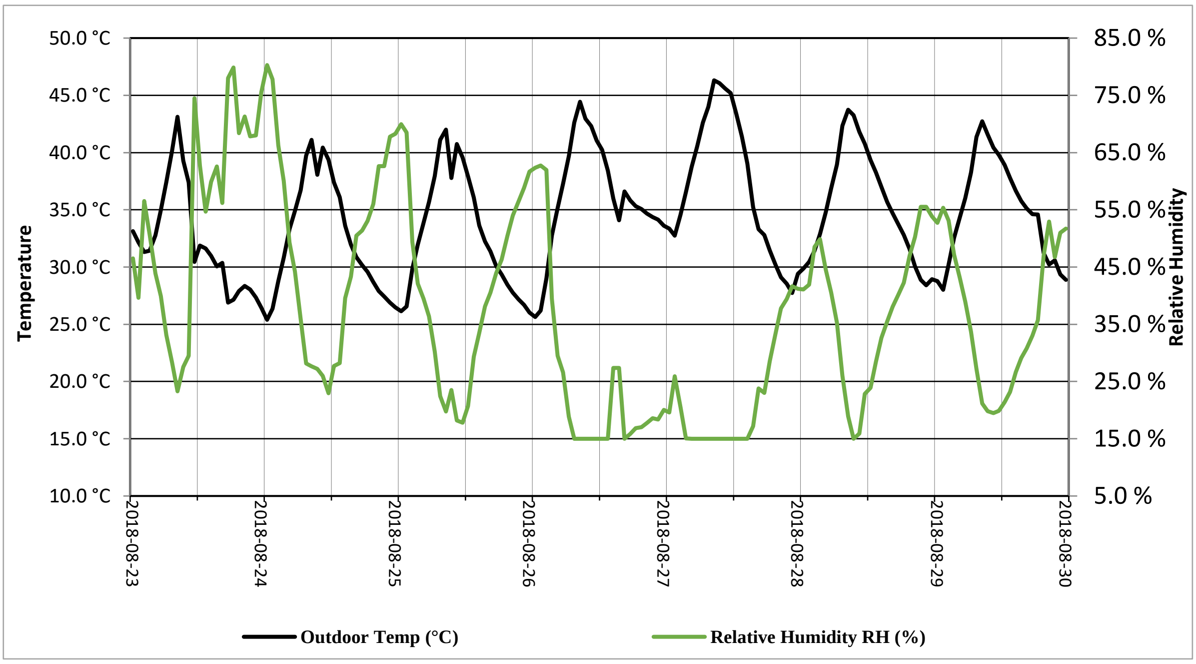



***Figure 5.86 The recorded outdoor dry-bulb temperature and relative humidity***

The living room at the ground floor experienced a mean temperature range of 32.5°C to 37.5°C, which is not within the ASHRAE 55 range, while the first-floor room shows a temperature fluctuation between 37.5°C to 32.5°C which is considered the hottest place in the house.

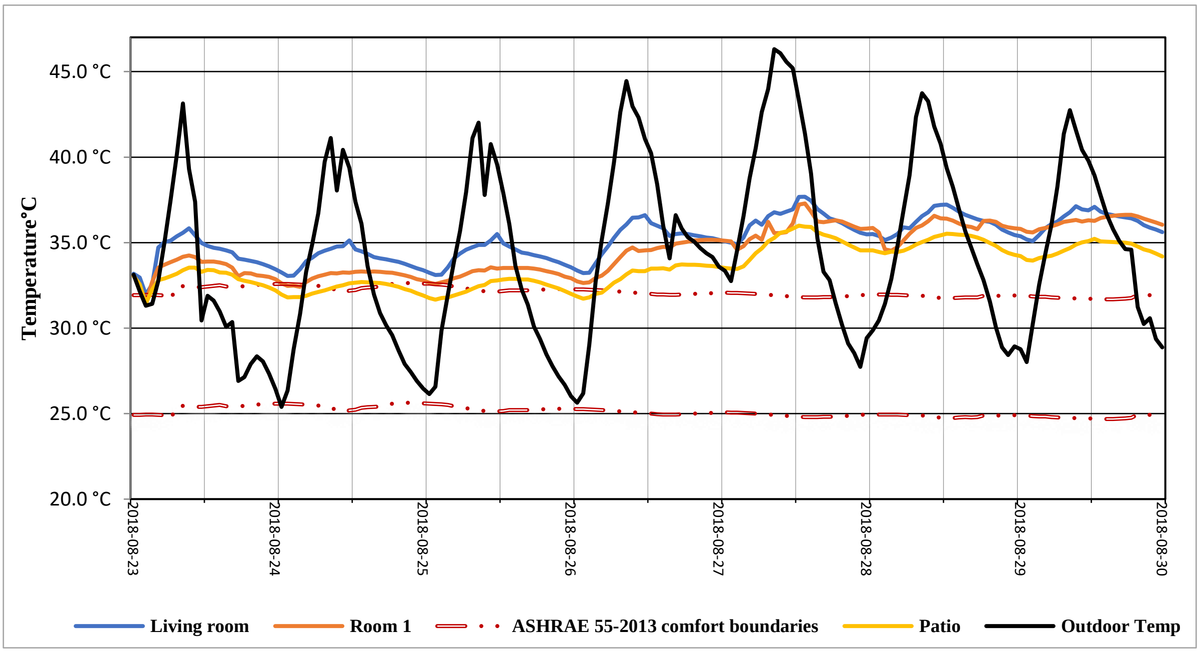



*Figure 5.87 Indoor temperatures with the comfort boundaries of ASHRAE 55 (80% acceptability)*

Comparing the diurnal fluctuation of RH of all indoor spaces, were from 15% to 55%, which considered very dry and failed to meet the acceptability limits of ASHRAE adaptive comfort criteria, however the Outdoor mean relative humidity was fluctuation from 15% to 80%, on average 50% of this period the average outdoor relative humidity was within the adaptive thermal comfort range. The lack of clouds and vegetation contributes to the extreme climate and low humidity on the site. Hence, the high intensity of direct radiation falling on these areas and the high intensity of terrestrial radiation during the night, in addition to the low amount and percentage of humidity in the air where the relative humidity ranges between 15% during noon and reaches less than 80% at night.

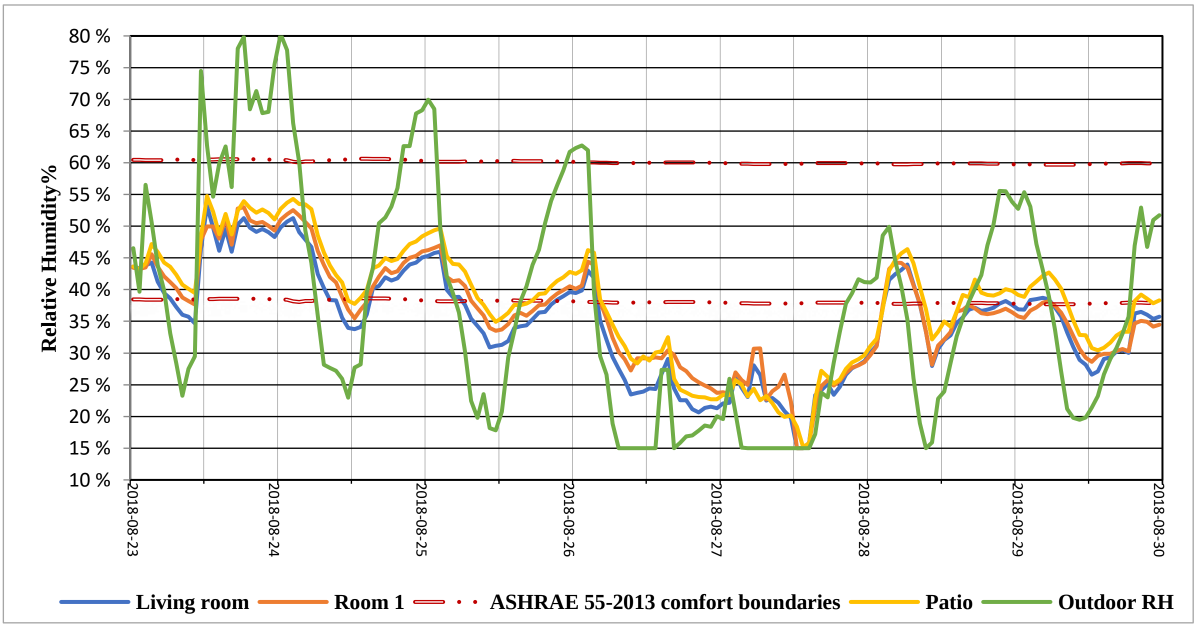



*Figure 5.88 Mean relative humidity with the comfort boundaries of ASHRAE 55*

### 5.10.4 Winter Measurements in MH2 From 10/01/2019 to 17/01/2019:

It is important to note that the traditional and modern houses monitored for the winter period were occupied for the summer period as well. During winter, the residents use different spaces; more specifically, they do not use open, and ventilated spaces, such as the Patio and the terrace during the night. The inhabitants use a different living room which is considered as a winter room, conducting the same activities during lunch when the temperature rises in the patio. It is to be noted that the MH2's occupants do use a Radiant Portable Gas Heater regularly for heating during the winter.

***Table 5.19. The average, maximum and minimum temperatures of MH2***

| MH2 Space | Temperature (C°) | | | |
|---|---|---|---|---|
| | **Mean Temp** | **Daily Max** | **Daily Min** | **Mean Diurnal Range** |
| **Living room** | 17.8 **°C** | 18.5 **°C** | 17.2 **°C** | 1.3 **°C** |
| **Room 1** | 16.7 **°C** | 17.0 **°C** | 16.4 **°C** | 0.6 **°C** |
| **Patio** | 11.2 **°C** | 16.1 **°C** | 06.2 **°C** | 9.9 **°C** |
| **Outdoor** | 11.35 **°C** | 16.5 **°C** | 06.2 **°C** | 10.3 **°C** |

It can be seen from figure 5.89 that the outdoor mean daily temperature ranges from 6.2°C to 16.5°C, which is considered cold and failed to meet the acceptability limits of ASHRAE adaptive comfort criteria. According to the prescribed thermal comfort standard, 100% of the outdoor relative humidity range between 32% and 70%, which is within the adaptive thermal comfort range.

***Table 5.20. Winter occupation of internal and external spaces in MH2***

| **Winter** | **Morning** | **Lunch** | **Afternoon** | **Evening** |
|---|---|---|---|---|
| **Internal Spaces** | | | | |
| **Kitchen** | **Eat** | **Eat** | **N/U** | **Eat** |
| **Living room (ground floor)** | **Eat** | **Socialise** | **N/U** | **N/U** |
| **Hall (First floor)** | **N/U** | **Socialise** | **Socialise** | **Socialise** |
| **Rooms (first floor)** | **Sleep** | **N/U** | **Sleep** | **Sleep** |
| **External Spaces** | | | | |
| **Courtyard** | **N/U** | **Socialise** | **Socialise** | **N/U** |
| **Roof terrace** | **N/U** | **Socialise** | **N/U** | **N/U** |

*Key: Never used (N/U), Sometimes used, frequently used at this time.*

The living room on the first floor is one of the main habitable rooms due to the heater installed there. Needless to say, it becomes the family room during the winter season, and they had generally experience slightly as a warm place to gather which can notice from the figure 5.90, it remains steady during the monitoring record with mean daily temperature ranged from of 17.2°C to 18.5°C

(Figure 5.90). According to the prescribed thermal comfort standard, 100% of the patio is out the adaptive thermal comfort range.

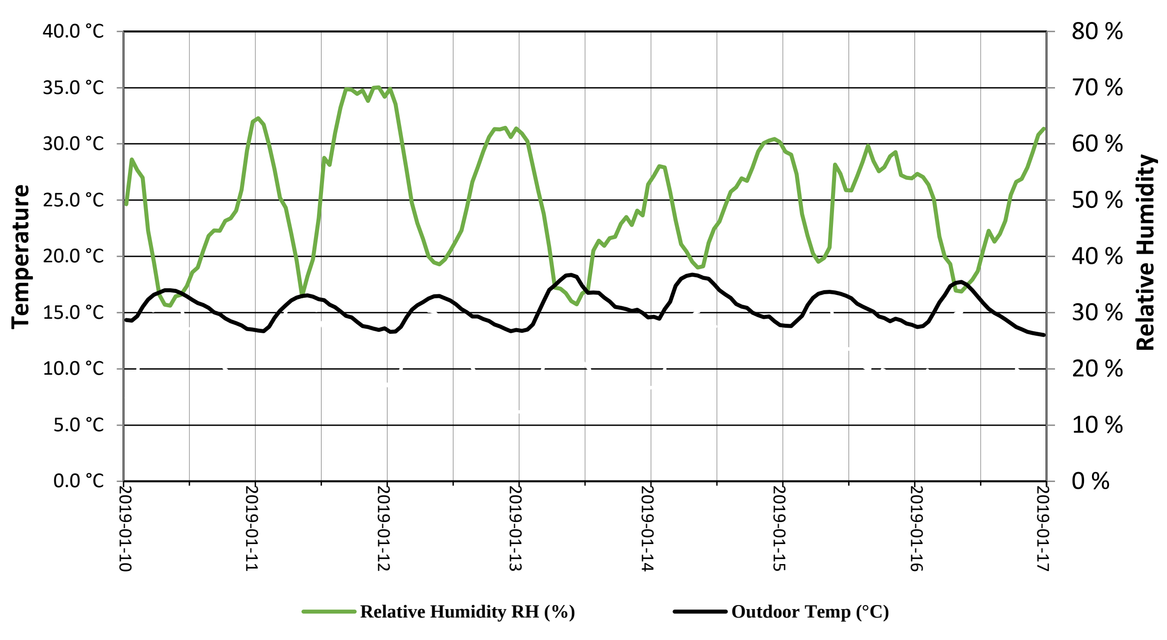



*Figure 5.89 The recorded outdoor dry-bulb temperature and relative humidity*

As per their diary entries, the occupants of MH2 spent most of their time in the living room and first floor room, owing to the comfort provided by the heating. Despite this, the Patio is still used during the afternoon, such as sitting to receive a little sunlight and washing clothes.

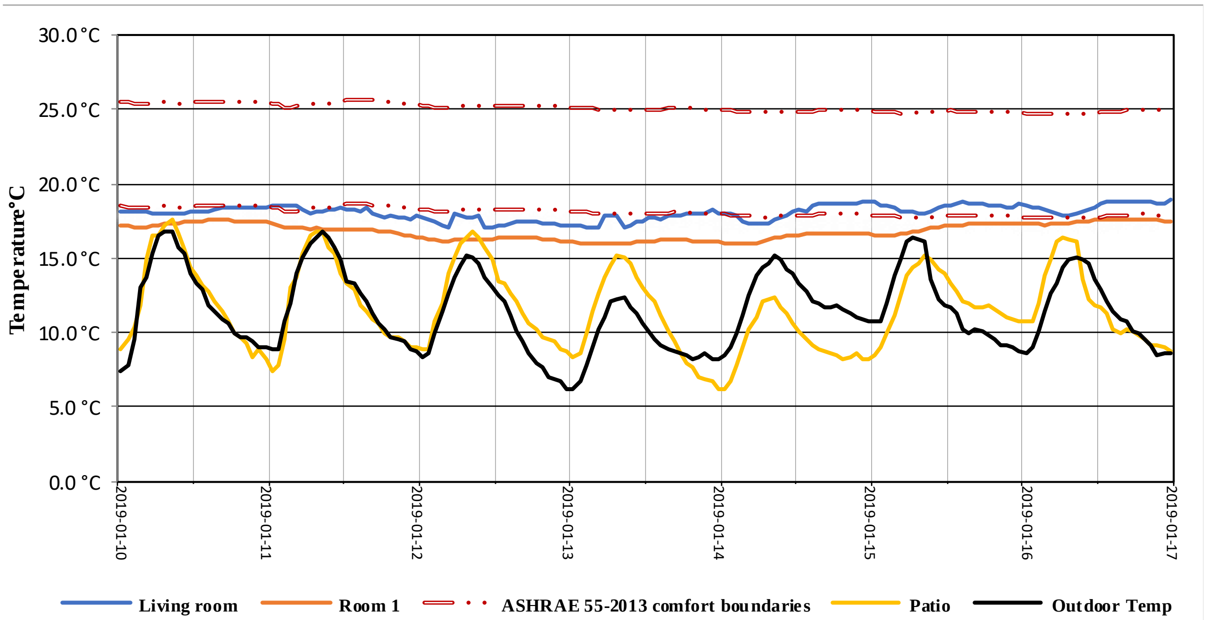



*Figure 5.90 Indoor temperatures with the comfort boundaries of ASHRAE 55 (80% acceptability)*

The Outdoor mean relative humidity range was between 32% and 70%. meanwhile the mean relative humidity for the living room was from 24% and 39%, where the patio and first floor room data showed the average RH ranged between 23% and 38%, which considered lower than the prescribed ASHRAE 55 range (Figure 5.91), which in turn, implies that they had dry weather conditions.

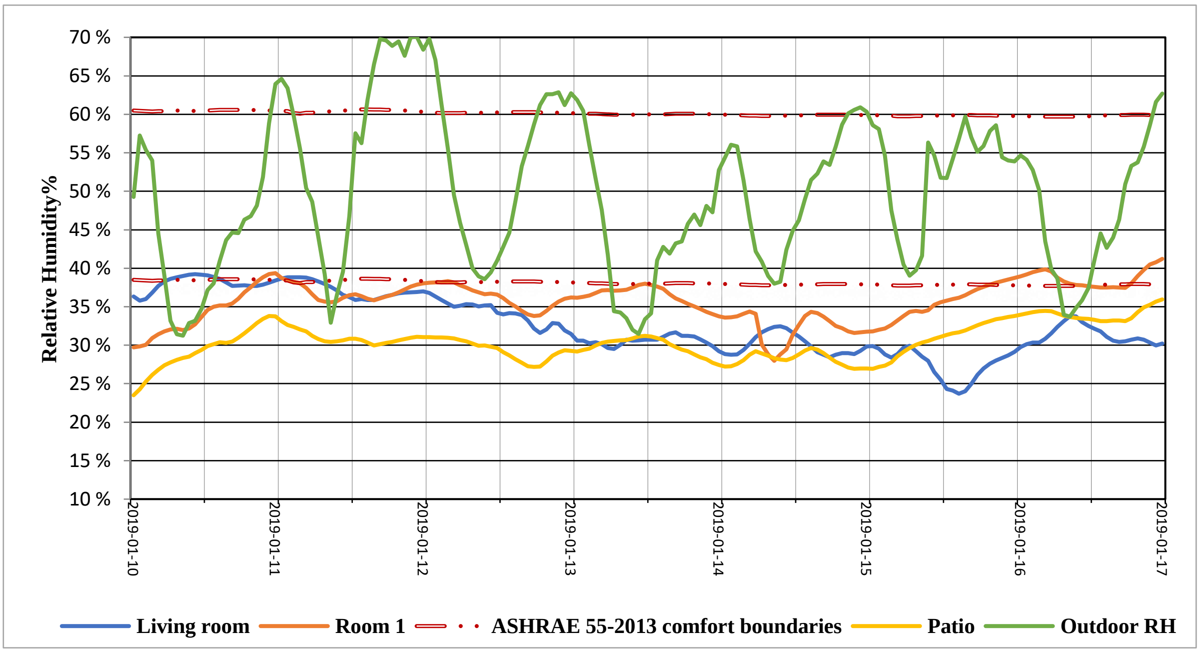



***Figure 5.91 Mean relative humidity with the comfort boundaries of ASHRAE 55***

## 5.11 Comparison of the case studies MH2 and TH2:

This section analyses the aforementioned findings together with an analytical comparison of the thermal performance of TH2 and MH2 for one week during the summer and for another week during the winter to understand the current occupants' comfort, satisfaction, and perception of the thermal performance of these houses. The measurements will present the air temperature and the RH values (average, maximum and minimum) graphically for four spaces (outdoors, patio, living room, and room 1) for both case studies. Then the comparison of the same measured spaces in each season for both houses were done separately.

### A- Summer Measurements From 23/08/2018 to 30/08/2018:

- **Outdoors:**

Generally speaking, the flow of recorded temperature data has the different curve pattern with big variations on both houses. Running mean outdoor air temperature (Trm) for MH2 was ranged from 26°C to 46°C, on average, the diurnal temperature variation is found to be around 20 K. Meanwhile TH2 Running mean outdoor air temperature (Trm) ranged from 27 °C to 39 °C, on average, the diurnal temperature variation is found to be around 12K, considering to the location of the two houses, which is characterized by the same climatic characteristics, and are almost of equal height, typically of two stories with terrace; the walls of the buildings are constructed with similar materials thick stone and are painted with light colours. Same facade orientation, where the windows constitute about 20% of the walls.

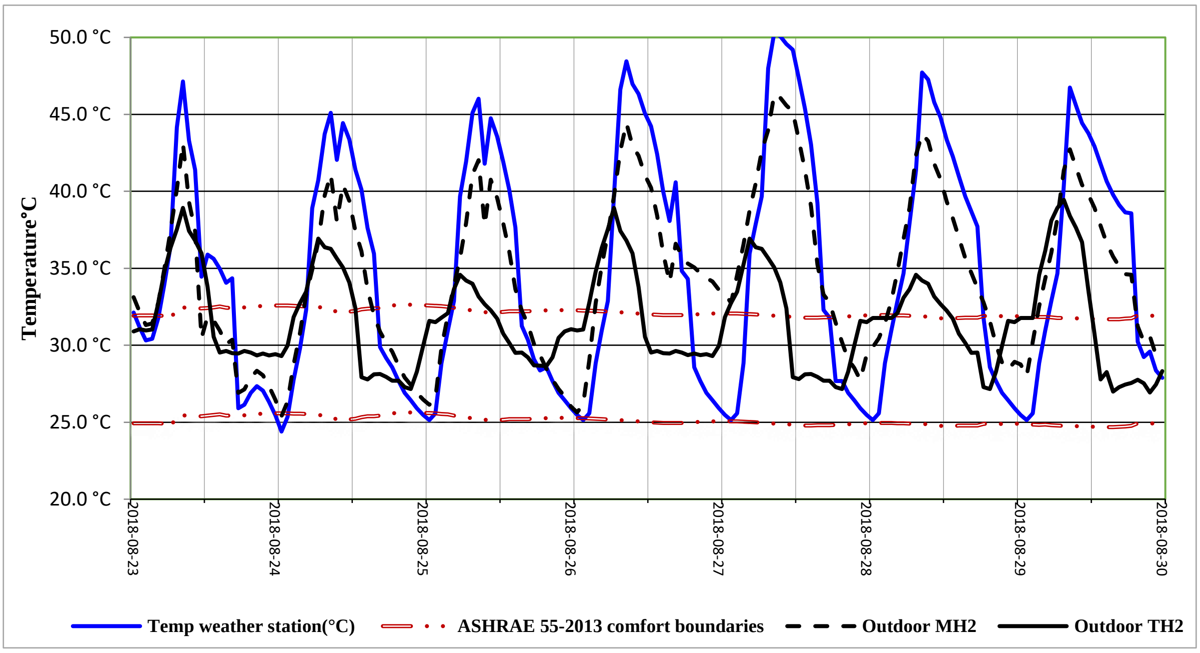



*Figure 5.92 Comparison of outdoor temperatures during the summer*

There are clearly differences in the thermal measurements, which in turn will negatively affect the movement of pedestrians and on the buildings envelop. Surfaces facing south were irradiated during most of the day and experienced high ground surface temperature (Ts) and wall surface temperature (Tw), leading to the increased transfer of heat to air as sensible heat flux, also shown that peak outdoors temperatures occurred around 39°C for TH2 and 46 °C for MH2 with differential of 7K.

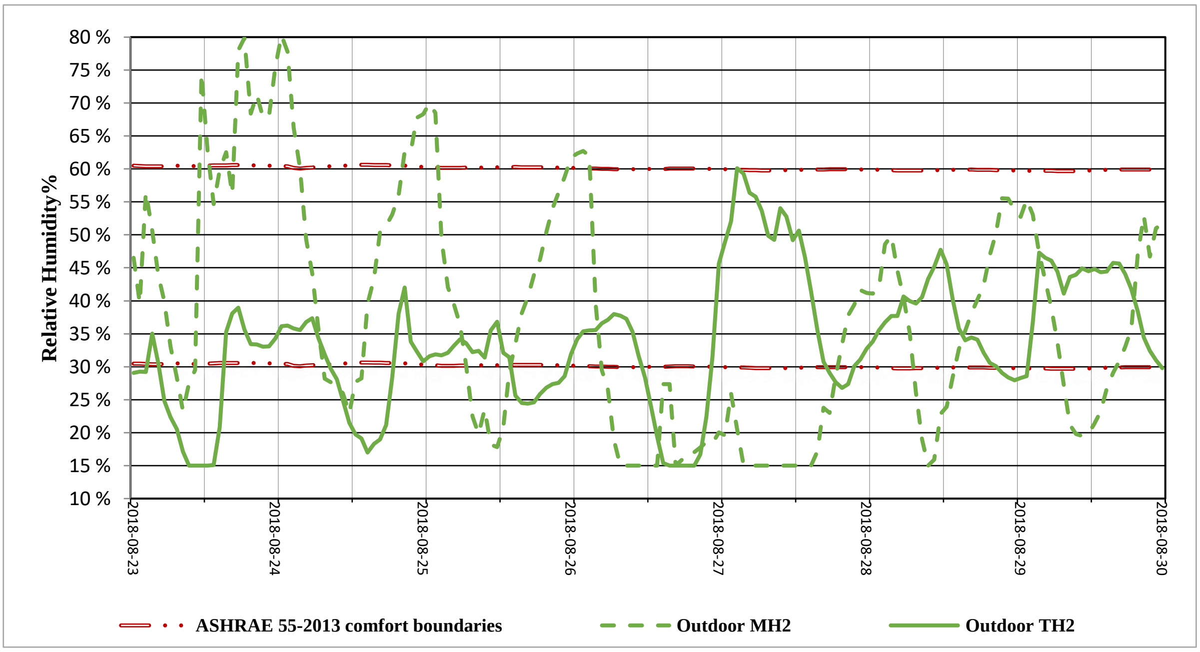



*Figure 5.93 Comparison of relative humidity during the summer.*

In support of that, in MH2, the width of the roads are larger which caused more heat transfer from the heated walls, more high solar radiation creates a temperature gradient which the structure ends up being loaded with heat and takes longer to empty itself of the stored overheating and causes high outdoor temperatures (Figures 5.92/ 5.93). It can be observed that for 50% of the measurement period, the temperatures in TH2 were not within the ASHRAE 55 range; the recorded temperature reached about 39°C around midday and 28°C after midnight. In the meantime, at MH2, the temperature reached about 46°C around midday and 26°C after midnight. The relative humidity was not within the ASHRAE 55 range (60%), indicating dry climate conditions in MH2. In TH2, on the other hand, the relative humidity was well below the ASHRAE 55 range for some parts of the day. It was also noted that on Monday, the occupants poured water on the narrow roads to humidify the air which, needless to say, increased the humidity (Figure 5.93). In general, the data flow follows the same pattern with significant variances. The weather station is often colder at night and warmer during the middle of the day due to its location in an open desert region with no shelters, while the presence of urban mass in the surrounding area has a considerable impact on the temperature of Ghardaia City.

- **Living room:**

The records for TH2 showed that the daily temperature ranged from 27 to 32°C while the relative humidity ranged from 15 to 45% (Figure 5.94 and Figure 5.95). The air temperature started to increase rapidly at 6:00 in the morning, reaching the peak around 32°C at 14.00 hrs when the occupants started using the living room as a gathering place, then the temperature started to decrease after midnight after the structure elements empty itself from the stored overheating heat during the day which usually takes and takes around six hours. It should be noted that the peaks and cooling loads for TH2 are the same throughout the week. However, on Saturday, a peak temperature of 32°C, the highest temperature for all spaces on both the buildings (Figure 5.94) was recorded.

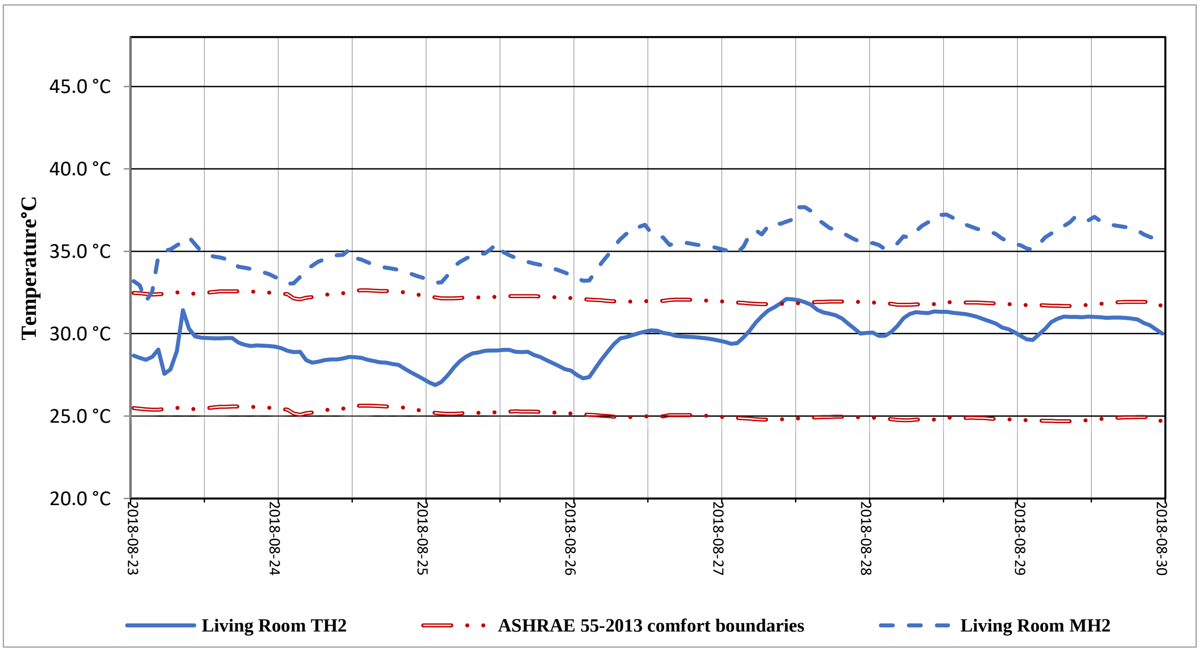



*Figure 5.94 Comparison of the living room's temperatures during the summer.*

It shows an inverse relationship between the air temperature and relative humidity; as the air temperature drops, the relative humidity increases and vice versa. This would be expected, given the dehumidification process. On the other hand, in MH2's case, the air temperatures fluctuated, albeit steadily, between 32 and ~38°C (Figure 5.94) which is about 5°C higher, compared to TH2. Its temperature was well above the ASHRAE 55 range throughout the week, despite the fact that the thermal mass influences the amount of excess heat accumulated during the day which is sorted in the mass and then released the night. The living room is almost unventilated, and far from the patio, the windows remain closed throughout the year, out of respect for the occupants' privacy and beliefs. Overall, the occupants on modern houses were not satisfied with their thermal environment during the summer.

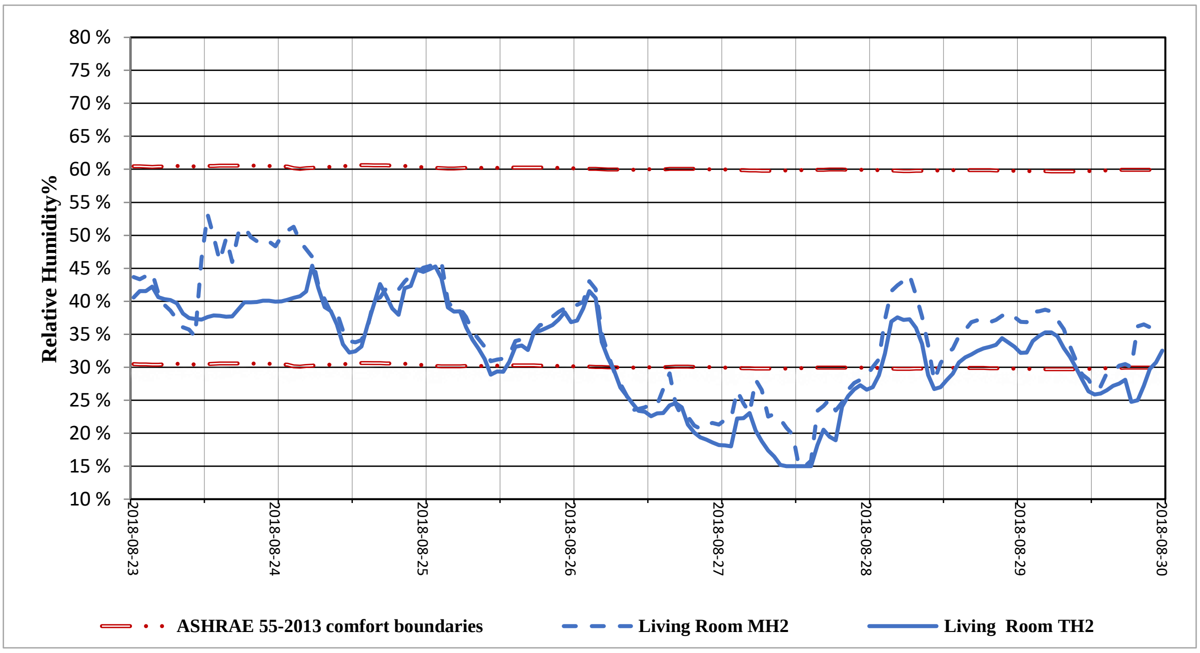



***Figure 5.95 Comparison of the living room's relative humidity during the summer).***

Meanwhile, the readings on TH2 shows the diurnal fluctuation of RH was from 15% to 45%, which observed 50% of the measurement period the RH in TH2 was within the ASHRAE 55 range and considered a dry climate; In relation to MH2, it worth noted that on first day, the occupants poured water on the narrow roads to humidify the air which, needless to say, increased the humidity (Figure 5.95), and found the readings on MH2 shows the diurnal fluctuation of RH was from 15% to 52%, which observed that for 50% of the measurement period.

- **Rooms:**

Both rooms (TH2/MH2) are located on the top floor. Based on Figure 5.96, the mean daily air temperature for TH2 ranged between 31.5°C and 36.0°C, with noticeable diurnal temperature variation is found 4 K. Meanwhile, the data reveals that the diurnal fluctuation of the relative humidity is from 15% to 47% (Fig. 5.97). This temperature range can be attributed to the roof's flat structure, in contrast the dome-like roofs of other buildings within other cities of the Algerian Sahara, making to severely high levels of solar radiation. Given that the thermal mass influences the amount of excess heat accumulated during the day, the high and solid parapet walls along the edge of the roof is assumed to have the disadvantage of creating an undesirable stagnant pool of hot air and leads to thermal inertia in buildings. However, on the contrary, it is works to save and spread the temperature at night, explaining the reason why both houses show an increase in temperature during the night.

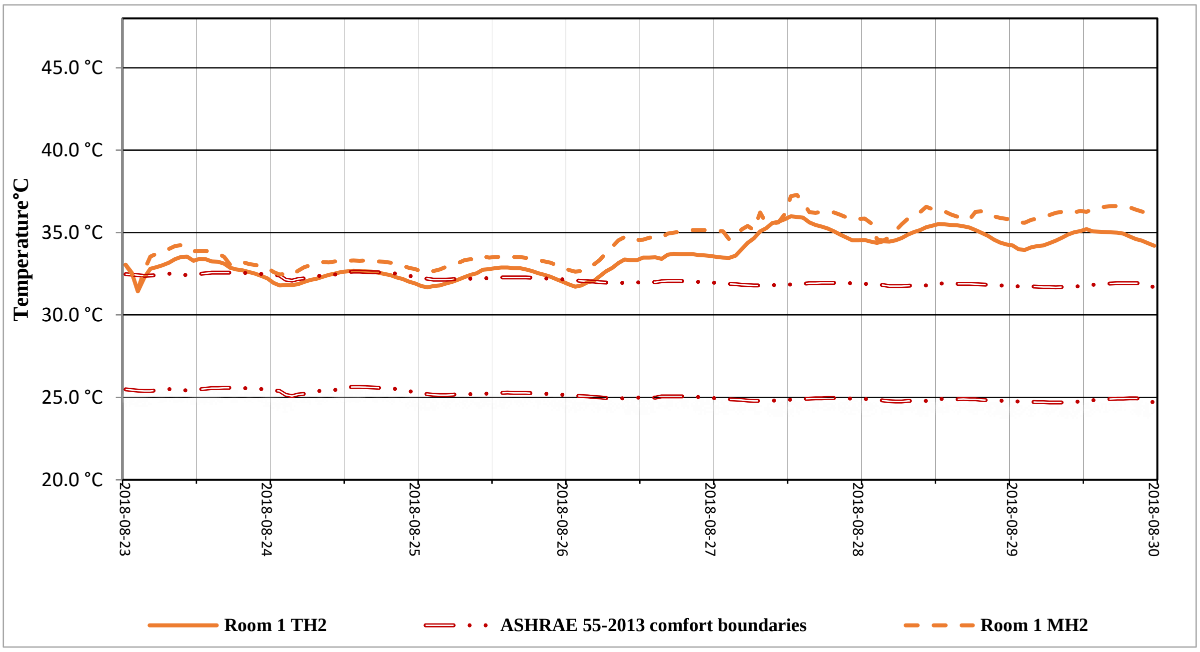



*Figure 5.96. Comparison of the rooms' temperature during the summer*

On the other hand, the first-floor room on MH2, the mean daily air temperature ranged between 32.5°C to 37.0°C with diurnal temperature variation of 4.5K, the data reveals that the diurnal fluctuation of the relative humidity is from 15% to 53% (Fig. 5.97); whereas the temperature started to increase rapidly during the morning to reach the peak around 37.0°C around the midday,

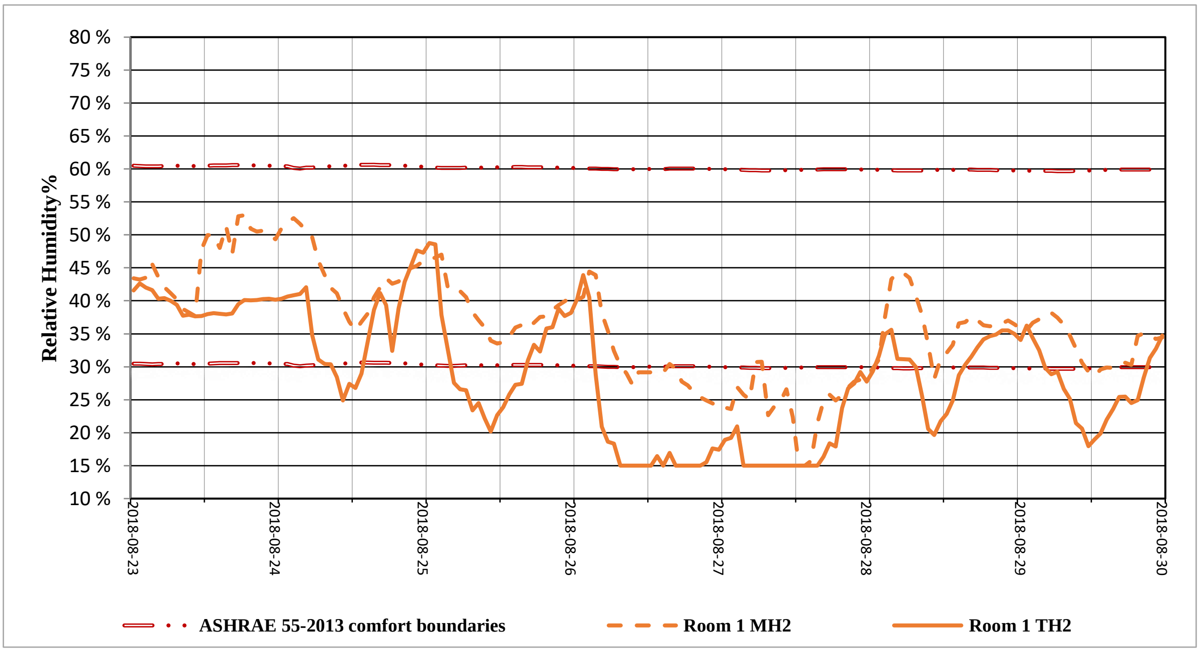



*Figure 5.97 Comparison of rooms' relative humidity during the summer*

then the temperature started to decrease after midnight as the structure elements released the stored overheating heat during the day which usually takes hours where the minimum temperature was 32.5°C, at early morning, however this is still considered high compared to the ASHRAE 55 boundary range, it can be interpreted that the thermal mass of a building absorbed, stored during the sun exposure, and progressively released the heat during the night time. Furthermore, buildings with a large amount of thermal mass need more time to reach the cooling temperature. This might cause thermal discomfort for occupants and result in an increased energy consumption due to a longer preheating period. Humidity is considered relatively acceptable given that the climate is hot and dry 50% of the RH were within the ASHRAE 55 range.

- **Patio:**

Figure 5.98 indicates the flow of recorded temperature data has the different curve pattern with big variations on both houses. The diurnal temperature for TH2 ranged from 27°C to 32.0°C, a noticeable diurnal temperature variation is found (5 K as an average). Meanwhile the relative humidity ranged from 25% to 45% (Figure 5.98/Figure 5.99). It is important to note that the patio in TH2 was covered all daytime to avoid the exposure of the sun and maintain moisture, this explains the preservation within ASHRAE 55 boundary range even though it is considered as semi external space. Moving to MH2 results, the temperature ranged between 31°C and 36°C, making it out of the ASHRAE 55 range by 75%. Most of MH2's occupants reporting feeling uncomfortable during the summer season. considering to the location of the patio on MH2, where it was designed on the side of the house, not all areas overlook on it.

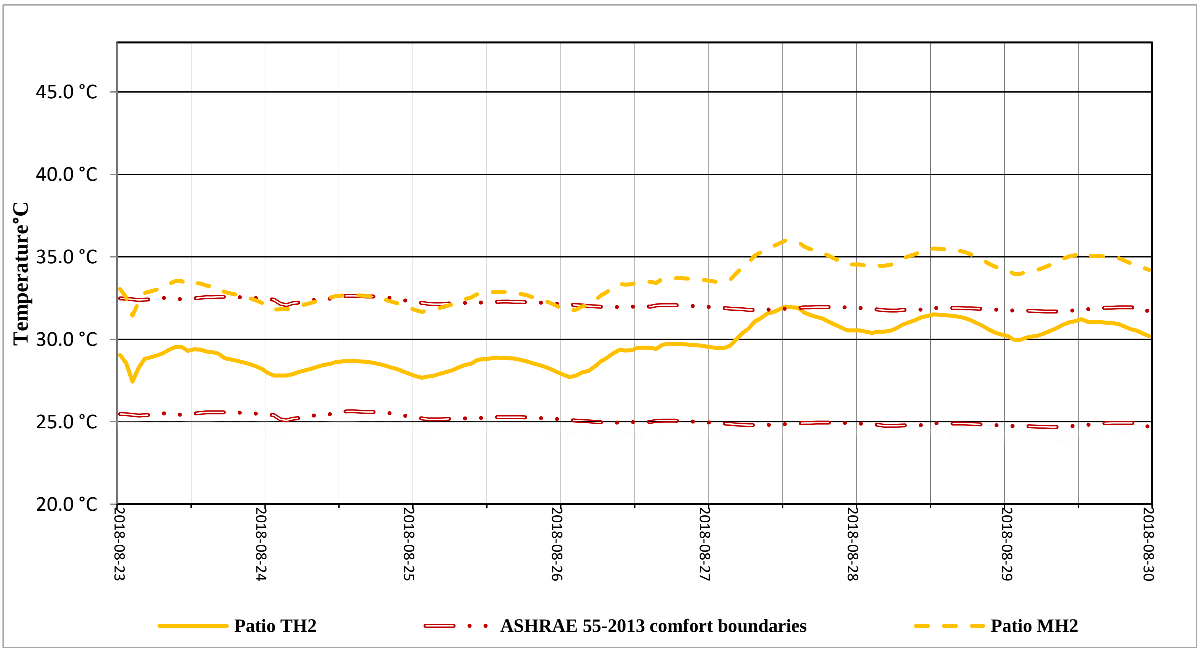



*Figure 5.98 Comparison of the Patio temperature during the summer*

On the contrary, it was only designed in the middle of the house which is more beneficial. In addition, the high patio surface temperature, and its wall surface temperature through convection heat, leading to the increased transfer of heat to the surrounding walls from there to the internal spaces, which in turn will negatively affect the buildings envelop. The relative humidity levels kept fluctuating in the ranges 15% ~ 55% and 25% ~ 45% for MH2 and TH2, respectively. Based on the collected data, it can be concluded that the average relative humidity in both the patios reached 55% and was well within the ASHRAE 55 range.

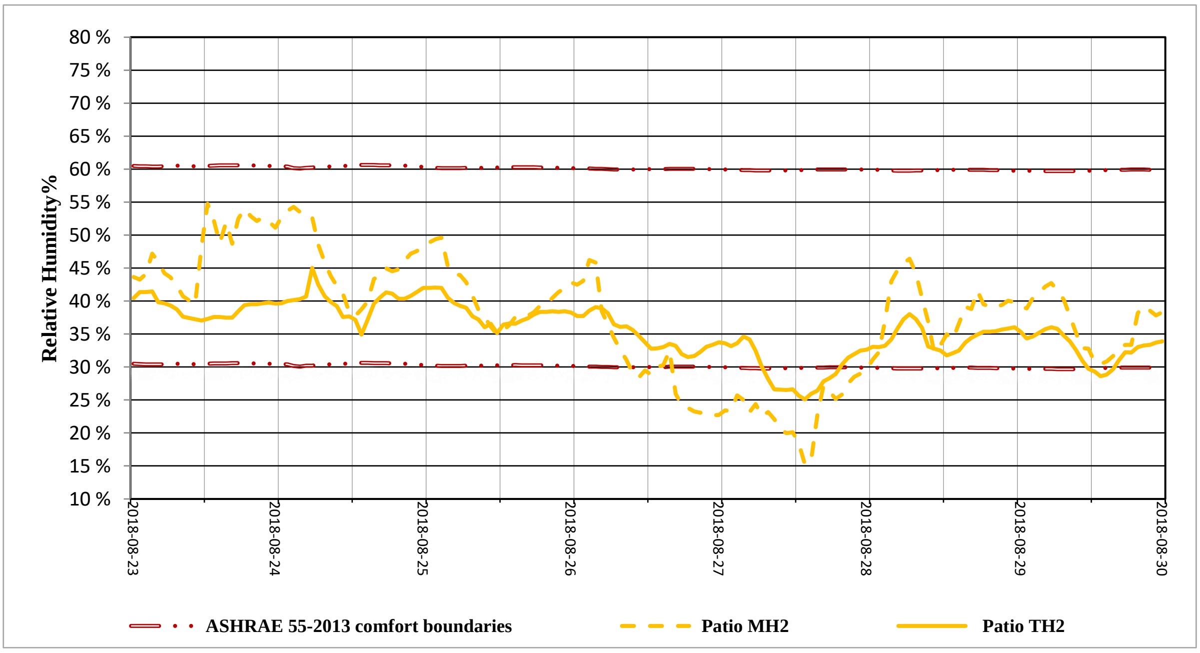



*Figure 5.99 Comparison of patios Relative Humidity during the summertime for one week*

### B. Winter Measurements From 10/01/2019 to 17/01/2019:

- **Outdoor:**

From figure 5.100. Significantly, the flow of recorded temperature data has the same curve pattern with small variations on both houses. Running mean outdoor air temperature (Trm) for TH2 ranged from 6.5 °C to 16.5 °C,

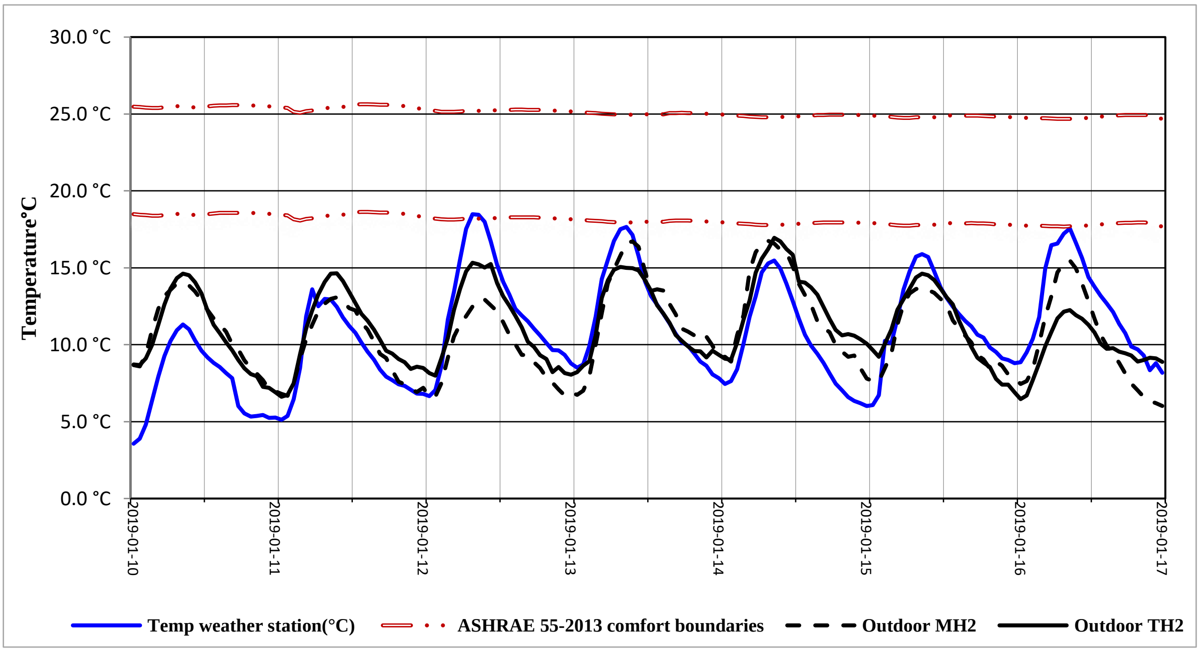



*Figure 5.100. Comparison on outdoor temperatures during the winter*

on average, the diurnal temperature variation is found to be around 10.0 K. Meanwhile MH2 Running mean outdoor air temperature (Trm) ranged from 6.0 °C to 16.5°C, on average, the diurnal temperature variation is found to be around 10K. Both houses failed to meet the recommended ASHRAE 55 range. Clearly the range of the relative humidity was from 25%to 68% for TH2 and 35%to 70% for MH2, it rises to its maximum during the night and decreases around midday to reach its lowest value 25%.

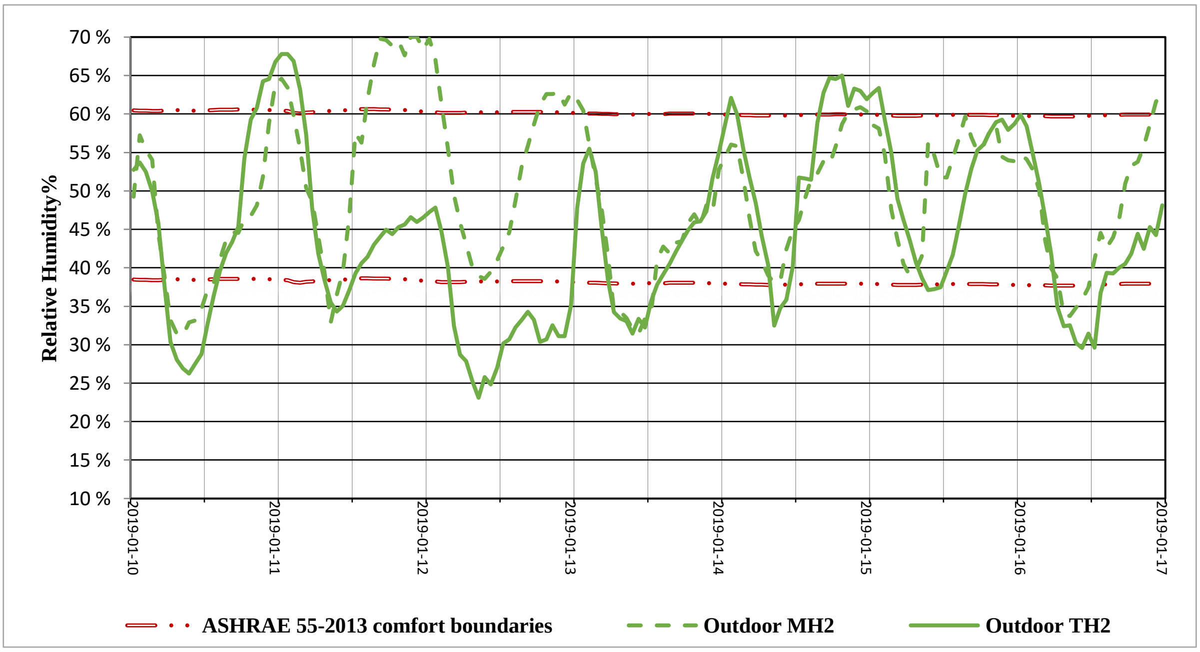



*Figure 5.101 Comparison of outdoor relative humidity levels during the winter.*

- **Living Room:**

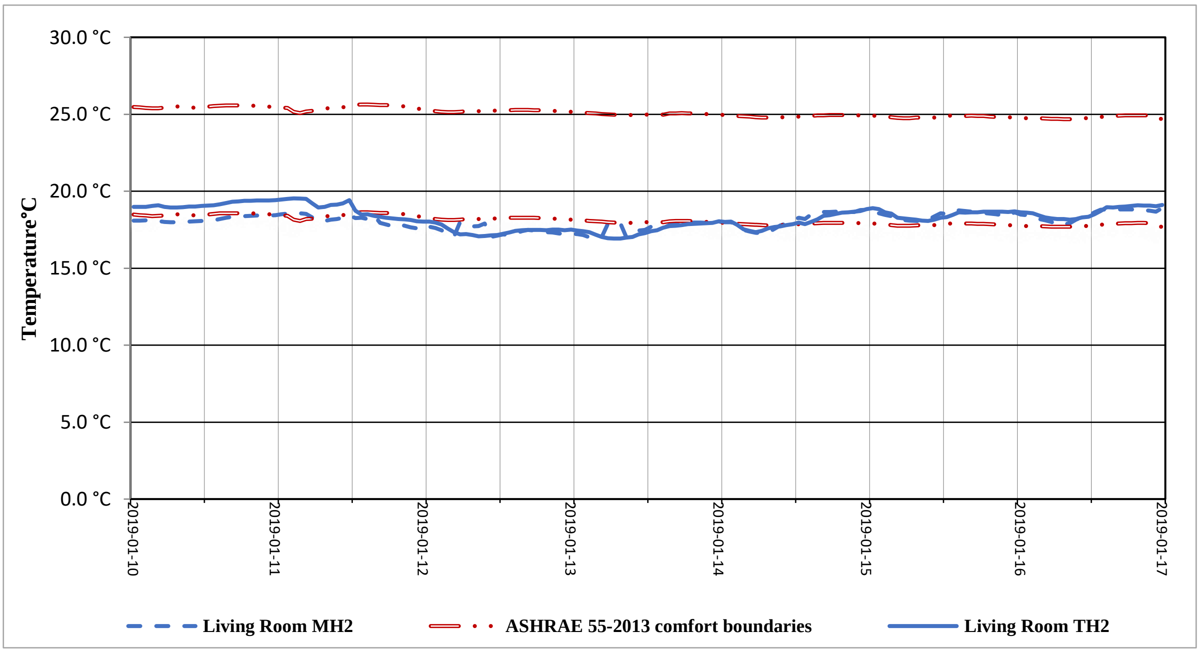



*Figure 5.102 Comparison of the living room temperatures during the winter*

Based on the outdoor weather conditions, indoor temperature was constantly fluctuating. However, the diurnal temperature range for both TH2 and MH2 was between 17.5 and 18.5°C and remained steady throughout the week, the temperatures were low enough to be within the ASHRAE 55 range (18°C) (Figure 5.102).The relative humidity range is between 44 % and 58% for TH2, which making them lie completely within the ASHRAE 55 range, and 24 % and 38% for MH2, which failed to meet the ASHRAE boundary and considered very day environment (Figure 5.102). In order to obtain comfortable indoor thermal comfort conditions, the occupant used constantly gas stove as heating technical systems, which helps to restore the room's heat balance to an equilibrium, hence maintain a constant indoor temperature. Generally speaking, that the space considered uncomfortable this enforces the occupant to use the gas heater to increase the indoor temperature.

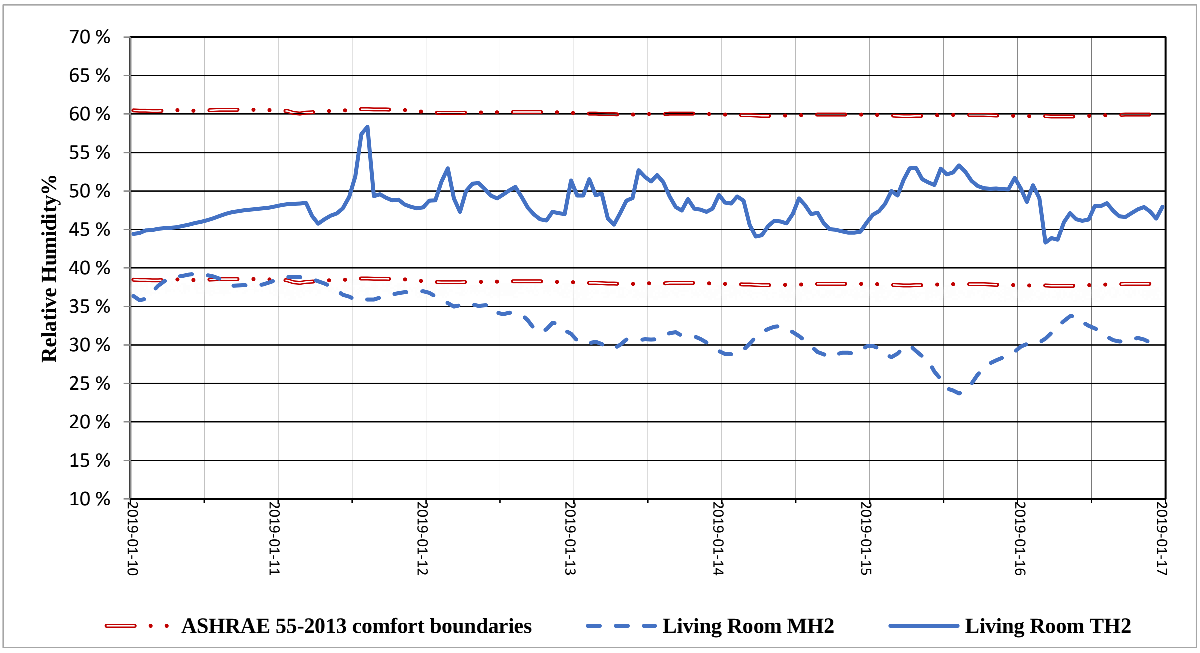



*Figure 5.103 Comparison of the living room's relative humidity during the winter*

- **Rooms:**

Whilst solar radiation and convective heat flows vary simultaneously with the fluctuation of the outdoor boundary conditions, the conductive heat flows through the building skin will display a time lag compared to the external excitation, however, the diurnal temperature range for both TH2 and MH2 between 16.5°C and 18.0°C and remained steady throughout the week, the temperatures were low enough to be within the ASHRAE 55 range (Figure 5.104).

The relative humidity range is between 37% and 58% for TH2 making the traditional house lie completely with the ASHRAE 55 range (Figure 5.105), and 28% and 42% for MH2. In order to obtain comfortable indoor thermal comfort conditions, the occupant used constantly a gas stove for heating, which helps to restore the room's heat balance to an equilibrium, hence maintain the indoor temperature.

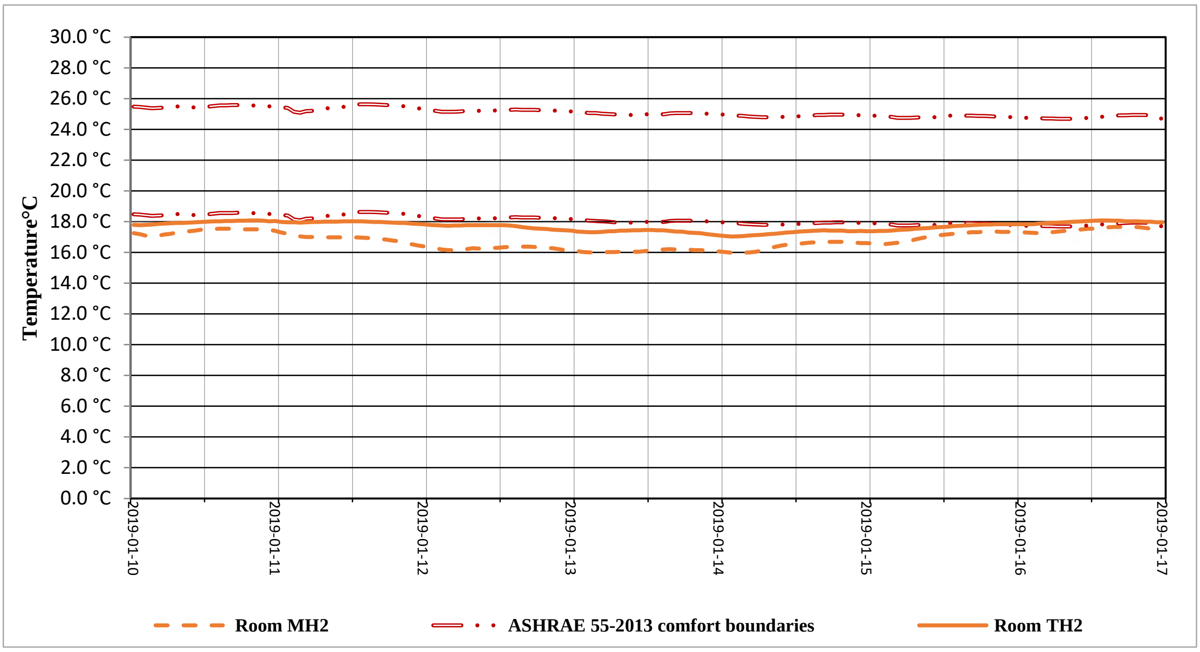



*Figure 5.104 Comparison of the rooms' temperatures during the winter*

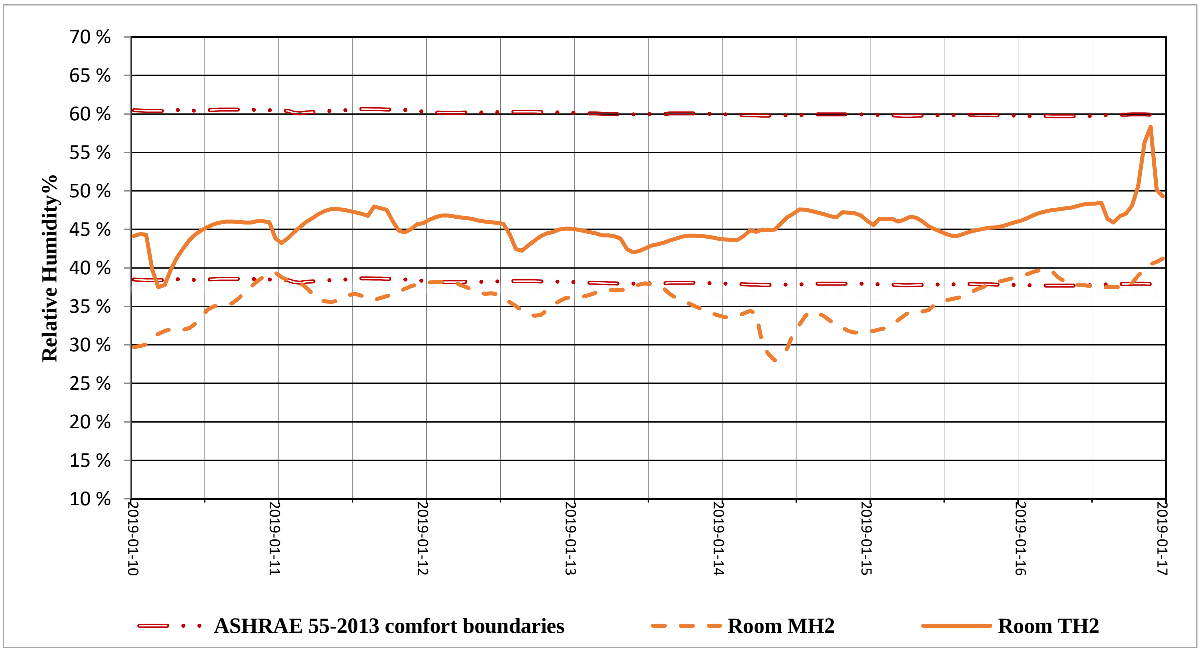



*Figure 5.105 Comparison of the rooms' relative humidity levels during winter*

- **Patio:**

The diurnal temperature range for TH2 ranged between 13.0°C and 14.0°C; in MH2, the patio kept fluctuating between 6 and 17°C, well below the ASHRAE, with the diurnal temperature range for 6.5°C to 17.5°C which is highlighted in Figure 5.106. On the other hand, the relative humidity ranges between 30% and 46% for TH2 and 24 and to 35% for MH2 indicating that TH2 is does not meet all the period the comfort range.

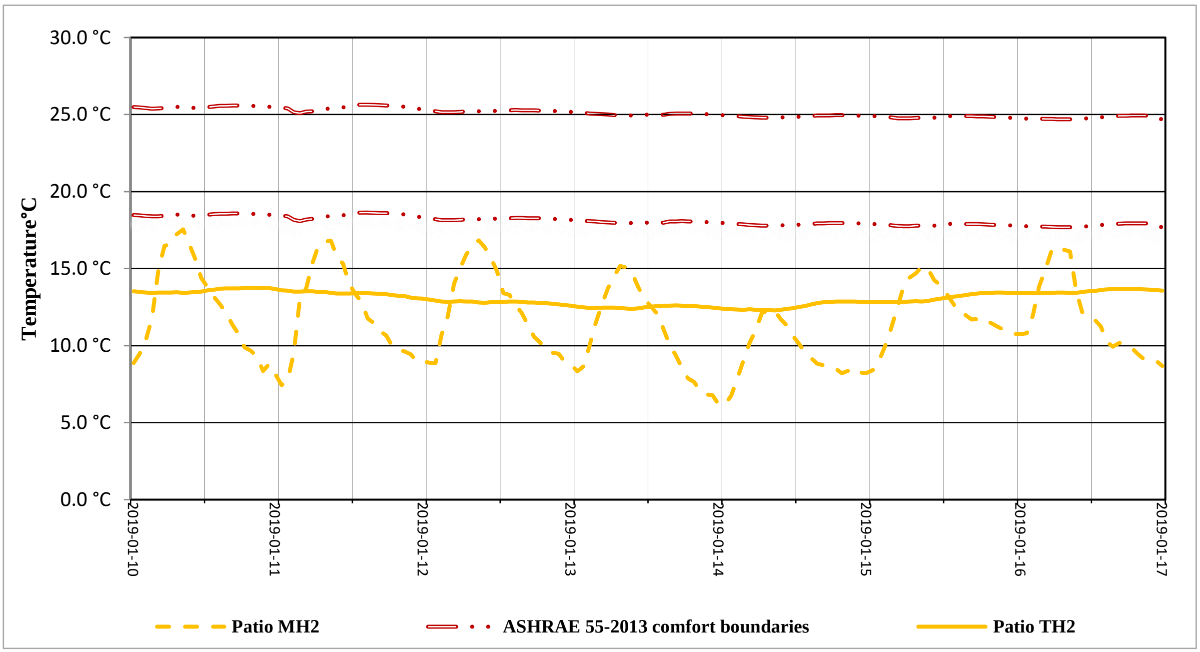



*Figure 5.106 Comparison of the patio's temperatures during winter*

TH2's patio recorded a steady temperature at 13.5°C due to covering the patio also during the winter season. From this, it is evident that both spaces' temperatures were completely beyond the ASHRAE 55 range.

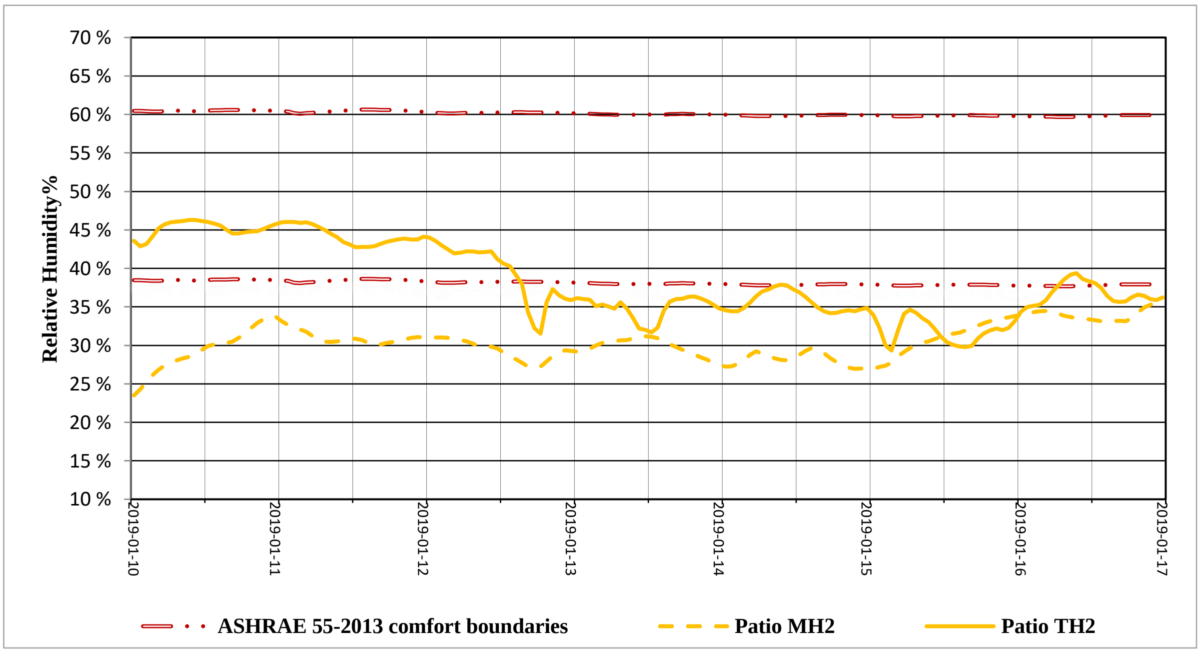



*Figure 5.107 Comparison of the patio's relative humidity levels during winter*

## 5.12 Conclusion:

The result of the comparisons for both the traditional and modern buildings in Tafilelt and Beni Isguen showed a lot of differences, in terms of the temperature and relative humidity. For instance, the patios of traditional buildings were able to reduce the temperature and increase humidity while the ones in modern buildings could not, due to them being covered. This is also due to the fact that patio was located at a side corner/edge of the building. In the traditional houses of Beni Isguen, the patios were in the middle due to which, they were covered well. Moreover, the concentration of activities like doing the laundry or pouring water here also helped to give a cooling effect to the space.

Compared to the ground floors, the first floors of all the buildings showed significant differences in temperatures during both the seasons, especially in summer. In fact, the outdoor temperatures were the highest during the measurement periods. However, despite being semi-open to the patio which would allow the convection of heat, the floors failed to meet the acceptability limits of the ASHRAE adaptive comfort criteria. Similar on winter the first floor rooms were the average minimum temperature being approximately lower , despite using the a gas stove during the day , still the temperature under the acceptability limits of the ASHRAE , which reveals the failure of the building fabric in delaying the cold transfer, moreover the building materials has negative impact to transmission the heat and the clod to the ground floor the type of material and the thickness doesn't help to reduce the thermal mass and the heat gain or let the building breath. It is worth noting that of both the types, the traditional buildings of Beni Isguen use the vernacular passive cooling strategy to improve and maintain their thermal performance. This strategy ensures that the buildings stay within the thermal comfort zone during both seasons, as was seen in the use of shading and natural ventilation in TH1 and TH2.

By comparing the outdoor temperatures of the old city with the new city, a difference can be noticed in how the urban design of each city influences the local climate, as described in Chapter Overall, the temperatures in the old city have constant fluctuations while being tolerable in the urban areas due to the organic design; all the streets are protected from the sun by the covering of light wells in order to provide natural lighting and ventilation. The city itself is protected by an oasis from all directions. All these features help provide sufficient cooling to the buildings in these areas. Moreover, the effectiveness of the building envelope design lies in the fact that it is made from local materials. However, the range of temperatures in the new and modern city of Tafilelt sees large fluctuations between daytime and night-time during the summer and winter, whereas the urban area's design in the new city of Tafilelt has ignored the arid nature of the desert, as is the case in the design of the old city.

# CHAPTER
# VI
# DEVELOPMENT OF THE MODEL TO PREDICT THE BUILDING PERFORMANCE

# CHAPTER VI

## Model Validation and Simulation Results

### 6.1 Introduction:

This chapter introduces simulation modelling and the creation assumption of the model and its validation which contains two parts:

- First, a description of the climatic conditions on both sites is given.
- Second, the materials used for both pairs on both sites is also highlighted

This description is based on the results of the measurements made during the summer and winter seasons for both the traditional and modern houses. A series of simulations were undertaken with the selected software to assess, check and compare the results and the effect of urban geometry and building materials on indoor thermal comfort conditions. In the first part, the simulation results will be compared with the real results and then validated accordingly. On the basis of this, in the second part, the research will propose optimisations through numerical simulations, using a new model with an aim to propose alternative solutions to the problems observed.

### 6.2 Tools and Validity:

Dynamic thermal simulations are used to obtain precise evaluations of the functioning of buildings. The objective is to control all energy exchanges to design new high-efficiency buildings and seek efficient solutions to quantify and reduce the time and cost variances over the life of the building to make it more durable especially during the summertime. The variation of the input parameters is made possible by the increase in the computing power of workstations and by the generalisation of dynamic simulation tools.  The Design Builder software was chosen for many reasons in that it is considered as a complete and multiplatform tool with a significant development and a capacity for an advanced energy systems simulation. In addition, it has inputs and outputs in text format and can be used in parallel without a graphical interface; it has been subjected to numerous validations and has strong support from the scientific community, allowing model calibration, a confidence index on the results and an efficient search for solutions. To achieve this goal, the following steps are followed: specify the variables, simulate, collect the results and calculate the effect after interpreting and presenting the results.

A simulation model includes a building context that is composed of thermal zones which have geometric, operational and constructional elements as well as more technical networks and control systems within a model. Material properties are available for building characteristics e.g., wall descriptions, composition and surface properties that assist in understanding the model data when evaluating the entire building. In the present study, were analysed rigorously such that the heating and cooling loads were calculated for each model. Following this, the results were evaluated to optimise the thermal behaviour of the models.

### 6.2.1 Design Builder:

Design Builder is a powerful software tool for creating and assessing building designs. It has been specially developed so it can be used effectively at any stage of the design process, from the concept stages where just a few parameters are needed to capture the building design to a much more detailed building model for established designs (Design Builder 2021).

Design Builder is suitable for use by architects, building services engineers, energy consultants and university departments. Some typical uses are:

- Evaluating a range of façade options for their effect on overheating, energy use and visual appearance.
- Checking for an optimal use of natural light, modelling lighting control systems and calculating savings due to electric lighting.
- Calculating the temperature, velocity, and pressure distribution in and around buildings using Computational Fluid Dynamics (CFD)
- Visualising the sites' layout and solar shading.
- Conducting the thermal simulation of naturally ventilated buildings.
- Ensuring a heating, ventilation, and air conditioning (HVAC) design including heating and cooling equipment sizing.

Design Builder uses the latest Energy Plus simulation engine to calculate the energy performance of the building, as it is used for modelling building heating, cooling, lighting, ventilating, and other energy flows. Energy Plus is a stand-alone simulation program without a 'user friendly' graphical interface. Design Builder rectifies this issue by creating an elegant and easy-to-use interface for Energy Plus. Data templates allow the user to load common building constructions, HVAC activities and lighting systems into the design by selecting them from drop-down lists. They can also add their own templates if they often work on similar types of buildings. This, combined with data inheritance, allows global changes to be made at the building, block or zone level. Moreover, users can also control the level of detail in each building model, allowing the tool to be used effectively at any stage of the design process. A comprehensive range of simulation data can be shown in annual, monthly, daily, hourly, or sub-hourly intervals:

- Energy consumption broken down by fuel and end-use
- Internal air, mean radiant and operative temperatures and humidity
- Comfort output, including temperature distribution curves and the ASHERAE 55 comfort criteria.
- Site weather data
- Heat transmission through building fabric, including walls, roofs, infiltration, ventilation etc.
- Heating and cooling loads.
- $CO_2$ generation.
- Heating and cooling plant sizes that are calculated using data.

The data can be displayed graphically or in tabular form and can be exported in a range of formats, such as spreadsheets and custom reports.

#### 6.2.1.1 Ventilation and Infiltration:

The ventilation and infiltration were defined as spaces of constant air exchange/transfer where an infiltration rate of 1 ac/h was assumed for the zones. The air leakage distribution was in form of air leaks through the cracks around windows, openings, and doors from the external environment. This infiltration was governed by a flow network airflow. The flow network comprises several types of nodes assigned for the internal zones and the external environment; these are connected by components (openings, cracks, windows, and doors). The programme simulation predicts the real indoor temperatures based on the selection and classification of the windows opening times for the natural ventilation during summer. The airflow is controlled by a control loop that is set for certain periods and temperatures and connected to a sensor in a defined zone. In total, 14 nodes, six components and 21 connections were defined for the airflow network.

## 6.3 Energy Simulation Procedure:

The procedure was done in three phases, as described in Figure 6.3:

a) Set up the input data for the two pairs (TH1/MH1, TH2/MH2) based on the standard weather and construction material databases within the software that represent information about the climate conditions such that it is considered the same for all the dwellings.
b) Model of the two cases for study simulation as well as for the evaluation of the building simulation. Following this, the reliability of Design builder simulation is confirmed with the current case studies
c) Compare the results and analysis.

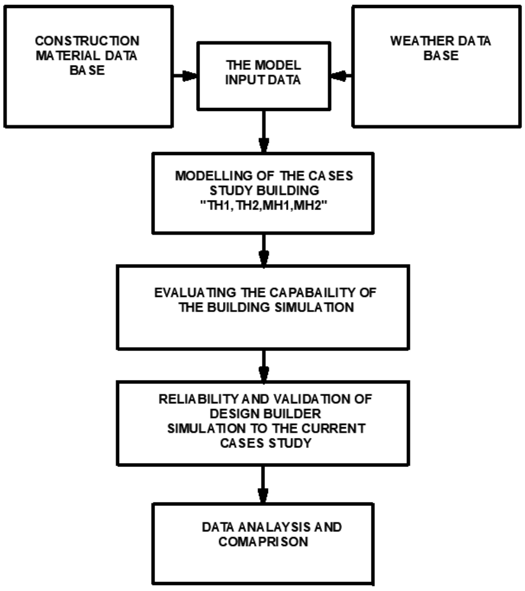



***Figure 6.1 Energy simulation strategy***

### 6.3.1 Climate Database:

The dynamic simulations were carried out for climate conditions similar to the climate conditions of the site, such as outdoor temperature, solar irradiation, and relative humidity. A climate database for

Ghardaia city was obtained from Meteonorm as EPW files. Design Builder was the first choice for this task but since the data pertaining to Ghardaia was not updated in its library, Meteonorm was used to get data that is comparable to the real weather data of Ghardaia. To develop the building's geometry, the location was then automatically set to provide the pre-determined site conditions and the hourly weather data file for all the selected case studies. The climate database comprises the hourly values of diffuse horizontal solar intensity (W/m$^2$), dry bulb temperature (tenth of a degree), direct global horizonal solar intensity (W/m$^2$), wind speed (tenths of m/s), wind direction (degree from North, clockwise) and relative humidity (percent) for ten years from 2010 to 2020. The climate parameters for the Ghardaia city were presented earlier in Chapter 4.

### 6.3.2 Material Database:

Design Builder's material database includes similar materials to those used in case studies, all material characteristics are available for building e.g., walls description, composition, and surface properties. Moreover, the software allows modification of any materials to be changed and new characteristics added that are compatible and similar with the existing ones at MH1/MH2 and TH1/TH2.

Table 6.1 represents the building materials for modern and traditional houses.

***Table 6.1 The building materials for modern and traditional houses***

| Construction TH1, TH2 | |
|---|---|
| **Structure type** | Heavy building with traditional materials |
| **External walls** | Paint<br>25 mm lime sand render<br>450 mm limestone<br>25 mm lime sand render<br>Paint |
| **Internal walls** | Paint<br>10 mm gypsum<br>200 mm limestone<br>10 mm gypsum<br>Paint |
| **Roof** | 20 mm lime sand render<br>150 mm clay or silt<br>250 mm limestone<br>20 mm wood<br>Paint |
| **Internal floors** | 20 mm lime sand render<br>150 mm clay or silt<br>150 mm limestone<br>20 mm wood<br>Paint |
| **Windows, doors** | Windows Single un-insulated glazing<br>Wooden frames |
| **HVAC system** | No heating or cooling system |

| Construction MH1, MH2 | |
|---|---|
| **Structure type** | Heavy building with traditional materials |
| **External walls** | Paint<br>50 mm lime sand render<br>350 mm limestone<br>50 mm lime sand render<br>Paint |
| **Internal walls** | Paint<br>10 mm plaster<br>200 mm limestone<br>4 mm plaster<br>Paint |
| **Roof** | 20 mm lime sand render<br>150 mm clay or silt<br>150 mm limestone<br>20 mm wood |
| **Internal floors** | 20 mm clay tiles<br>20 mm lime sand render<br>100 mm clay or silt<br>100 mm limestone<br>20 mm wood |
| **Windows, doors** | Windows Single un-insulated glazing<br>Wooden frames |
| **HVAC system** | No heating or cooling system |

## 6.4 Modelling of the Case Studies:

The houses selected for modelling were same cases monitored as described in Chapter 5. The two case studies were based on the building composition and geographical locations of the houses that were monitored during winter and summer. Design builder has good accessibility and determines the building's dimensions and materials and can also integrate the design by input from the AECHICAD model geometry with the interoperability of 3D building model (Figure 6.2).

Design Builder provides a range of thermal performance analysis options, where the mass design of the building shows the outer envelope shell of the model and contains the rest of the building's aspects, such as the external and internal walls, floor and roof, the activities and the type of HVAC system used. Moreover, the description of the materials is supported by libraries of standard components and combinations of components that helped to edit and create new materials.

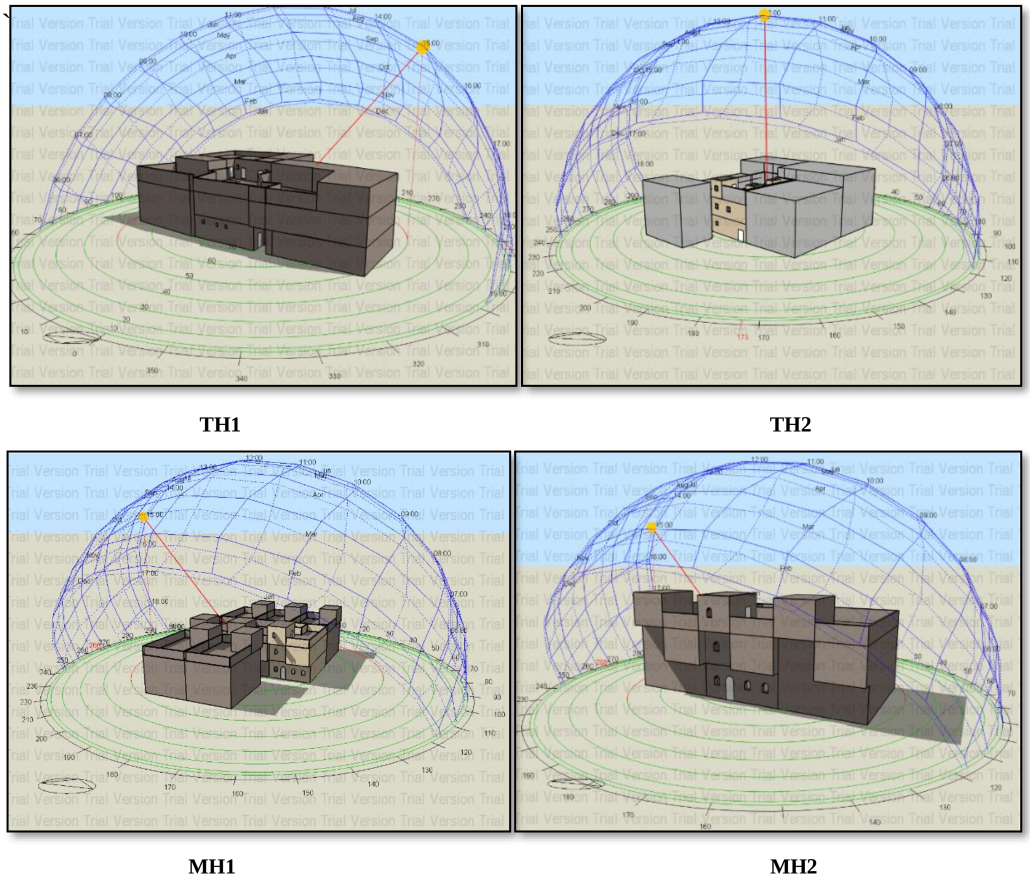



*Figure 6.2 The geometry of the case studies ( source: by the Author).*

### 6.5 Prediction and Validation of Design Builder:

In order to validate the model, i.e., to verify its ability to correctly identify radiative transport and airflow processes, numerical simulations were performed on the Design Builder experimental configuration. The same week was selected in which the measurements were made to compare TH1/MH1 (chaper5). This particular week (02/08/2018 to 09/08/2018) was a relatively hot period with various weather conditions:

- Six days of sunshine with a clear sky and two days with a cloudy sky
- Variable wind speeds between 3.2 and 4.5 m/s, measured at a height of 10 m

The simulation run for this period with a calculation time step of one week, using the occupant density for each space and zone times of occupancy, which has individual template that allows activities, temperatures, HVAC systems, lighting, internal gains, and ventilation that was set for each space.

### 6. 6 Reliability and Validation of Design Builder Simulation for the Current Case Study:

In order to compare the difference between the actual microclimate of indoor conditions and the predicted study by Design Builder, the actual field measurement data collected by HOBO data loggers was compared with the predictions of Design Builder data, which were based on dynamic simulations on an hourly basis, during a week on summer (2ND August 2018 to 9th august 2018) and week on winter (3rd January 2019 to 10th January 2019).

The modelled buildings had the same orientation and urban environment as the real buildings. Design Builder allows to set and determine the building type, occupancy number, activities, use of indoor spaces, the time of opening and closing windows and doors, which were adjusted to the building simulation in the summertime and wintertime period.

The demonstrated results showed a good agreement with a small variation between real weather data and the simulated data; Therefore, it is a quite reasonable calibration for the simulation model.

### 6.6.1. Summer Season Weather Data Validation (TH1/MH1):

- **Outdoors:**

**a- Air Temperature:** Figure 6.3 describes the empirical actual field measurement data collected during the specified week by the HOBO data logger UX100-003 for the buildings in both Tafilelt and Beni Isguen. This data counters the predicted Design Builder output of the two models MH1 and TH1 for the same time period, as the weekly results show that both their temperature graphs are similar to each other. It can be seen from Table 6.2 that were found a small variation within the range of ±3°C degree between outdoor simulated temperatures and outdoor measured temperatures in the summer, in both cases, and consequently, It gave a similar result, which it is a quite reasonable calibration for the simulation model.

***Table 6.2. Simulation results against measured results for Outdoor TH1/MH1 during the summer***

| Building | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Outdoor MH1** | 34.7 °C | 33.0 °C | 42.2 °C | 42.0 °C | 27.2 °C | 24.0 °C |
| **Outdoor TH1** | 31.5°C | 32.0 °C | 39.2 °C | 41.0 °C | 23.5 °C | 23.0 °C |

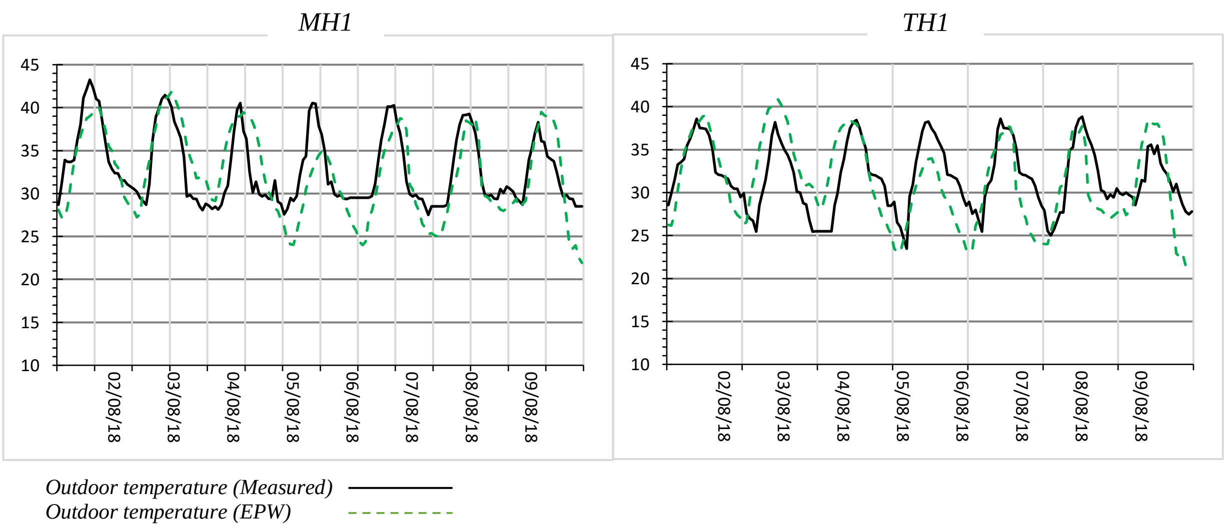



***Figure 6.3 Comparison between the monitored outdoor temperature and the Predicted temperature during summer (MH1/TH1)***

**b- Relative Humidity:** There were clear differences between the outdoor relative humidity for the collected field measurements and data and the predictions of Design Builder, this is due to the fact that the humidity used on Design Builder were taken from the actual weather data that was collected from outdoor monitoring by Easy Weather station, where its located far from both urban settlements which made such as difference

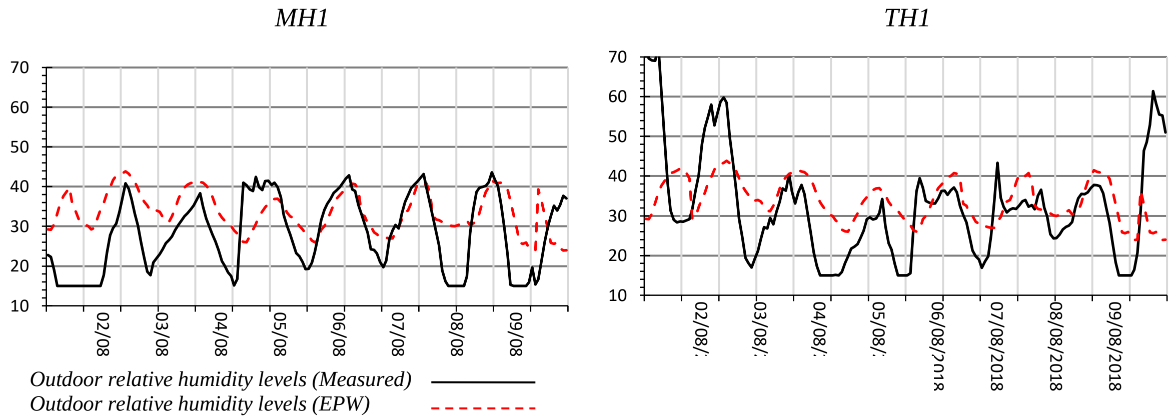



***Figure 6.4 Comparison between the monitored and outdoor relative humidity levels during the summer (MH1/TH1)***

- **Living Room:**

**a-Air Temperature:** In Figures 6.5 and Table 6.3, it can be seen that the actual and the average weather data that were predicted by Design Builder simulation produced identical living rooms air temperature ranges in both TH1 and MH1 with range of 3K temperature difference, despite there were small difference, they reached the pick together around midday and the lowest point around midnight on the same time.

***Table 6.3 Simulation results against measured results for Living room TH1/MH1 during the summer***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Living room MH1** | 35.1 ºC | 34.0 ºC | 36.7 ºC | 37.5 ºC | 33.5 ºC | 30.5ºC |
| **Living room TH1** | 30.1ºC | 32.2 ºC | 30.8 ºC | 34.0 ºC | 29.5 ºC | 30.5ºC |

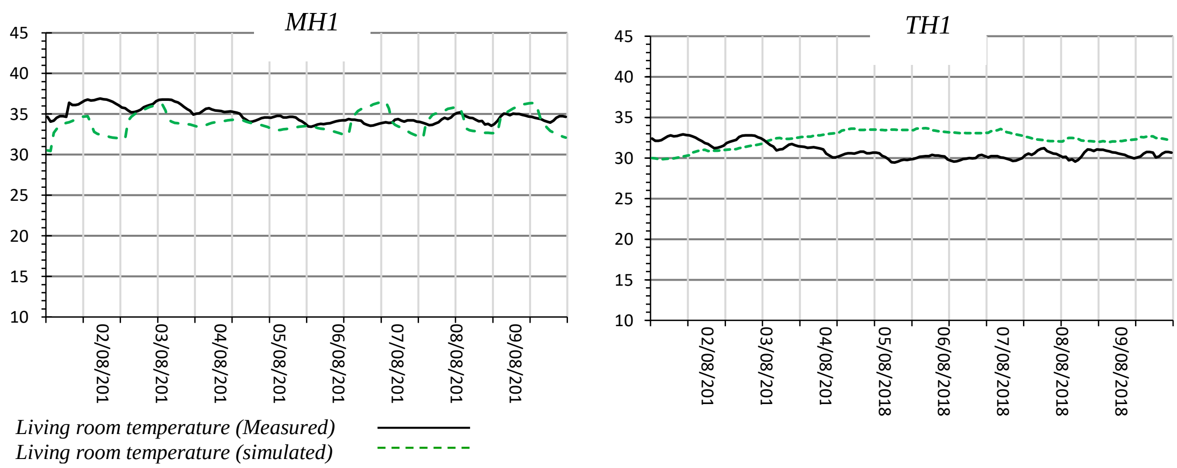



***Figure 6.5 Comparison between the monitored and simulated living room temperatures (MH1/TH1)***

**b-Relative Humidity:** It was seen that there were small differences between the measured and simulated relative humidity levels. This difference could be due to unexpected of occupants activities, which it is difficult to measure it and to predict, generally the relative humidity range seems to be similar and both below the ASHRAE boundary limit

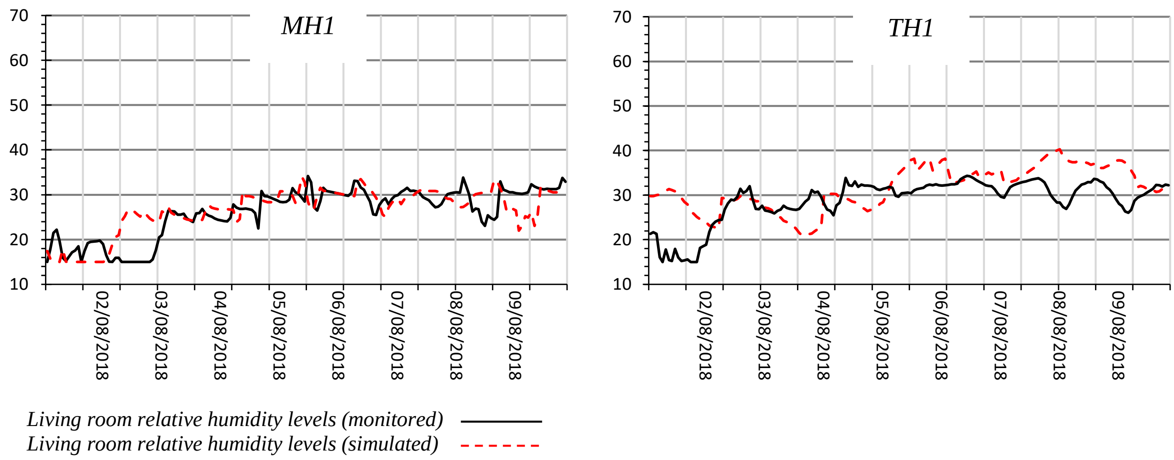



***Figure 6.6 Comparison between the monitored and simulated relative humidity levels in the living room during the summer (MH1/TH1)***

- **Patio:**

**a-Temperature:** The observed and simulated temperatures differed by approximately 3K. However, the graphs remained steady throughout the measurement period, which indicates a similar building response and nearly similar in the graph shape.

***Table 6.3 Simulation results against measured results for Patio TH1/MH1 during the summer***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Patio MH1** | 34.8 ºC | 35.5 ºC | 36.5 ºC | 38.0 ºC | 33.2 ºC | 33.0 ºC |
| **Patio TH1** | 32.3ºC | 35.0 ºC | 33.3 ºC | 38.0 ºC | 31.3 ºC | 33.0 ºC |

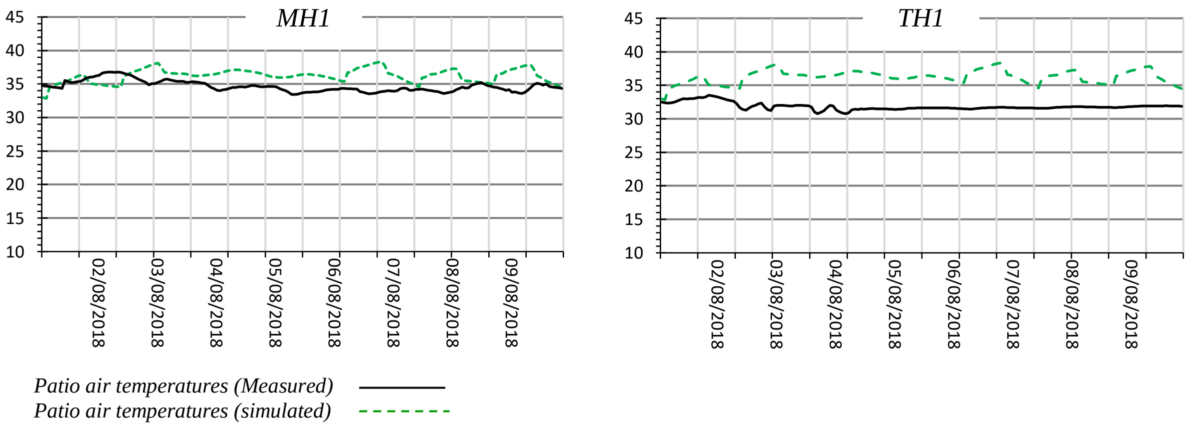



***Figure 6.7 Comparison between the monitored and simulated temperatures on the patio during the summer (MH1/TH1)***

They demonstrate this low response and relatively small temperature excursions expected of a heavy building with traditional materials as well as direct-gain building, having thermal storage along with night insulation. It can be noticed from figure 6.7 that on TH1 the temperature was slightly different form the simulated one, this due covering the patio during the period of the measurements to avoid the sun exposure.

**b-Relative Humidity:** The results of relative humidity showed reasonably variation in corresponding with actual measurements and that were predicted by Design Builder simulation, the data as shown in Figures 6.8, where a 7% performance gap can be noticed on MH1. On TH1 was completely difference, which could be due to unexpected of occupant's activities, which it is difficult to measure it and to predict.

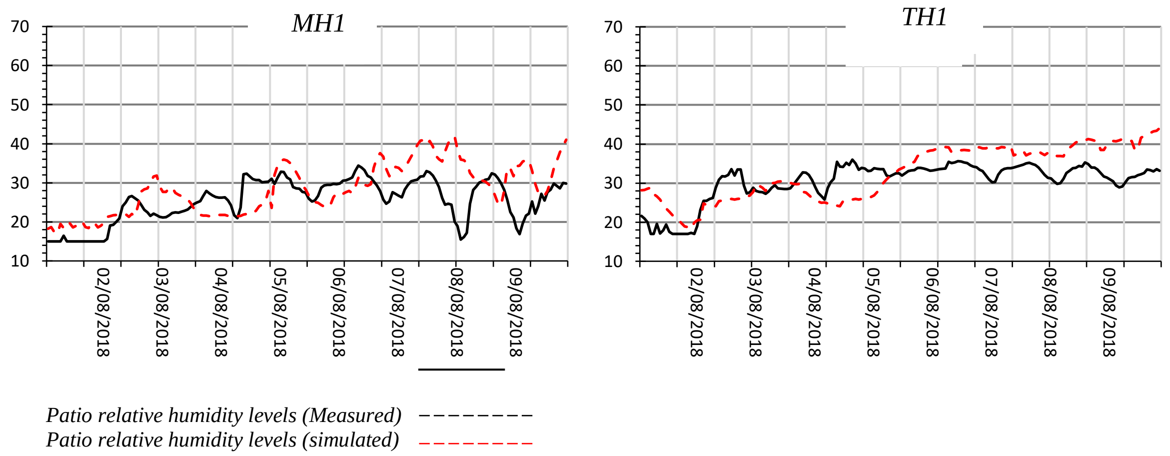



***Figure 6.8 Comparison between the monitored and simulated relative humidity levels in the patio (MH1/TH1)***

### 6.5 Winter Season Weather Data Validation (MH1/TH1):

- **Outdoor:**

**a-Air Temperature:** The measured outdoor temperature and the predicted by Design Build were based on dynamic simulations on an hourly basis, during the first week of January 2019 (03/01/2019 to 10/01/2019).

***Table 6.4 Simulation results against measured results for Outdoor TH1/MH1 during the winter***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Outdoor MH1** | 11.1 ºC | 11.7 ºC | 18.6 ºC | 19.0 ºC | 3.5 ºC | 4.5 ºC |
| **Outdoor TH1** | 11.5ºC | 11.2 ºC | 16.5 ºC | 19.0 ºC | 6.5 ºC | 3.5 ºC |

The results showed similar temperature graphs over the period of the week, as the curves are nearly similar in shape, where can see they both reached to the pick on the same time. table 6.4 an shows that were found a small variation within the range of ±2K between outdoor simulated temperatures and outdoor measured temperatures in the summer, in both cases, and consequently, it gave a similar result, which it is a quite reasonable calibration for the simulation model.

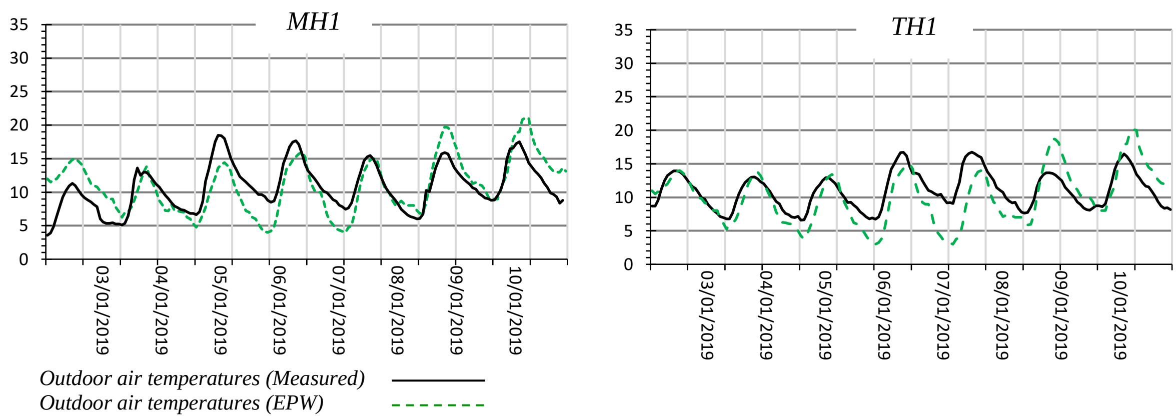



***Figure 6.9 Comparison between the simulated and monitored outdoor air temperatures during the winter (MH1/TH1)***

**a-Relative Humidity:** There were differences on relative humidity between the measured by HOBO data loggers and predicted by Design Builder, as can be seen in the graph. Figures 6.10 subsequently shows difference on the curve shapes, due the design builder software used EPW file as database, where collected from the Ghardaia airport 15 km from the city.

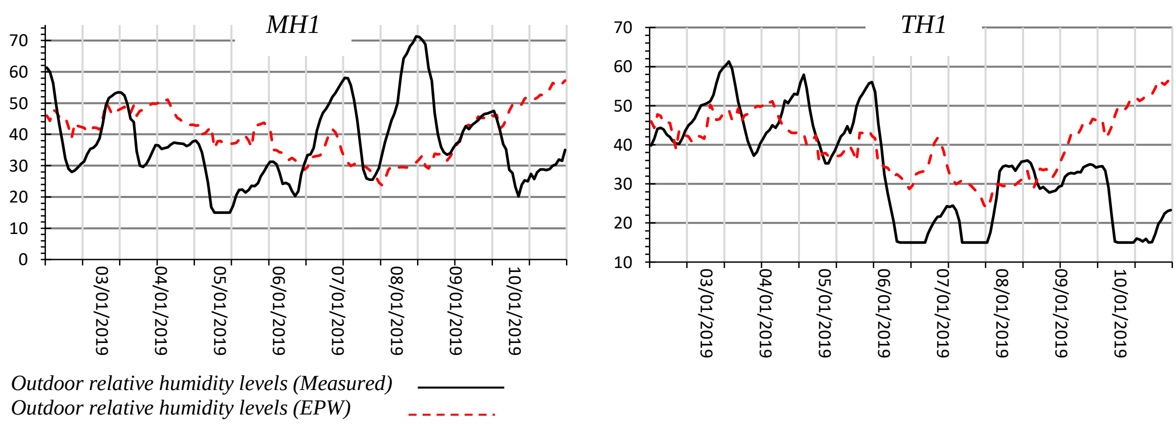



***Figure 6.10 Comparison between the monitored and simulated outdoor relative humidity levels during the winter (MH1/TH1)***

- **Living Room**:

**a-Air Temperature:** It can be seen from Table 6.5 that were found a small variation within the range of ±3K. Even though the data does not perfectly reflect the microclimate of the selected sites, the monitored and simulated temperatures were similar to each other, despite the temperature being higher by 2K at TH1. They demonstrate the quick response by switching on the usage of the heating source at the night, which led to differential in graphs trend specially onTH1. Generally, it seems the predicted by Design Builder accurate with a small performance gap and aligned to the measured temperature.

***Table 6.5 Simulation results against measured results for Living room TH1/MH1 during the winter***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Living room MH1** | 17.5 **ºC** | 16.7 **ºC** | 18.5 **ºC** | 19.5 **ºC** | 16.4 **ºC** | 14.0 **ºC** |
| **Living room TH1** | 21.2**ºC** | 19.2 **ºC** | 22.5 **ºC** | 19.5 **ºC** | 20.0 **ºC** | 19.0 **ºC** |

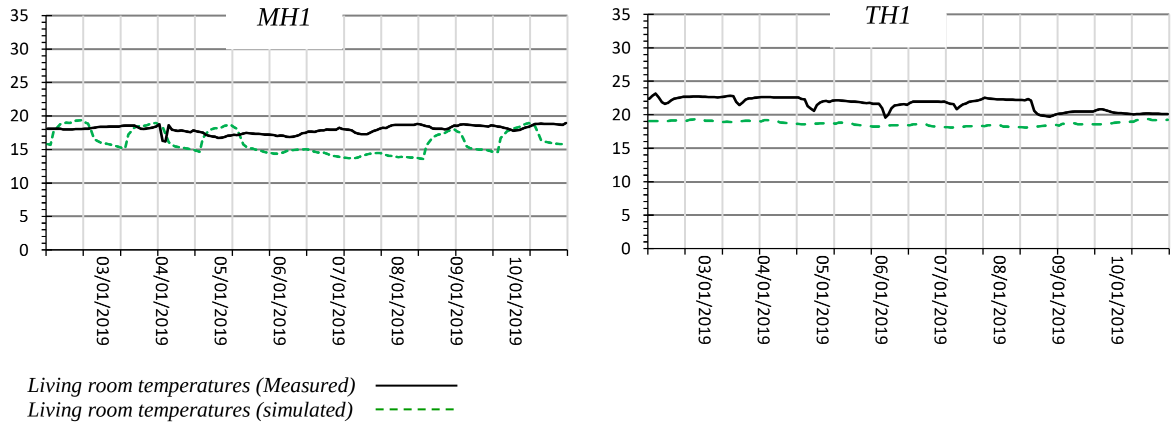



***Figure 6.11 Comparison between the monitored and simulated temperatures in the living room during the winter (MH1/TH1)***

**a- Relative Humidity:** The Relative humidity results showed quite a bit of variation in corresponding with actual measured data as shown in Figures 6.12, where a small performance gap can be noticed in coordination with the actual performance of weather data monitoring, this difference could be due to unexpected of occupants activities, which it is difficult to measure or predict, generally the relative humidity range seems to be similar and both below the ASHRAE boundary limit.

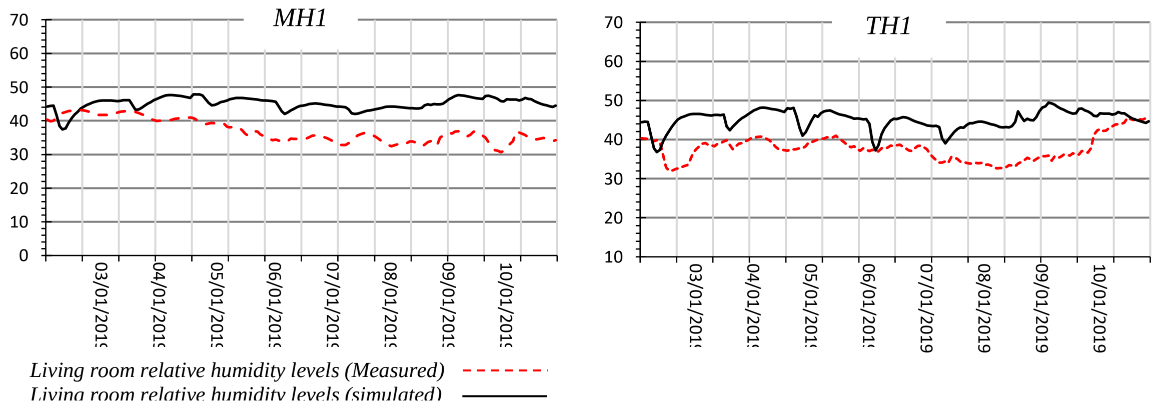



***Figure 6.12 Comparison between the monitored and simulated relative humidity levels of the living room during the winter (MH1/TH1)***

- **Patio:**

**a-Air Temperature:** Due the similarity in the shapes of the curves for TH1, the measured patio temperature and the predicted by Design Build were based on dynamic simulations on an hourly basis, where can see they both reached to the pick on the same time. Table 6.6 and figure 6.13 shows that were found a small variation within the range of ±2 K between outdoor simulated temperatures and outdoor measured temperatures, at MH shows little difference with small performance gap can be noticed in coordination with the actual performance of weather data monitoring.

***Table 6.6 Simulation results against measured results for Patio TH1/MH1 during the winter***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| **Patio MH1** | 16.5 ºC | 19.2 ºC | 23.5 ºC | 27.5 ºC | 9.5 ºC | 11.0 ºC |
| **Patio TH1** | 14.0ºC | 15.5 ºC | 22.0 ºC | 21.0 ºC | 12.0 ºC | 10.0 ºC |

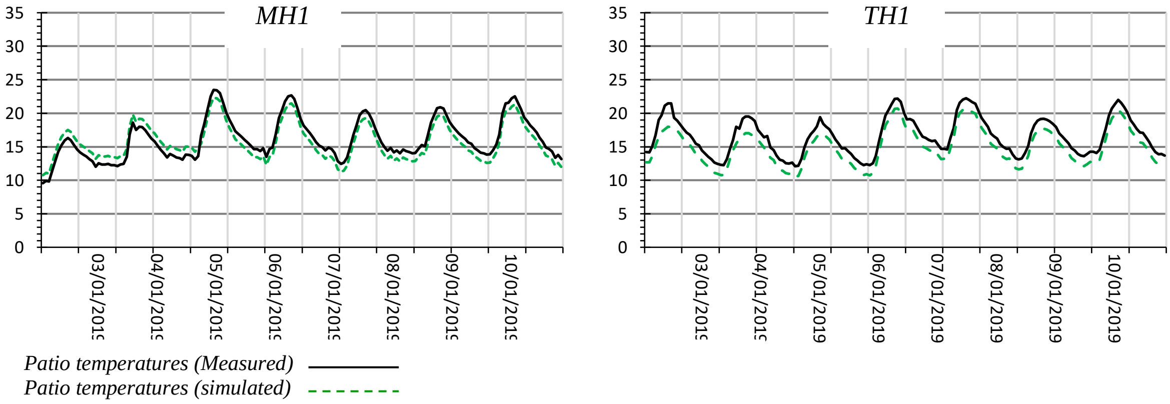



***Figure 6.13 Comparison between the monitored and simulated air temperatures in the patio during the winter (MH1/TH1)***

**a-Relative Humidity:** A 5% difference was seen between the measured Relative humidity and the predicted by Design Builder on the patio for both the sites throughout the week. In MH1, there is almost a similarity in the two graphs, but in TH1 there is a difference of about 5%, which could be due to unexpected activities of occupants, which it is difficult to measure it and to predict.

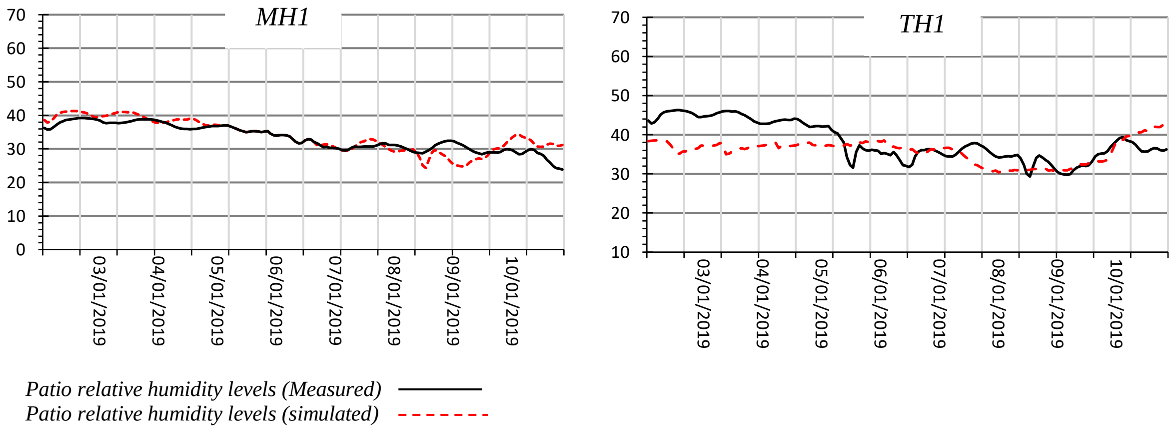



***Figure 6.14 Comparison between the monitored and simulated relative humidity levels in the patio during the winter (MH1/TH1)***

### 6.6 Conclusion:

There were no major differences between the measured data and the weather file data in Design Builder air temperature data, which confirms the reliability of Design builder, with accuracy of the result during the simulation period. Despite these challenges, Design Builder provided a close comparison to the real data in terms of thermal performance. Therefore, it will be used to predict the optimisation of thermal performance for model buildings which, in turn, can rectify the prevailing issues with the architecture in Tafilelt; this will also enable to create new strategies for the new Tafilelt. The following chapter 7 investigates the model by simulating different scenarios under natural ventilation conditions during the winter and summer time.

# CHAPTER
# VII
# PREDICTING THE EFFECT OF IM-PROVING THE BUILDING FABRIC

# CHAPTER VII
## Predicting the Effect of Improving the Building Fabric

### 7.1 Introduction:

In the previous chapters, case studies were compared, and the effect gathered some of factors that help the thermal comfort of a building element under the climatic conditions of Ghardaia.

It should be specified that this chapter not only constitutes a theoretical basis enabling progress towards the most influential factors related to heating and cooling loads in buildings but also added others to refine the design methodology of the building as a bioclimatic construction.

Indeed, in this chapter, an analysis of dynamic thermal simulations is conducted to determine the effect of these parameters on the heating/cooling loads, as well as on the hours of discomfort in the studied building. To this end, the same model of a Tafilelt building with the same character, materials, and orientation was considered as a case study to build a well-validated simulation model using the experimental results of winter and summer monitoring. This model is then used to assess the impact of the techniques studied on the thermal performance and energy savings of the dwelling, considered in two climates (cold and hot). In this chapter, we offer a tool, validated experimentally, for the dynamic thermal simulation of buildings. This tool, due to the multitude of parameters it uses and the climatic conditions it considers, can be applied to other buildings in similar climates. Further, following the results obtained, and for each climate, ideal combinations have been proposed for the passive and semi passive techniques capable of ensuring substantial energy efficiency in the building.

This part aims to analyse and evaluate the impact of certain passive and semi passive techniques on the energy performance of a typical dwelling in winter and summer seasons, ranging from cold arid to hot arid climates. To this end, a typical case study is considered in the city of Tafilelt. A digital model of this dwelling is developed using the Design Builder software. This model is validated by comparison with the results of a long-term winter and summer experimental monitoring in Chapter VI. Thereafter, dynamic thermal simulations are conducted to evaluate the impact of the techniques studied on the thermal performance and energy saving of the dwelling considered in two seasons: summer and winter. The rationale for the choice of these seasons is that they can be used to generalize the study for all the climatic zones of southern Algeria. Moreover, the new model enables us to evaluate the Thermal Regulation of Constructions in hot arid climates, which permits us to design new Tafilelt with more new thermal standards and achieve enhanced efficiency. More specifically, this part aims to examine the effect of the thermophysical properties of the envelope (such as thermal insulation and absorption), mechanical ventilation control (MVC), building orientation and ground connectivity on performance, i.e., the thermal and energy savings of this apartment, considering occupancy scenarios in the above two climates. In this study, the researcher tried to pay particular attention to the important of the thermal mass and the insulation materials and include them in our evaluation of the thermal performance of the studied building.

**7.2 Design Intervention:**

The envelope design of a building has a significant impact on how a building behaves and performs, which in turn has a direct bearing on the thermal performance of a building. To ensure that occupants are comfortable, it is necessary to gain an understanding of the behaviour of materials when subjected to the influence of thermal loads. Additionally, it is essential to determine the "passive design" and construction materials' specifications and details that are most appropriate for the new envelope design. As well as the building's periphery, which plays a significant part in the provision of shade by varying the widths of the roads (shading the facades, shading the roof). (Doran and Bernard, 2008). In layman's terms, the simulation analysis is applied to the entirety of the building as an integrated system in order to capture the interactive impacts of the building components on the thermal performance of the building in regard to the following factors( see below).

From this vantage point, the researcher makes many intervention suggestions for the building in order to compare and contrast the differences and results, as well as to assist in comprehending how the building will react. All of these interventions are feasible, and all of them take place within the community itself. For example, to narrow the road because the same measurements that were found in Beni Isguen, the walls and ceilings could be insulated them with various materials. An environmentally friendly material was adopted that came from the same place and was proven to be used by the indigenous people in the old Ksar in Beni Isguen, by using a simple wooden structure such as a pergola allowing deciduous plants to climb and grow all over the roof. People in this part of the world traditionally utilise such material to shade an outdoor sitting area as a cultural practice that is not only economical but also friendly to the environment and has a long history. As was discussed earlier in this thesis, such a roof covering intends to alleviate the excessive heat gains that are taking place through the non-insulated exposed flat roof. The suggested interventions are detailed below:

1- **Shading strategy modifications: (** Road width strategy/ Pergola strategy).
2- **Glazing strategy**
3- **Insulation strategy:** ( Wall Modification/ Roof Modification).
4- **Combine strategies**.

As suggested earlier, by using the proved model with the actual input parameters on Design builder, six scenarios were proposed to improve the building envelope’s thermal performance as follows:

### 7.2.1 Shading strategy:

The width of a road negatively or positively affects the heat gain and loss through the external elements, which, in our case, are the external facade and the roof. The greater the external area exposed to external factors, the greater the heat loss and gain, and this affects the indoor thermal comfort. In the first test, the purpose was to study the impact of reducing the road width, and for the second setup, it was covering the roof with simple wooden structure such as a pergola during both seasons. A simulation was run for a year and a graph was plotted for the hottest week in summer and the coldest week in winter (see Figure 7.2 and Figure 7.3).

**A- Layout and contextual road design strategy:**

In the simulations, the naturally ventilated building had bedroom windows oriented towards the South, North, and North-West directions, while the living room had just a door used as a window, oriented towards the North-West. The design should consider the appropriate shape of the building by reducing the exposed size of the façade as much as possible. By reducing the width of the street from 3.5 m to 2 m, which is closest to the roads width in Beni Isguen and comparing it with the previous results, this intervention aims to ascertain whether the width or height of the building will make a difference and, in these changes, and evaluated in the Design Builder software. In this scenario, the façade was completely shaded throughout the day (see Figure 7.1)

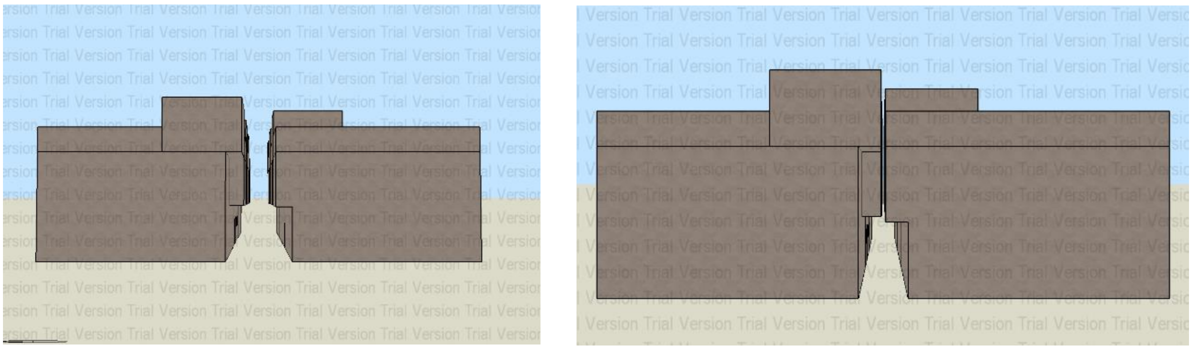


***Figure 7.1: Reducing the road width from 4m to 2 m ( source: by the Author).***

The following comparison will be conducted between the base and the predicted with regards to spaces (living room on the ground floor and the first-floor room 1) both in summer and winter:

- **Winter: from $02^{nd}$ January 2019 to 09 January 2019**

Based on the simulated data on the first scenario, so can see clearly changing the width of the road less effective during the cold season, the results shows that the mean temperature for the base model and Scenario I are totally similar $14.7^0$C for the first floor room1. The graph shows that the predicted first-floor room temperature was less than 0.5K below the base model MH1 temperature for the entire period of simulation. On the other hand, the temperature in the living room was almost similar, about 0.5–1K below the base model room temperature. Although the living rooms on show a different fluctuation in the winter but considered with the same temperature range 16.5 °C to 19.0°C which were close to the minimum acceptability limits of ASHRAE adaptive comfort criteria.

***Table 7.1 Simulation results against base model results for Living room and Room1 during the Winter***

| **Building** | **Temperature (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** |
| **Room MH1** | 14.7 **°C** | 14.7 **°C** | 16.0 **°C** | 16.0 **°C** | 13.5 **°C** | 13.5 **°C** |
| **Living room MH1** | 18.0**°C** | 17.7 **°C** | 19.0 **°C** | 19.0 **°C** | 17.0 **°C** | 16.5 **°C** |

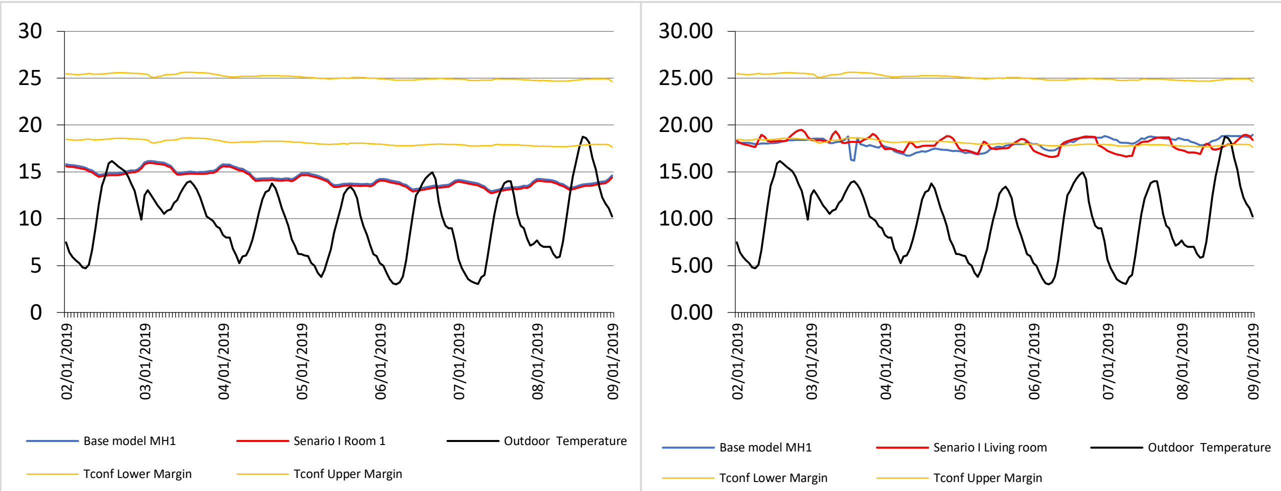



***Figure 7.2: Effects of road width on the internal operative temperature for the living room and first-floor room against the base model during the coldest week in winter.***

## - Summer: from 02$^{nd}$ August 2018 to 09$^{th}$ August 2018

***Table 7.2 Simulation results against base model results for Living room and Room1 during the Summer***

| **Building** | **Temperature (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** |
| **Room MH1** | 36.5 **°C** | 34.7 **°C** | 38.5 **°C** | 37.0 **°C** | 34.5.0 **°C** | 32.5 **°C** |
| **Living room MH1** | 35.2**°C** | 34.7 **°C** | 36.5 **°C** | 35.5 **°C** | 34.0 **°C** | 33.0 **°C** |

Despite reducing the road width for all the summer and the façade was completely shaded, the effect on the indoor temperature over the hot season (see table 7.2). Overall, living rooms showed a 1 K reduction in the mean temperature compared to the one of the base models. Despite the roof still receiving the direct sun specially during the summer season, the simulated data of the first floor room1, showed 2 K a reduction in the mean temperature compared to the base model. It is noteworthy that reducing the width helps to decrease the temperature in the top floor, but the result still didn't meet the acceptability limits of ASHRAE adaptive comfort criteria.

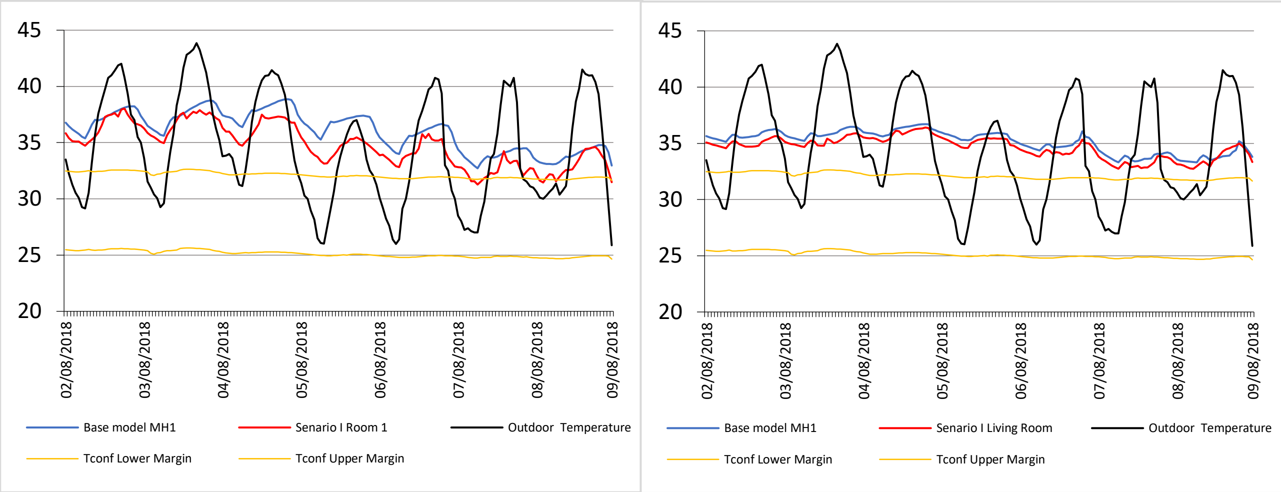



***Figure 7.3: Effects of road width on the internal operative temperature for the living room and first-floor room against the base model during the hottest week in summer***

The simulation results for scenario I was close to the base model, which indicates that reducing the width of the street from 4 m to 2 m have no influence on the building's during the winter, considering the notable temperature decrease on the first floor during the cooling season.

### B- Shading roof and patio with pergola:

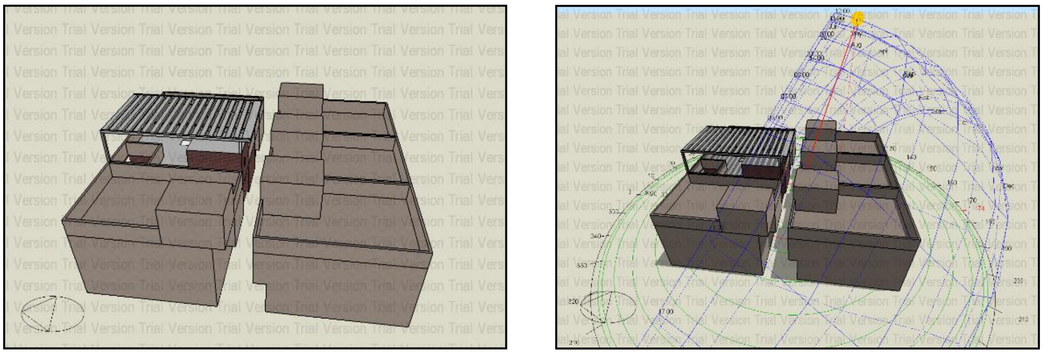


***Figure 7.4 Using the pergola to shade the terrasse and patio (source: by the Author).***

In the second scenario. The simulation was run using the base model, and modified shade model, by adding shading elements to cover the terrasse and the patio, (using the high wooden pergola constructed from palm trunk) (figure 7.4). this also will reduce the excessive heat gains on the terrasse and the patio, this would also be beneficial to use during day for gathering and on the night to sleep. And by covering the terrasse, the place becomes larger than the patio, these changes it would be preferable to use by women during the daily life, this is due to the socio-cultural considerations of the region.

- **Winter: from 02nd January 2019 to 09th January 2019**

In the second scenario, during the winter the graph shows that there was small effect from the roof shading on the model's thermal performance during this period. the indoor data showed a similarity on base model and the simulation, on the ground floors, the mean temperature for the base model and Scenario II are totally similar, (table 7.3). For the first-floor room 1 the simulated results coincided from actual base model as presented in figure 7.5, with temperature ranging from 18.0 °C to 18.5 °C. These similarity in results can be attributed to the fact that there is no effect to shade the roof and the patio to reduce or increase the temperature during the winter.

***Table 7.3 Simulation results against base model results for Living room and Room1 during the Winter***

| **Building** | **Temperature (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario II** | **Base Model** | **Scenario II** | **Base Model** | **Scenario II** |
| **Room MH1** | 14.7 °C | 15.0 °C | 16.0 °C | 16.5 °C | 13.5 °C | 13.5 °C |
| **Living room MH1** | 18.0 °C | 18.5 °C | 19.0 °C | 19.5 °C | 17.0 °C | 17.5 °C |

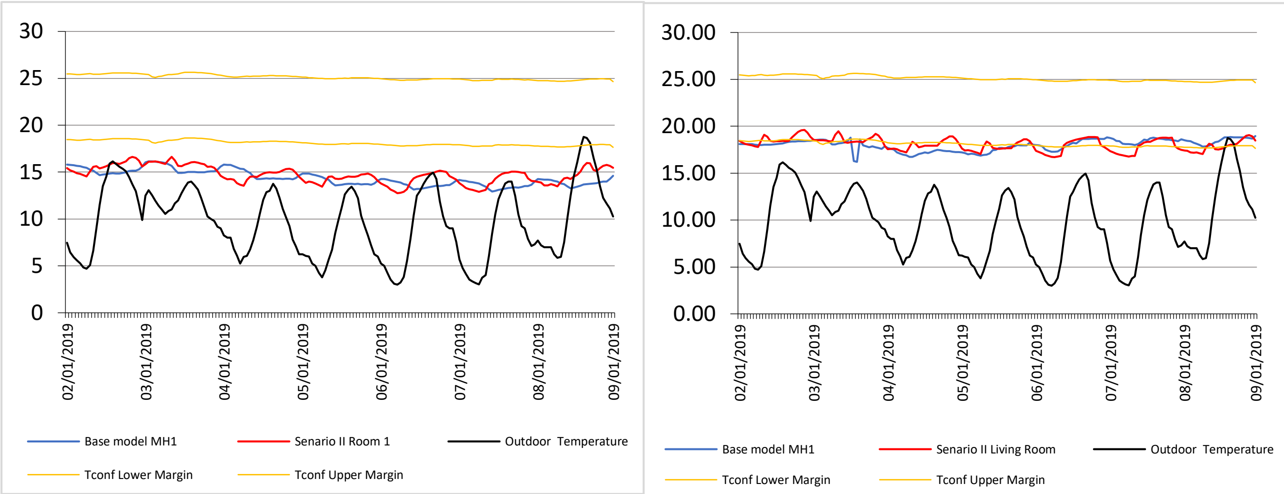



***Figure 7.5: Effects of covering the roof and patio on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer***

- **Summer: from 02nd August 2018 to 09th August 2018**

This time during the summer it clearly shows a significant improvement by reducing the indoor temperature, the physical interventions on terrasse and the patio. the pergola intervention was found to be far more effective and significant, with a temperature reduction between 7 ~ 8 K in the living room compared to the based model, however, in the first-floor room 1 were 4 ~5 K less (table 7.4), meeting the acceptability norms of the ASHRAE adaptive comfort criteria (figure 7.6).

***Table 7.4 Simulation results against base model results for Living room and Room1 during the Summer***

| **Building** | **Temperature (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** | **Base Model** | **Scenario I** |
| **Room MH1** | 36.5 **°C** | 32.0 **°C** | 38.5 **°C** | 34.5 **°C** | 34.5.0 **°C** | 29.5 **°C** |
| **Living room MH1** | 35.2**°C** | 28.0 **°C** | 36.5 **°C** | 29.0 **°C** | 34.0 **°C** | 27.0 **°C** |

for instant shading the roof during the summer led to reduction of the excessive heat gains on the terrasse and the patio, will display a reduced and delayed reaction to an initial excitation such as a sudden rise in external ambient temperature.

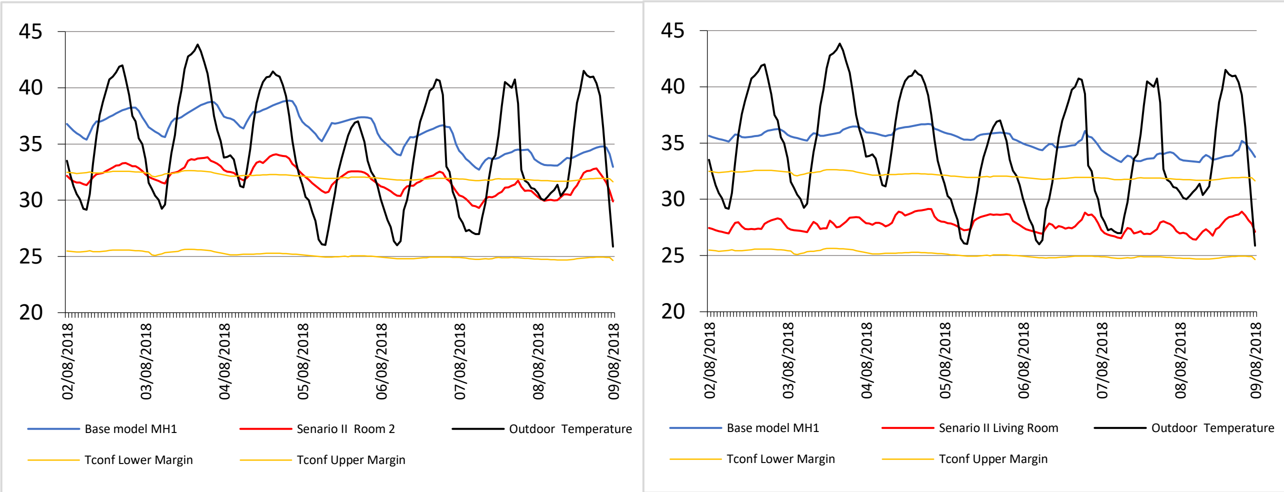



***Figure 7.6: Effects of covering the roof on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer.***

Overall, compared to the scenario I, the second scenario provided much better results compared to the base model, especially during the summer. Although the indoor temperature for the first-floor room exceeding 33.5°C at midday, the living room temperature remained the same at 28.0°C during the same period.

### 7.2.2 Glazing strategy:

In a house, a window is an element with a significant effect on heat loss/gain, owing to its high conductivity. In the base case, the use of single glazed windows with no shutters leads to high heat gain; therefore, using a Quadruple panel can improve the thermal performance of the building. Double-glazed windows can be used as a replacement for single glazed windows. According to Design Builder, the U value of single glazed windows is 5.77 W/m2K, while that of Quadruple Low E and argon filled is 6 mm, less than 0.78 W/m2K. Double-glazing is the most effective strategy to reduce the heat loss through windows (by 63%) while adding timber shutters to single glazing reduces heat loss by 51%, and curtains reduce it by 14% (Hegger et al. 2008). The simulation was rerun after replacing the single-glazed windows with Quadruple windows. The result for a week was plotted in Figures 7.7 and 7.8. Using a Quadruple windows has a barely noticeable effect, compared to the insulation strategy; this can be attributed to the small area of the glazed windows, accounting for only 6% of the exterior building envelop of the model.

**Winter: from 02$^{nd}$ January 2019 to 09$^{th}$ January 2019**

In winter, Figure 7.7 show the effects of indoor temperature with the Quadruple Low E and argon windows against the base model, indicated that using the new windows materials maintains the temperature the same during the period of simulation, the living room temperature kept similar the base model which about 17.5°C to 19.5°C. However, in the top floor room 1 was much cooler 13.5°C to 16.5°C but similar to the base model with variation of 1K see table 7.5.

***Table 7.5 Simulation results against base model results for Living room and Room1 during the Winter***

| **Building** | **Temperature (ºC)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario III** | **Base Model** | **Scenario III** | **Base Model** | **Scenario III** |
| **Room MH1** | 14.7 ºC | 15.0 ºC | 16.0 ºC | 16.5 ºC | 13.5 ºC | 13.5 ºC |
| **Living room MH1** | 18.0 ºC | 18.5 ºC | 19.0 ºC | 19.5 ºC | 17.0 ºC | 17.5 ºC |

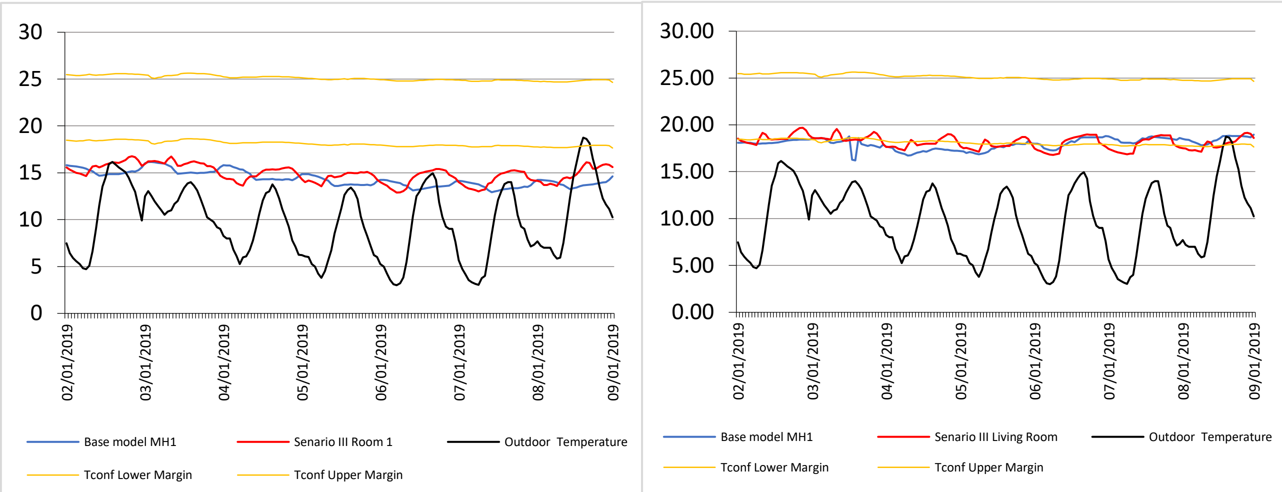



***Figure 7.7: Effects of using double glazing windows on the internal operative temperature of the living room and first-floor room against the reference building during the coldest week in winter.***

- **Summer: from 02nd August 2018 to 09th August 2018**

In the same way, in summer the indoor temperature for the simulated model maintains the same with the base model with variation of 1k on both spaces, living room was about 33.0°C to 35.5°C and the first-floor room 1 recorded 33.5°C to 35.5°C (table 7.6).

***Table 7.6 Simulation results against base model results for Living room and Room1 during the Summer***

| **Building** | **Temperature (ºC)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario III** | **Base Model** | **Scenario III** | **Base Model** | **Scenario III** |
| **Room MH1** | 36.5 **ºC** | 35.5 **ºC** | 38.5 **ºC** | 37.5 **ºC** | 34.5.0 **ºC** | 33.5 **ºC** |
| **Living room MH1** | 35.2**ºC** | 34.2 **ºC** | 36.5 **ºC** | 35.5 **ºC** | 34.0 **ºC** | 33.0 **ºC** |

From Chapters 4 and 5 we noted that all the windows had been designed to avoid direct exposure to the sun. From the figures for winter and summer, scenario III shows a 1K reduction in the indoor temperature, and no changes in the thermal performance in both places. Despite the deferential U Value, the small windows produce a similar result. Overall, in scenario III, the operative temperatures are close to the temperature in the base model and fail to meet the acceptability limits of ASHRAE adaptive comfort criteria for both seasons.

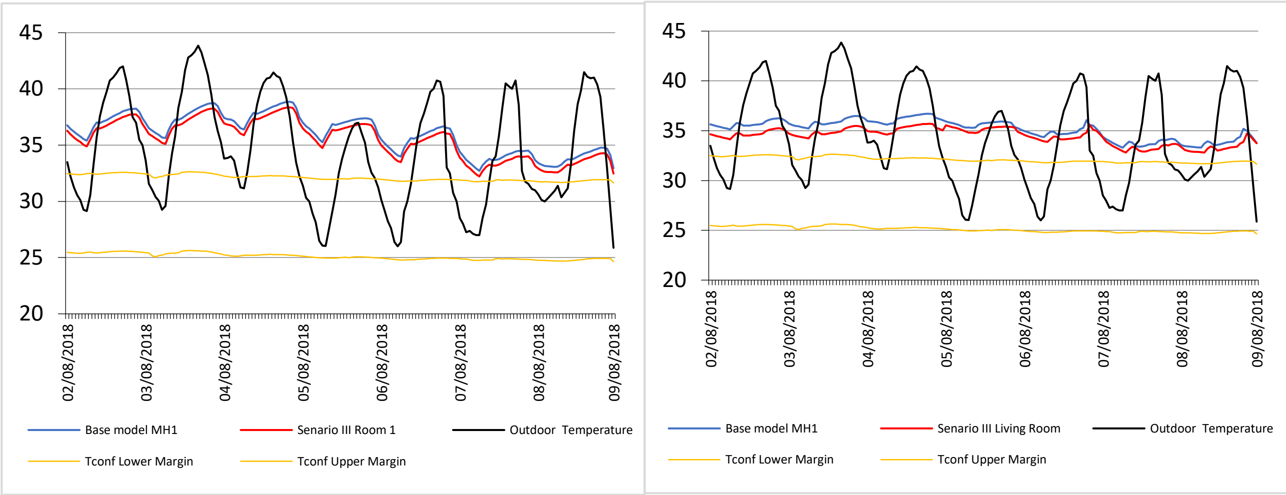



***Figure 7.8: Effects of using double glazing windows on internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer***

### 7.2.3 Insulation strategy:

In the fourth scenario, an intervention has been made on the building envelope, by using the insulation on the building skin (wall, roof), the interventions aim to reduce the U-value of the wall from 2.147 W/m$^2$K and the roof from 1.88 W/m$^2$K by adding new material to the existing layers, in such way that minimise or eliminate thermal breaks, the proposed material (Natural fibres) are very promising and have immense potential as eco-friendly raw materials, especially in thermal insulation (Ali 2013). Further, natural fibres are biodegradable and have a low environmental impact. Natural fibre composites are likely to be environmentally superior to glass fibre composites in most cases for several reasons such as lower environmental impact compared to glass fibre production and higher fibre content for equivalent performance (Figure 7.9).

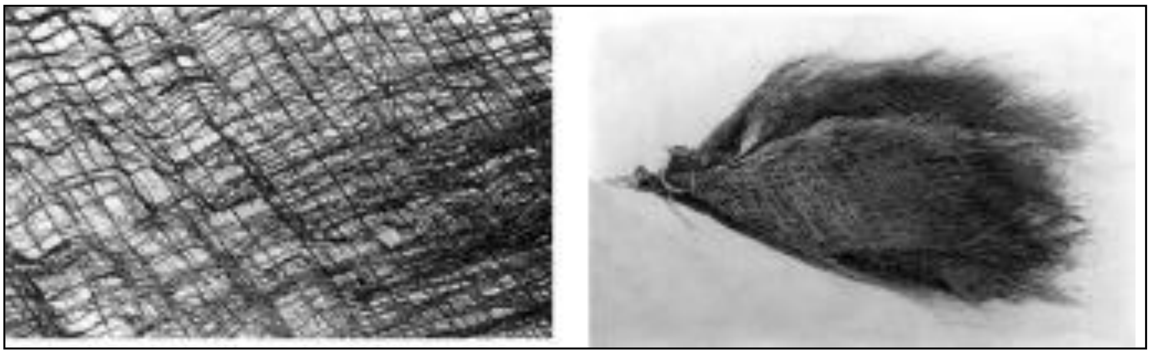


***Figure 7.9 Date palm tree surface fiber (DPSF) from the leaf base as it comes from the palm. (Source: Ali et al. 2013)***

Date palm tree surface fibres (DPSFs) are the cheapest environmental waste in the south of Algeria. The thermal properties and microstructure of DPSFs enable their use as new building insulation materials in this study. The distinctive features of DPSFs, such as coherent layers and stretching and contraction properties, make the insulation material totally natural. Further, they have positive effects on the microclimate and can lower the internal temperature and ambient air and reduce energy consumption. This, in turn, reduces fuel consumption and facilitates pollution control (Figure 7.10).

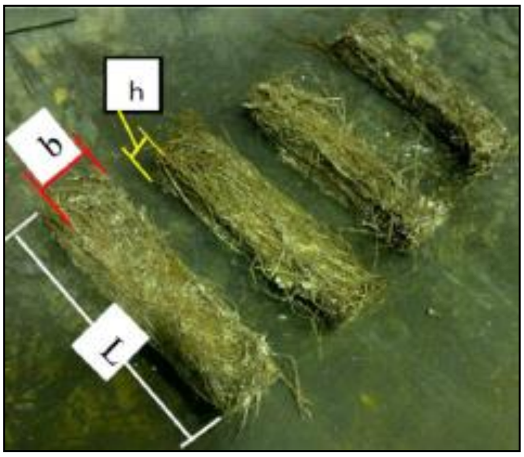
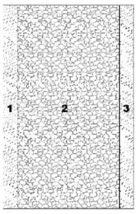
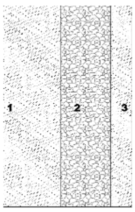



*Figure 7.10 Specimens used for the thermal conductivity test. (source: Ali et al. 2013).*

### A- Wall modification:

The walls were modified by applying a 15cm DPSF insulation board on the default limestone modelled exterior wall used in Ghardaia (Table 7.7).

*Table7.7: Thermal insulation intervention for the external wall*

| Scenario/ Base Model | Thick-ness (mm) | Wall Section | External Wall Materials | U-value |
|---|---|---|---|---|
| **Base exterior wall** | 450 mm |  | - 5 cm lime sand render<br>- 35 cm limestone<br>- 5 cm lime sand render | 2.174W/m$^2$.K |
| **Scenario IV** | 400 mm |  | - 100 mm cement<br>- 150 mm DPSF<br>- 1 50 mm cement | 0.147W/m$^2$.K |

The board thickness is 15 cm with U Value 0.04 W/m$^2$K, which was simulated in the base model, to find the most appropriate thickness for wall insulation in a naturally ventilated and air-conditioned building. The effect of this passive cooling intervention on a naturally ventilated model is shown in this section. Through the use of the DPSF material, the U-value of the external walls was reduced from 2.17 W/m2K to 0.14 W/m2K (table 7.7).

- **Winter: from 02nd January 2019 to 09th January 2019**

Figure 7.7 [A] indicates how wall insulation helps to improve the indoor thermal conditions, can clearly see the simulated living room temperature rises to reached 20 with daily minimum and maximum dry-bulb temperature up to 3 K, meanwhile the base model temperature kept fluctuation between 17 to 19, although, upgrading the insulation material on this scenario to elevate the mean indoor temperature by 2 K. Although the change in the thermal performance was small, it is still better than the other scenarios during midday time.

***Table 7.8 Simulation results against base model results for Living room and Room1 during the Winter***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario IV | Base Model | Scenario IV | Base Model | Scenario IV |
| **Room MH1** | 14.7 ºC | 16.0 ºC | 16.0 ºC | 17.5 ºC | 13.5 ºC | 14.5 ºC |
| **Living room MH1** | 18.0 ºC | 18.5 ºC | 19.0 ºC | 20.0 ºC | 17.0 ºC | 17.0 ºC |

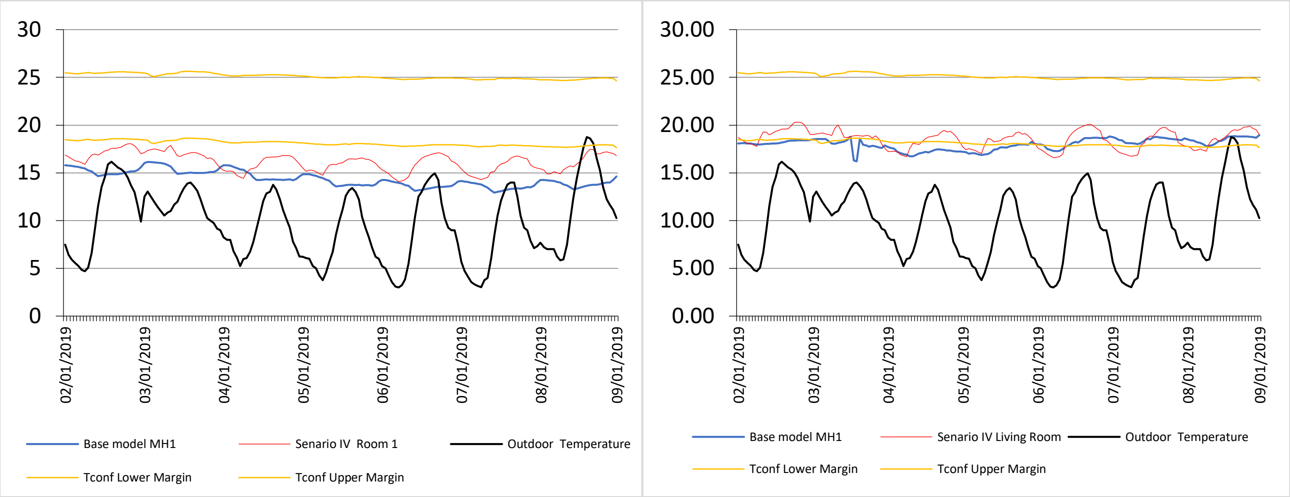


***Figure 7.11: Effects of using wall insulation on the internal operative temperature for the living room and first-floor room against the reference building during the coldest week in winter.***

The wall insulation contributes to the heat balance of the building by allowing the heat flow through the opaque building envelope during the midday and helps to rise the indoor temperature throw the conductive heat transfer through the materials to reach 20 ºC. Moreover, it has bad effects of indoor space during the night when the indoor temperature drops to reach 14.5 ºC at midnight for room 1 see figure 7.11.

- **Summer: from 02nd August 2018 to 09th August 2018**

Comparing the two graphs during summer revealed the strategy to be far more effective and significant and yielded a 7 to 8 K reduction in the living room. Whilst the living room based on the ground floor many of the conditions inducing these results, most import that the conductive heat flows through the building skin will display a time lag. meanwhile the insulation on the top floor (room1), didn't play a big role compared to the ground floor. The Solar radiation and convective heat flows, with high thermal mass defeat the wall insulation and did not give a similar result for the ground floor, some of the heat entering the material will be absorbed and stored inside the construction assembly, and as a consequence the temperature of these materials will slightly rise and gives fluctuation 32 ºC to 34.5 ºC.

*Table 7.9 Simulation results against base model results for Living room and Room1 during the Summer*

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario IV | Base Model | Scenario IV | Base Model | Scenario IV |
| **Room MH1** | 36.5 **ºC** | 34.5 **ºC** | 38.5 **ºC** | 37.0 **ºC** | 34.5.0 **ºC** | 32.0 **ºC** |
| **Living room MH1** | 35.2**ºC** | 28.5 **ºC** | 36.5 **ºC** | 30.0 **ºC** | 34.0 **ºC** | 27.0 **ºC** |

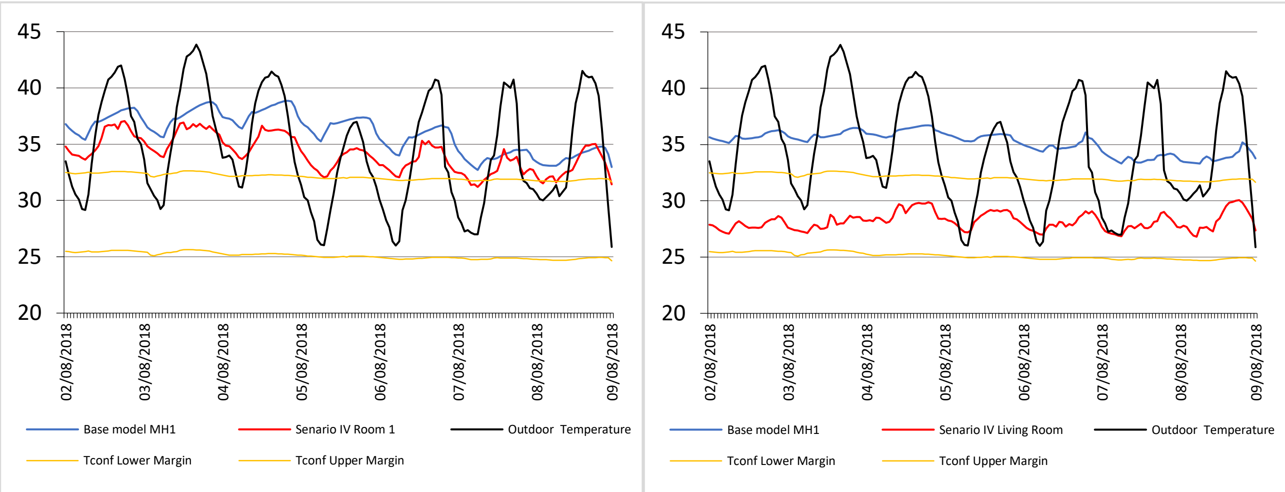


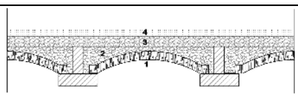
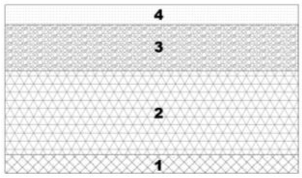

***Figure 7.12: Effects of using wall insulation on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer.***

Generally, by comparing the last figures of the first scenarios (figure 72/7.3), it is noteworthy that in this scenario, the thermal performance on the ground was observed to be significantly better even for the traditional building, with a drop in the mean temperature during summer, increase in the temperature by 1.5 K during winter, and 8 K during summer, leading to better thermal performance for the occupants, especially during hot weather.

### B- Roof modification:

By using DPSF material for roof insulation, this intervention aimed to create an archetypal place for better indoor thermal performance, and make the resident feel comfortable, without any energy consumption. DPSF seems to have a better performance than limestone, which is considered softer and has better thermal mass efficacy with a U-value of 0.04W/m$^2$K. Exchanging the existing layer of 15 cm limestone with 15 cm DPSF (see Table 10) can reduce the U-value from 1.88 W/m2K to 0.32W/m$^2$K, the simulation model was run for the cold and hot seasons. Design Builder predicted the effectiveness of replacing the new layer and the thermal performance (Figure 7.13/ 7.14).

*Table 7.10: Thermal insulation intervention for the external roof.*

| Scenario/ Base Model | Thickness (mm) | Roof Section | Roof Materials | U-value |
|---|---|---|---|---|
| **Current exterior roof** | 340 mm |   | 1- 10 mm lime sand render<br>2- 150 mm clay or silt<br>3- 150 mm limestone<br>4- 20 mm woods | 1.88 W/m²K |
| **Scenario IV** | 250 mm |   | 1- 20 mm core tiles<br>2- 120 mm component Blok cément<br>3- 150 mm DPSF<br>4- 20 mm Gypsum | 0.32W/m²K |

- **Winter: from 02nd January 2019 to 09th January 2019:**

In this attempt, we can see distinctly from Figure 7.11 that the roof intervention leads to a significantly reduced heat demand especially for the ground floor "living room" during the simulation time; one can see a 1.5–3 K reduction in the living room temperature and a 1.5 K–4.5 K reduction on the first floor mean operative temperature, which appeared to meet the acceptability limits of the ASHRAE adaptive comfort criteria.

***Table 7.11 Simulation results against base model results for Living room and Room1 during the Winter***

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario V | Base Model | Scenario V | Base Model | Scenario V |
| **Room MH1** | 14.7 ºC | 18.2 ºC | 16.0 ºC | 20.0 ºC | 13.5 ºC | 16.5 ºC |
| **Living room MH1** | 18.0 ºC | 19.5 ºC | 19.0 ºC | 21.0 ºC | 17.0 ºC | 18.0 ºC |

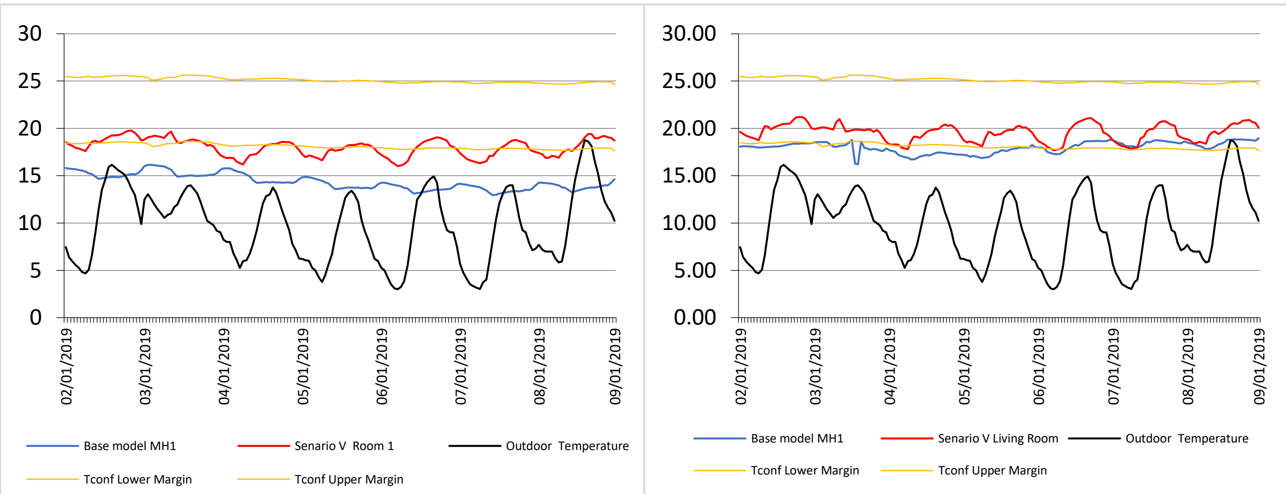



***Figure 7.13: Effects of using roof insulation on the internal operative temperature for the living room and first-floor room against the reference building during the coldest week in winter.***

It is evident that the roof intervention in scenario V significantly improved the first roof room performance during winter, which shows that the roof has a significant influence on the building's thermal performance.

**- Summer: from 02 August 2018 to 09th August 2018**

During the summer simulation, a significant improvement of the roof insulation and enhanced ability to reduce the interior temperature fluctuation (Table 7.12); however, it failed to ameliorate the first floor, since the difference is still similar to scenario III.

*Table 7.12 Simulation results against base model results for Living room and Room1 during the Summer*

| Building | Temperature (ºC) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario V | Base Model | Scenario V | Base Model | Scenario V |
| **Room MH1** | 36.5 ºC | 32.7 ºC | 38.5 ºC | 36.5 ºC | 34.5 ºC | 29.0 ºC |
| **Living room MH1** | 35.2ºC | 29.5 ºC | 36.5 ºC | 32.0 ºC | 34.0 ºC | 27.0 ºC |

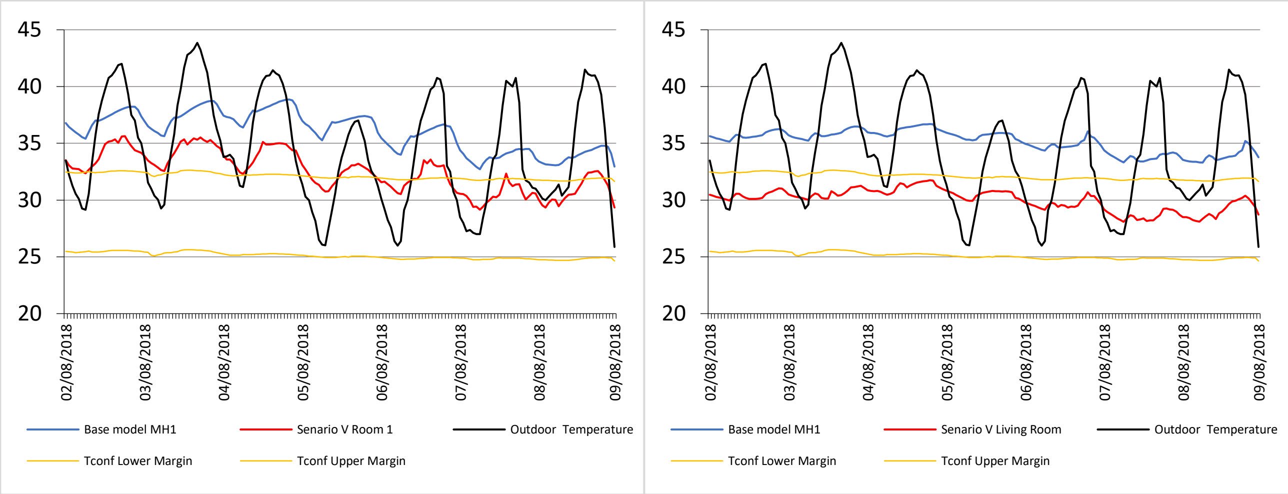



***Figure 7.14: Effects of using roof insulation on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer.***

The ground floor living room maintained an adaptive comfort boundary with ASHRAE, as it was not affected due to its distance from the heating source, which is the ceiling. In the other hand, weather conditions such as outside air temperature and solar irradiation are constantly fluctuating and will provoke the roof for around 10 hours during day, which will raise the indoor temperature due the heat gains and the convection. One result of that the temperature of the top floor is considered high and out the comfort boundary ASHRAE see figure 7.14.

### 7.2.4 Combined strategies between proposed wall, pergola, and roof design:

A comparison was made between previous scenarios, which steer to combine all the previous strategies. The interventions that were the best options to keep the operative temperature within the ASHRAE boundary during both seasons were defined. The scenario interventions which, as described earlier, were found to be more efficient were developed and amalgamated. The second scenario was combined, by covering the terrasse with pergola and using the Glazing strategy. Considering the use of insulation material in the external walls and the roof in scenario IV, the simulation showed a significantly different average temperature, compared to the early layouts. It was a satisfactory result, in the cold and hot seasons, as it led to thermal relief, which is one of the most important goals of the thermal design of the building. This physical intervention proved that it stores a large part of the indoor heat during the heating time of the building in winter and retains the heat for a long time, which we can see in the operative temperature fluctuation between 20°C–25°C in both the living room and the first-floor room. On the other hand, it impedes the transfer of the stored heat and prevents its loss and protects the roof from exposure to the sun during summer, maintaining the operative temperature between 24°C ~27°C in the living room and 28°C ~32°C on the first-floor roof.

- **Winter: from 02nd January 2019 to 09th January 2019**

***Table 7.13 Simulation results against base model results for Living room and Room1 during the Winter***

| **Building** | **Temperature (°C)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario VI** | **Base Model** | **Scenario VI** | **Base Model** | **Scenario VI** |
| **Room MH1** | 14.7 °C | 20.2 °C | 16.0 °C | 25.0 °C | 13.5 °C | 18.5 °C |
| **Living room MH1** | 18.0 °C | 20.5 °C | 19.0 °C | 22.5 °C | 17.0 °C | 18.5 °C |

This intervention succeeded in keeping the operative temperature within the ASHRAE adaptive comfort boundary; the rise in the mean operative temperature during cold weather was between 1.5 K and 3.5 K in the living room and between 5 K and 9 K in the first-floor room compared to the base model and remained within the comfort zone during simulation.

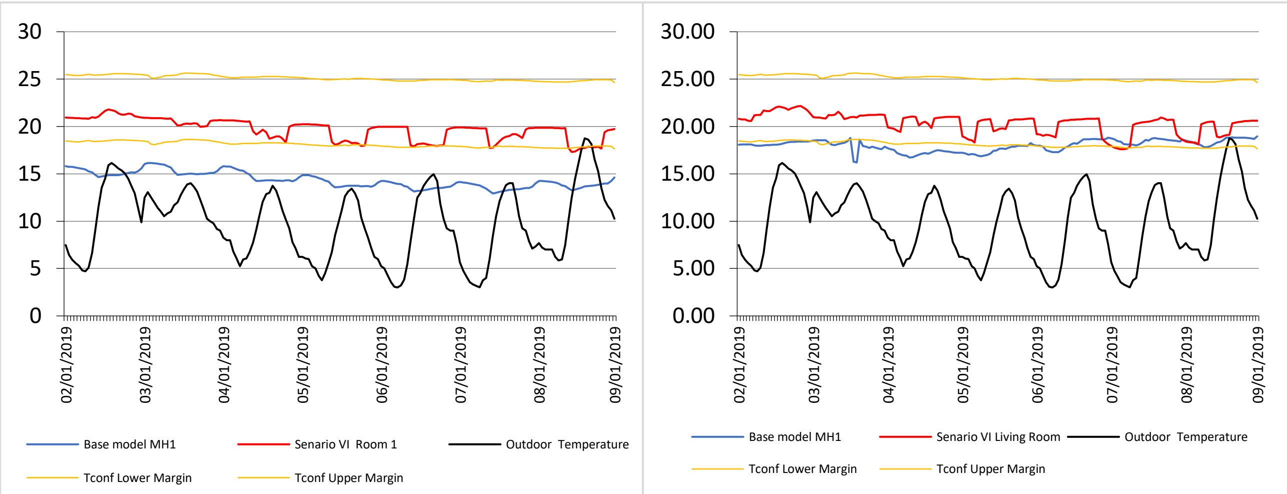


***Figure 7.15: Effects of using combination methods on the internal operative temperature of the living and first-floor rooms against the reference building during the coldest week in winter.***

- **Summer: from 02nd August 2018 to 09th August 2018**

This intervention showed an impressive result (Figure 7.16)-the operative temperature dropped to 10 K, while the temperature reached 24.5 °C in the living room, which is better than its counterparts using air conditioners; moreover, in the first-floor room, the mean operative temperature dropped to 6 K during summer.

*Table 7.14 Simulation results against base model results for Living room and Room1 during the Summer*

| Building | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario VI | Base Model | Scenario VI | Base Model | Scenario VI |
| Room MH1 | 36.5 °C | 30.0 °C | 38.5 °C | 32.0 °C | 34.5.0 °C | 28.0 °C |
| Living room MH1 | 35.2°C | 25.7 °C | 36.5 °C | 27.0 °C | 34.0 °C | 24.5 °C |

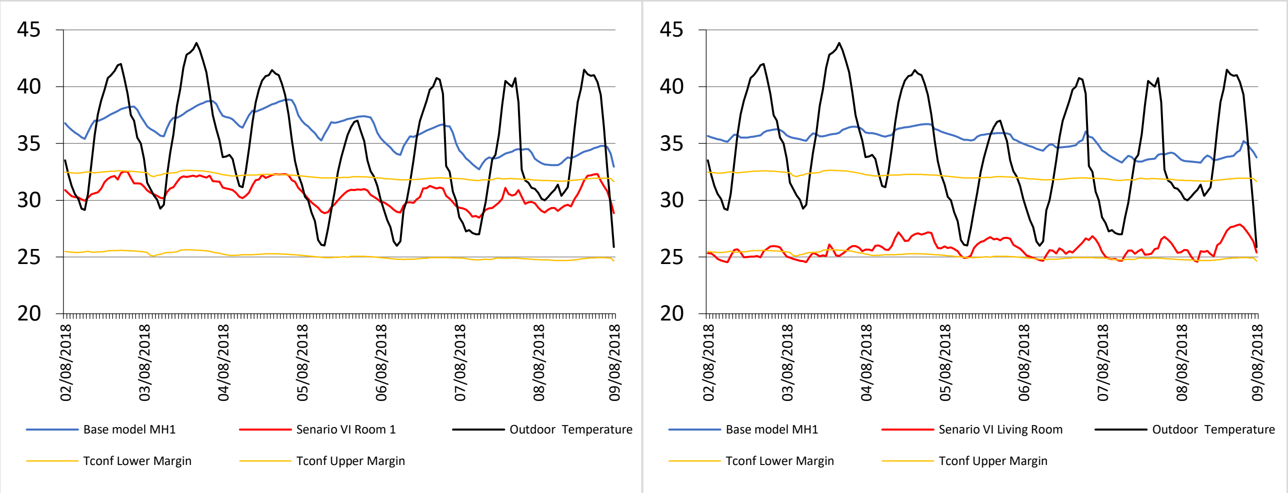


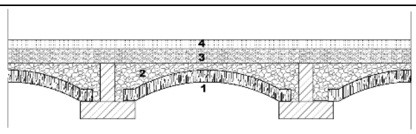
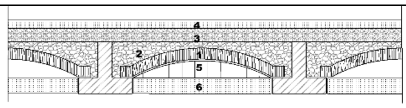

***Figure 7.16: Effects of using combination methods on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer.***

Overall, during the winter days, in the performance scenario VI, the operative temperature fluctuated between 18.5°C and 22.5°C in the range by 4 K and by 3–5 K higher, compared to the base building model. On hot summer days, the figure shows the remarkable effects the combining of the three scenarios has on the building, not just in the simulated places but for all the building places also, where the drop in operative temperature was 10 K compared to the base model; however, during the night, the temperature reached the minimum at 24.5°C, both meeting the acceptability limits of the ASHRAE adaptive comfort criteria. This clearly confirms the effect of the proposed building intervention in delaying the heat transfer in both seasons.

### 7.2.5 Immediate intervention strategy on the current building (roof, pergola):

The first intervention forms the bottom of the roof that has a vault shape, and the space between the beams is filled with a DPSF material, where material shapes are made (Table 7.15), The space between the beams was fixed and coated with materials that prevent their fragmentation or allow the woodworm to spread from one piece of wood to another, ultimately causing damage, and in some cases, serious structural problems. Using lime appears to be a workable solution to kill weevils in palm trunks.

*Table 7.15: Thermal insulation intervention for the existing external roof*

| Scenario/ Base Model | Thickness (mm) | Roof Section | Roof Materials | U-value |
|---|---|---|---|---|
| **Current exterior Roof** | 340 mm |  | 1- 20 mm woods<br>2- 150 mm clay or silt<br>3- 150 mm limestone<br>4- 10 mm lime sand render | 1.88 W/m$^2$K |
| **Scenario VII** | 340 mm |  | 1- 20 mm woods<br>2- 150 mm clay or silt<br>3- 150 mm limestone<br>4- 10 mm lime sand render<br>5- 20 mm air<br>6- 150 mm DPSF | 0.21 W/m$^2$K |

The second intervention was made on the top roof, which was also covered with beams of palm trunks, as in the previous scenario. This interference with the existing buildings will help improve the thermal performance of the building and living area, where the occupants can enjoy the improvement without the shifting to other dwellings. This led to noteworthy refinements in the reduction of the U-value from 1.88 W/m$^2$K to 0.21 W/m$^2$K, which is considered better for the thermal performance of the house, as can be seen in Figures 7.17 and 7.18.

- **Winter: from 02$^{nd}$ January 2019 to 09$^{th}$ January 2019**

The result shows an increase of 4-5 K in the top floor room and from 1-2 K in the ground floor living room compared to the base model; despite using the current roof with adding DPSF below the roof, the average temperature still exceeds the limits of the ASHRAE adaptive comfort criteria in the first-floor room. contrarily, the living room temperature maintains comfort during all the periods; generally, during winter, the intervention is considered better than the base model, maintaining the indoor space warmer and more comfortable.

*Table 7.16 Simulation results against base model results for Living room and Room1 during the Winter*

| Building | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|
| | Mean Temp | | Daily Max | | Daily Min | |
| | Base Model | Scenario VII | Base Model | Scenario VII | Base Model | Scenario VII |
| **Room MH1** | 14.7 °C | 19.0 °C | 16.0 °C | 21.0 °C | 13.5 °C | 17.0 °C |
| **Living room MH1** | 18.0 °C | 17.2 °C | 19.0 °C | 19.0 °C | 17.0 °C | 15.5 °C |

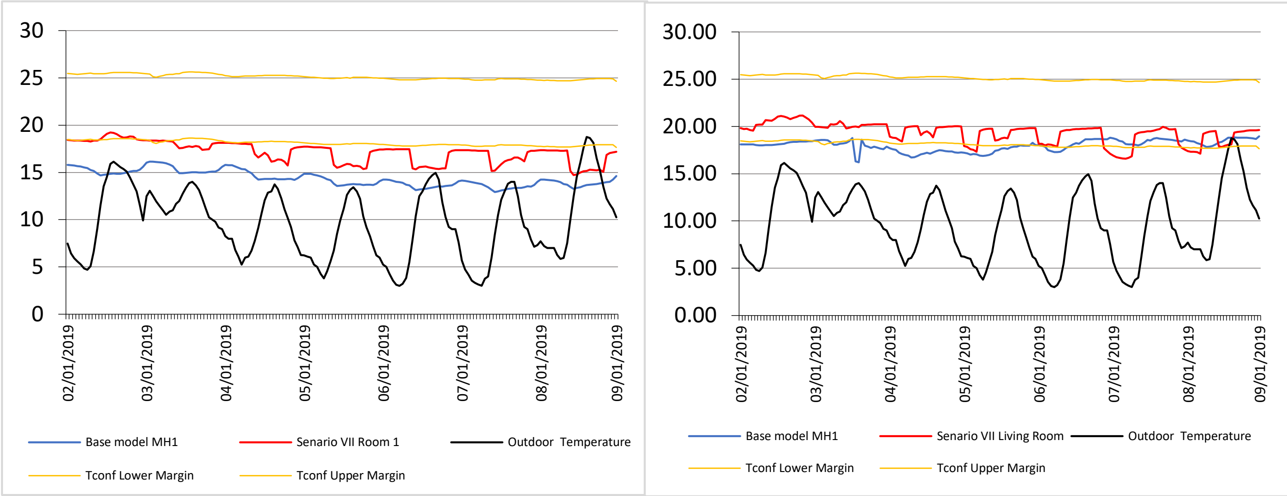



***Figure 7.17: Effects of using combination methods on the internal operative temperature for the living room and first-floor room against the reference building during the coldest week in winter.***

- **Summer: from 02nd August 2018 to 09th August 2018**

***Table 7.17 Simulation results against base model results for Living room and Room1 during the Summer***

| **Building** | **Temperature (ºC)** | | | | | |
|---|---|---|---|---|---|---|
| | **Mean Temp** | | **Daily Max** | | **Daily Min** | |
| | **Base Model** | **Scenario VI** | **Base Model** | **Scenario VI** | **Base Model** | **Scenario VI** |
| **Room MH1** | 36.5 **ºC** | 29.0 **ºC** | 38.5 **ºC** | 31.0 **ºC** | 34.5.0 **ºC** | 27.0 **ºC** |
| **Living room MH1** | 35.2**ºC** | 25.0 **ºC** | 36.5 **ºC** | 27.0 **ºC** | 34.0 **ºC** | 24.0 **ºC** |

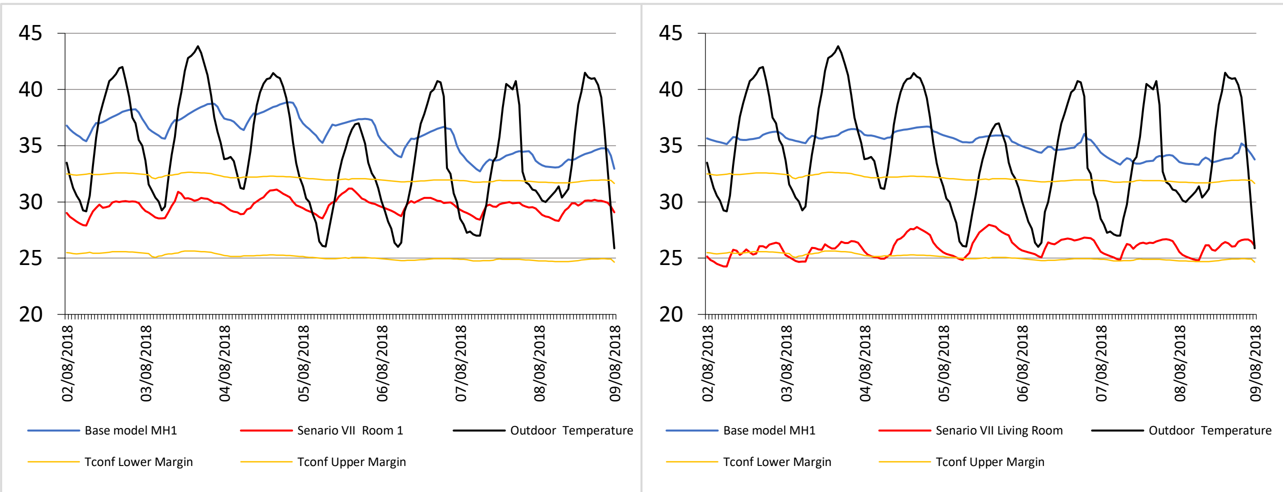


***Figure 7.18: Effects of using combination methods on the internal operative temperature for the living room and first-floor room against the reference building during the hottest week in summer.***

The physical overlaps on the roof were found to be very satisfactory in terms of reducing thermal conductivity for delaying the heat transfer; it seems very clear from the simulation comparison that during summer, the temperatures of both locations were within the thermal comfort range; from Figure 7.18, we can see a 10 K reduction in living room and around 7 K in first-floor room temperatures, which leads to improvement in the house thermal performance.

Overall, the interventions at the roof level were by adding the DPSF material to fade and covering the roof with palm trunks (Pergola) yielded an elegant result, especially in summer. The indoor operative temperature fluctuations in both locations were within the comfort zone range, which is considered very satisfactory, with fewer losses compared to the other scenarios, and around 15 K less than the outdoor temperature during the peak time. This scenario gives a new option for the residents to change for better the indoor conditions, as they do not have to shift to a new building or change the roof completely. Concerning cold weather, it provided an acceptable result but less than the comfort requirements. However, using a heating system for a short period gives a better result than the base model.

**7.3 Summary:**

Reflecting on the preceding study, it should be obvious from this discussion that, when constructing naturally ventilated structures, it is critical to consider the reaction of the building envelope with the climate, particularly for buildings in Algeria’s hot dry weather.

Thus, it is evident from this research that it is essential to consider the building envelope's ability to respond to the climate when designing naturally ventilated homes, especially in the hot, dry weather typical in the south of Algeria. Increased insulation, in particular, is quite beneficial. A well-insulated envelope with high emissivity surfaces and low solar absorption will absorb heat more slowly. For the final integrated design, all the examples that performed well in the various scenarios are taken into account. Accordingly, the following observations were made:

1. The "R-value," thermal capacity, absorption, and U-value of envelope structures characterise the heat flow through building materials. In the building modelling process, these criteria are very important because they help us better understand the physical properties of the building envelope design.
2. The heat gains from the roof contribute to a greater proportion of the building's design. Covering the roof with a pergola helps to impede the interior heat transmission. Even if shading the roof works, using 15-cm DPSF can reduce the U-value from 1.88 W/m$^2$K to 0.32 W/m$^2$K gain and, along with the walls, contribute to a large portion of the energy savings in the comfort zone.
3. The model appears to be effective for the intended use. Adding a pergola and the DPSF to the current roof in scenario VII, which provides cost savings by adopting new eco-friendly materials rather than choosing an existing roof design, may be useful at this point. This will improve the U-value dramatically, dropping it from 1.88 W/m2K to 0.32 W/m2K. In order to ensure that temperature swings are acceptable in terms of people's comfort, it was determined that implementing scenario VII results in greater thermal performance than the based model. This can be used for existing structures, which in this case are essentially identical.

4. A significant portion of the building envelope and a key recipient of direct radiation are the walls. By putting the 15 cm DPSF on the middle layer of the external wall, the U-value of 2.14 W/m2K for the base model walls that were 450 mm thick and made of 20 cm of lime stone was decreased to 0.14 W/m2K.

**All of these strategies can be combined to produce even better outcomes than the air conditioner alone.**

# CHAPTER
# VIII
# CONCLUSIONS

# CHAPTER VIII
## Conclusions and Recommendations

### 8.1 Research Overview:

This research work describes case studies in two areas located in Ghardaia, southern Algeria: Tafilelt and Beni Isguen. The areas were selected since they have two different patterns of neighbourhoods with a microclimate of approximately 1.5 $Km^2$. The comparisons were based on the urban thermal performance, building materials, and occupants' activities. These comparisons showed how differences in the urban patterns of land use and population densities affect the outdoor climate conditions and, in turn, human comfort and indoor conditions.

In the first phase of the thesis, the most notable aspects that connected to passive cooling techniques and natural ventilation were explained and investigate the issues related to the occupants thermal comfort and thermal performance of buildings in hot dry climates. In the literature review, the urban morphology, and architectural characteristics of building in a hot arid climate are described in the context of thermal performance impact of a city and the concentration of the urban heat island (UHI) on the convective movements of airflow at the level of the urban canopy and the urban canyon. The outcome of this research is contributing to the Ksour architecture by investigating and learning how the traditional architecture in the old settlement might be synthesised to form a new domestic vernacular with optimised thermal comfort.

In the second part of this thesis, a questionnaire survey to help the researcher to understand the inhabitants' behaviour and satisfaction during summer and winter time. From monitoring a comparative result between both the traditional and modern buildings in Tafilelt and Beni Isguen showed a substantial difference in terms of the temperature and relative humidity. By comparing the outdoor temperatures for both settlements in old and new city, a difference was observed in how the urban design of each settlement affected the local climate, as mentioned in Chapter V.

Overall, the temperatures in the old city have continual fluctuations while being tolerable in the urban areas due to the organic design as the city can protect itself in all directions by the surrounding oasis, all these features help contribute for sufficient cooling to the dwellings in Beni Isguen. Moreover, the effectiveness of the building envelope design lies in the fact that it is made from local materials, particularly like the new settlement Tafilelt . However, the temperatures range in Tafilelt noticed a considerable fluctuations between daytime and night-time during the summer with diurnal temperature variation is found (9.0 K as an average), and in winter with diurnal temperature variation is found (5.0 K as an average).

Following that the research developed wide selection of scenarios and expanded the results of the theoretical study by adding other factors and other climatic conditions in a life-size building. An analysis of dynamic thermal simulations was performed to determine the effect of these parameters on the heating/cooling loads, as well as on the hours of discomfort in the studied building. To this end, the same model of a Tafilelt building with the same characteristics, materials, and orientation were considered as a case study to build a well-validated simulation model using the experimental results of winter and summer monitoring. This model was then used to assess the impact of the techniques studied on the thermal performance and energy savings of the house considered in the two climates. A digital model of this house was developed using the Design builder software which was validated by comparison of the results on a long-term winter and summer experimental monitoring in Chapter VI. In this chapter, a validation was experimentally approved for the dynamic thermal simulation of buildings. Ideal combinations have been proposed for the passive and semi passive techniques capable of ensuring substantial energy efficiency in the building.

Chapter VII aimed to examine the effect of the thermophysical properties of the envelope (such as thermal insulation and absorption), building orientation, and ground connectivity on performance. The following proposed strategies were found to be the most efficient in terms of thermal comfort and energy savings of the house, considering occupancy scenarios in two seasons winter and summer; the strategies were proposed to consider naturally ventilated in the living room and the bedroom spaces for both seasons:

1-Shading strategy modifications

2-Wall modifications

3- Roof modifications

**8.2 Key Observations:**

Analysing the case studies of the building, and using thermal modelling in Chapter VI, it is indicated that:

- The new building in Tafilelt and old building within Beni Isguen have overheating during summer, especially on the top floors where the mean daily air temperature ranged between 32.5°C to 37.0°C with diurnal temperature variation of 4.5k and considered hight compared to the ASHRAE 55 boundary range .The roof is fully exposed to the sun gain where the selected houses relied solely on natural ventilation for cooling during hot times. The analysis also revealed that temperature increases result from the sun exposure for a long period, where the roof is considered, the main element absorbing the heat during daytime and simply continuing to conduct heat to the inside of the dwelling, making the place uncomfortable to live all year round. Hence, it becomes increasingly difficult to achieve comfort standards.

- Tafilelt was awarded at the Energy Globe Organisation in 2020 and recognised as a unique model in the field of architectural heritage that combines modernity and comfort; However, from this study, Tafilelt was indeed exceptional, but it still lacks comfort characteristics.

- The buildings studied under different improvements in Chapter VII suggest that their impact could be considerable, and the benefits remarkable. For both new and existing buildings, as outlined in the same chapter, the modelling results shows that using a physical intervention at the roof reduces the U-value from 1.88 W/m2K to 0.21 W/m2K when combined with covering the patio and the terrasse with pergola. This leads to a very acceptable result in both seasons; the intervention in the current buildings will result in lower heating and cooling energy demand, particularly for first floor rooms, which will generally result a better thermal performance for the buildings .

- This study considered the possibility of using palm fronds and residues in construction and making DPSFs through wooden panels, which are used for construction, with paved or natural stone or natural wood, as well as covered with dyes or various decorative coverings to expand the extent of their use. Wood-plastic panels can be made from a mixture of granules of palm tree residues in general and polyethylene, polystyrene, or polyester, with the addition of chemical bonding materials such as phenol resin or urea-formaldehyde, with the addition of other chemicals that make the panels resistant to fire, rotting or insects. Such panels not only have a high moisture resistance, which is a rare feature unique to such panels, but are also cheap, which puts them within the reach of families at all economic levels. In addition, they can use it for the current buildings without needs to demolish the building elements and rebuilt it again.

- The outcomes of this thesis constitute to some understanding of residential thermal behaviour in Ghardaia, which can provide a guidelines to improve the thermal performance for building fabric. furthermore the convenient solutions to be achieved, which support the architects and engineers to meditate the passive design strategies in the initial phase of the design and characterize the building envelope , which can increase the occupants comfort, especially during the summer. overall the concepts introduced on the research intervention are highlighted below:

  - **Shading and the Ventilation Strategy (Pergola):**

  During the daytime can noticed a high heat gain from the building envelope to the indoor spaces, which leads a high heat effect during the night and this effects the indoor thermal conditions for the building and the way of the occupants interact by using the air conditioner

or sleeping at the terrasse. In summer days and intense sunlight, covering the roof is the highly significant plan in reducing the high temperatures when the thermal mass increases due the exposure to the sun. It is conceivably to cool the building by night time, where the fresh air heightens the convective heat losses from the elements mass and
disperses the emitted heat to the temperature outdoor.

- **Effects of canyon's aspect ratio (H/W):**

The modelling simulation indicates the effect of canyons' geometry (H/w) on the measured parameters , especially the outdoor air temperature (Ta) and mean radiant temperature (Tmrt). Account that the maximum outdoor temperature Ta and the Tmrt were proved to be decrease with rising aspect ratio (H/w) to be like the Beni Isguen ratio. In addition, it was found that the air temperatures tended to be cooler than the wider roads due to the protection provide in opposition to solar radiation at canyons level, which they can benefit from this cooling effect on the urban canyon's aspect ratio through shading. The maximum daytime air temperatures in the deep urban canyons (e.g., H/w. = 5) can be 2.5k cooler than those observed in a wide street (e.g., H/w. = 2.5) (see e.g., Figures 7.2 and 7.3)

- **Building Materials and Thermal Properties:**

the selection of building materials and their thermal properties considered as important steps for evaluating the building thermal performance in respect of the heat gain in hot climate. Thus, DPSF material believed to be excellent at resisting the heat flow, which can be more efficient comparing to the used materials, which the results of simulation showed the influence of each materials on the comprehensive performance of the dwelling environment as follow:

- **Walls:**

Predominantly, by designing a better insulation for the wall is resulting a relieving of overheating for the internal wall, meantime the stored heat during the night the will result a high wall temperatures, which leads to warm the living space. Consequently, improving the natural ventilation during the night time and inactivate the wall higher thermal conductivity could has a positive impact on residents comfort.

The differential on the diurnal temperature during the hot time considered wider, so by using of the mass wall construction with a U-value of 0.14 W/m2k can resulting a decrease on heat gain during the summer time due to the thermal insulation. When the outdoor temperature reaches the excessive value of above "35°C", in this case, the heat will conduct from the warm side into the material and gradually move through it to the colder side.

Therefore, with high walls thermal mass, and a strong insulation, will deliver a perfect internal thermal condition as the decreasing the overheating time can be accomplished in integration with roof design to abstain the solar heat gain. during the cold night on winter, while using the night heating, it noted that increasing on wall mass by moderate temperature variations, therefore the wall mass is augmenting by moderate temperature variations thus increasing the thermal comfort, however in summer, there was permanently differential around 6K between the ground floor spaces and first floor spaces (see figure 7.12). consequently, openings size, and the position inside the wall having another effect on heat gains and are more important in parallel with thermal mass.

- **Roof:**

Generally, existing roof materials in both cases, the old house in Beni Isguen and modern house in Tafilelt, can contributing in the heat capacity of the building, where the high absorption of the heat or the cold in the roof and walls , this leads to heat travels from outdoor to indoor the building, by using materials" DPSF" the heat or cold flows can be reduced, this is due to the high resistance characteristics of the insulation materials. Consequently, the top floor can succeed to avoid the heat or cold gain, therefore the roof design should be considered carefully by employing DPSF insulation 150mm with thermal conductivity of 0.04 w/mk. using the new materials on the roof can reduce the temperature by 6 K on the top floor during the summer, which considered better than those observed in the existing roof.

Overall, in order to minimise the heat gains from the roof, it is desirable to apply the new insulation on structural mass to the existing roof or for the new design roof which comply with assembly u-value factor 0.32 w/m$^2$k, which effect the thermal building conditions.

## 8.3 Conclusion:

The purpose of this thesis was to evaluate and recommend an application of passive cooling techniques in dwellings located in two different urban settlements in the Ghardaia area. Additionally, the goal of this thesis was to develop an optimal model that can assist thermal design decisions to passively improve the thermal behaviour of buildings. The current review makes clear the support for the target that was accomplished in five objectives and that were fashioned in order to finish the task of this research study.

A- The substance of objective one, which is to **" *To study and explain the difficulties of crucial components of passive design methods and thermal performance in both the old and new ksar."*** , was addressed in Chapter Two's literature study, which centred on the conceptual framework. In this review, a descriptive and scientific study examined the methods of passive cooling applications and natural ventilation in relation to the thermal comfort of the occupants, as well as potential methods for achieving this comfort by reducing internal heat gain and minimising external heat gains. In order to increase indoor thermal comfort without the use of mechanical systems to dissipate heat, three concepts are examined in greater detail: thermal comfort, adaptive thermal comfort, and the characteristics that have an effect on these.

B- In support of objective two, which is to ***" To evaluate the internal environment and determine solutions that can provide qualitative, physical, and psychological benefits to dwelling occupants (adaptive, comfortable houses in a hot, dry climate)".***Chapter Three provides an introduction to the thermal performance of residential buildings in Ghardaia.
This review gives a general idea of how to study people's thermal comfort in the hot, dry climate of Ghardaia. It provides an opportunity to study prior research on thermal comfort in the field and provides considerable information on the thermal performance of buildings gleaned from several field investigations conducted by a variety of researchers. In Chapter Five, a broader view of an essential component of the vernacular desert architecture of Ghardaia and Tafilelt, Beni Isguen, in particular was provided as a continuation of Chapter Three. It implies that the opportunity to apply and compare the site temperature and relative humidity measurements for both settlements was made possible by a building that can be modified to meet the needs of the building's occupants and the environmental concerns of the local building's surroundings.

C- In support of the third objective, which was to ***" To examine the impact of the outdoor climate on building design and indoor comfort by evaluating the format of real weather data used in the simulation process."*** the fifth chapter of the field study outlined three key measures to analyse the current situation:
- The first stage was to collect indoor and outdoor data over the 2019 winter and 2018 summer. This was accomplished by installing indoor and outdoor data loggers in the building at Tafilelt and Beni Isguen, in two different pairs that helped collect and compare the actual data measurements during the hot and cold periods.
***** The second step was to collect the data gathered through environmental monitoring of the weather during the winter and summer of 2018 by local weather stations. This data was collected by the author and formatted into EnergyPlus weather files (EPW) to serve as the foundation for the building simulation using Design builder.
In general, the monitoring of weather conditions in the field revealed a large fluctuation between interior and exterior surroundings that had a significant impact on the temperature,

rising in summer in accordance with the outdoor temperature and falling in winter in accordance with the outdoor temperature.

***** Step three of Chapter Five provided a comprehensive picture of indoor settings by using comparisons and questionnaires to study and evaluate both the temperature feeling and the respondents' preferences in order to obtain a deeper understanding of how residents react to indoor surroundings. An in-depth sample analysis was conducted so as to take into account the whole difficulty of the respondents' current family situations in each of the four dwellings analysed for this study. The questionnaire was administered in the summer of 2018 and centred on the reported winter and summer interior climate experiences of dissatisfied residents. In addition to the questionnaire, individual measurements and a list of suggested fixes were presented in response to the residents' persistent complaints about the interior climate. There was consideration given to gathering data such as age, gender, housing construction, ventilation system, opening windows, period of occupation, and attire. Only 17% of respondents favoured "no change" during the summer, indicating that they were dissatisfied with the current conditions, while 10% selected "no change" in Beni Isguen. In addition, 39% of respondents favoured 'no change' during the winter for Tafilelt, while 20% selected 'no change' for Beni Isguen. Thermal unacceptability and thermal sensation indicated a high level of thermal dissatisfaction, whereas thermal preferences indicated a significantly lower level of thermal dissatisfaction—about 20% during both winter and summer. Because the building's shell and the weather outside aren't cooperating, it's impossible to maintain the same temperature inside and out, resulting in an uncomfortable environment.

D- Regarding objective number four, which was to " ***To create computer simulation models for the thermal performance analysis of naturally ventilated buildings and to examine the connections between passive design and performance characteristics."*** chapter seven demonstrated the evaluation of building simulations packages in order to select the optimal tool for use in the analysis phase. The technique of evaluation took into account all facts pertaining to the design of the models, the database of building materials. In addition, the validation of energy simulation performance, which is necessary for approving the output results and overall performance, was also considered. DesignBuilder approved the investigation of the outside envelope of a typical family dwelling prototype in the new urban region of Ghardaia by analysing the inside thermal conditions, external heat gain, and natural ventilation performance.

E- For the fifth objective, the final target is **" *To make use of the computer models to propose features that will improve the performance of the new ksar* "** is the title of this article. The seventh chapter demonstrated the significance of natural ventilation and thermal mass and discussed in detail in this thesis.to investigate the possibility of boosting thermal performance in residential structures where passive design methods are implemented and used to examine the thermal performance of a prototype dwelling in the Tafilelt region by combining field research with satellite imagery using simulated thermal analysis. DesignBuilder modelling this application is utilised while analysing local weather data.to study several circumstances affecting the make-up of enhancing the roof, walls, and shading strategy for thermal comfort inside. Consequently, the simulations included an alternative design option with varied The application of the hypothesis of design scenarios to minimise different design alternatives were implemented for summertime heating and wintertime cooling.

### 8.4 Limitations of the Study:

Results from this study highlight some benefits and limitations as described below:

**1.** The study examined a natural ventilated building only, examining temperature and relative humidity.

**2.** The investigation focused on a comparative study of the building in ksar Tafilelt and the one in old ksar in Beni Isguen, which used similar materials and with the same occupant activities. However, this study is limited to just these two settlements which was a greater choice compared to other types of residential buildings constructed with concrete which could be very different to this study. Hence, it will be useful to extend the study to all the buildings in Ghardaia city in the future.

**3.** In this study, the patio size was not considered, as also the vegetation. It is necessary to consider the role of vegetation and watering in the patio, and also how they improve moisture and reduce the heat during the summer.

**4.** It is noteworthy that due to the travel restrictions imposed by the global pandemic of Covid-19, more data was not collected especially related to air velocity and energy consumption for each house. This would have provided more input in designing a new Tafilelt within Ghardaia.

### 8.5 Recommendation for Future Work:

To address some of the limitations mentioned in the previous section, the researcher proposes the following items to be considered for future work including:

1. The impact of the urban density on the building thermal performance using CFD analysis as an example.
2. Extend the study to other buildings within Ghardaia to investigate their thermal performance especially related to the energy consumption
3. It would be very interesting to apply the simulated scenarios described within Chapter 7 in real life within Tafilelt which will further provide insight to thermal comfort and additional requirements for new to be built cities in hot dry areas in the South of Algeria.

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# APPENDICES

# APPENDIX 1: QUESTIONNAIRE

Questionnaire For Residents in Both sites houses in Beni Isguen and Tafilelt

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# RESIDENTIAL COMFORT SURVEY

**A Questionnaire designed for post-occupancy evaluation in residential buildings in Algeria: A case study of Ghardaia. Please fill in, tick or circle as many as you can**

SECTION A: **Background Information**

**1.** Address (Location): ____________________________________________________

**2.** Date:___________________

**3.** Time:___________________

| Morning: | Afternoon: | Evening: |
|---|---|---|

**4.** Sex:

| Male | Female |
|---|---|
| | |

**5.** Age:

| 18 – 30 years | 31 – 45 years | 46 – 59 years | 60 and above |
|---|---|---|---|
| | | | |

**6.** Marital status:

| Single | Married | Prefer not to say |
|---|---|---|
| | | |

**7.** Employment status:

| Public servant | Private employee | Self-employed | Student | Unemployed |
|---|---|---|---|---|
| | | | | |

**8.** Socio-economic status:

| Low-income | Lower medium-income | Upper medium-income |
|---|---|---|
| | | |

**9.** What is the highest level of your educational attainment?

| No formal education | Completed primary | Secondary | Post-secondary | Post-graduate |
|---|---|---|---|---|
| | | | | |

**10.** What is your current tenure status?

| Rented (tenancy) | Owner occupier |
|---|---|
| | |

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SECTION B: **BUILDING ATTRIBUTES/ ENERGY CONSUMPTION**

**11.** What is your house type?

| Single-Family Bungalow | Semi-detached Bungalow | Detached | Semi-detached building | Duplex |
|---|---|---|---|---|
| | | | | |

If "Other", please state: ____________________

**12.** How many bedrooms do you have in your apartment?

| 1 | 2 | 3 | 4 | More than 4 |
|---|---|---|---|---|
| | | | | |

**13.** How many people live in this apartment?

| 1 | 2 | 3 | 4 | More than 4 |
|---|---|---|---|---|
| | | | | |

**14.** How long have you been living in your apartment?

| Less than 1 year | 1 – 3 years | 4 – 5 years | More than 5years |
|---|---|---|---|
| | | | |

**15.** On average, how much do you spend on electricity bill per month from the national grid?

| Below DZD5,000 (£32.49) | DZD 5,000 – DZD 10,000 (£32.49- £ 64.97) | DZD 10,000 – DZD 15,000 (£64.97- £97.46) | DZD 15,000- DZD 20,000 (£97.46- £129.94) | Above DZD 20,000 (£129.94) |
|---|---|---|---|---|
| | | | | |

**16.** What is your alternative source of electricity supply, if any?

| Personal Power Generating sets | Power Generating Plant in the estate | Solar Panels (photovoltaic) | Other | None |
|---|---|---|---|---|
| | | | | |

**17.** On average, how much do you spend per month on alternative source of electricity?

| Below DZD5,000 (£32.49) | DZD 5,000 – DZD 10,000 (£32.49- £ 64.97) | DZD 10,000 – DZD 15,000 (£64.97- £97.46) | DZD 15,000- DZD 20,000 (£97.46- £129.94) | Above DZD 20,000 (£129.94) |
|---|---|---|---|---|
| | | | | |

**18.** What is your major source of cooking fuel?

| Electricity | Gas | Kerosene | Firewood | Other |
|---|---|---|---|---|
| | | | | |

If "Other", please state: ____________________

**19.** What is your major source of water supply?

| Public mains | Borehole | Well | Water vendors |
|---|---|---|---|
| | | | |

If "Other", please state: ____________________

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SECTION C: **INDOOR THERMAL CONDITIONS**

**Control vote**

**20.** Are you using anything to keep yourself comfortable, if yes which space are you using it?

| Space/ Control | Open Windows | Open Doors | Electric fan | A/C | Hand fan |
|---|---|---|---|---|---|
| Living room | | | | | |
| Bedroom | | | | | |
| Dining room | | | | | |

**21.** How often do you use the controls stated in (20) above?

| Very little | Little | Slightly little | Neutral | Slightly much | Much | Very much |
|---|---|---|---|---|---|---|
| | | | | | | |

**22.** Are you satisfied with the level of control?

| Very dissatisfied | Dissatisfied | Slightly dissatisfied | Neutral | Slightly satisfied | Satisfied | Very satisfied |
|---|---|---|---|---|---|---|
| | | | | | | |

**23. Thermal sensation:**

| What do you think about the thermal sensation in the room(s) during the: | Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Dry season at night? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |
| Rainy season at night? | | | | | | | |
| Overall indoor temperature | | | | | | | |

**24. Daylight:**

| What do you think about the day lighting in the room(s) during the: | Very dim | Dim | Slightly dim | Neutral | Slightly bright | Bright | Very bright |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |

**25. Humidity:**

| What do you think about the humidity in the room(s) during the: | Very dry | Dry | Slightly dry | Neutral | Slightly humid | Humid | Very humid |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Dry season at night? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |
| Rainy season at night? | | | | | | | |
| Overall humidity | | | | | | | |

26. Air movement:

| What do you think about the air movement in the room(s) during the: | Very little | Little | Slightly little | Neutral | Slightly much | Much | Very much |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Dry season at night? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |
| Rainy season at night? | | | | | | | |
| Overall air movement | | | | | | | |

26. Air quality:

| What do you think about the air quality in the room(s) during the: | Very stuffy | Stuffy | Slightly stuffy | Neutral | Slightly good | Good | Very good |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Dry season at night? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |
| Rainy season at night? | | | | | | | |
| Overall air quality | | | | | | | |

27. Indoor environmental rating:

| What do you think about the environment in the room(s) during the: | Very uncomfor -table | Uncomfor -table | Slightly uncomfor -table | Neutral | Slightly comfort- table | Comfort- table | Very comfort- table |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Dry season in the daytime? | | | | | | | |
| Dry season at night? | | | | | | | |
| Rainy season in the daytime? | | | | | | | |
| Rainy season at night? | | | | | | | |
| Overall thermal comfort | | | | | | | |

28. Thermal preference:

| How would you prefer air temperature during the: | Much cooler | Slightly cooler | No change | Slightly warmer | Much warmer |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Dry season in the daytime? | | | | | |
| Rainy season in the daytime? | | | | | |
| Dry season in the night? | | | | | |
| Rainy season at night? | | | | | |
| Overall satisfaction | | | | | |

**29. The Typical Clothing You Wear Indoors at Home:**
Using the table below please indicate what items of clothing you would typically wear when indoors. Please only choose one set that most typifies your indoor clothing at the listed time of the year.
<Circle all that apply in the season column>

| ITEM OF CLOTHES: | DRY SEASON | RAINY SEASON |
|---|---|---|
| **Shorts** | **1** | **1** |
| **Singlet** | **1** | **1** |
| **Track/ Jogging suits** | **1** | **1** |
| **Trousers/ slacks** | **1** | **1** |
| **Jeans** | **1** | **1** |
| **Short sleeved shirt or blouse** | **1** | **1** |
| **Long sleeved shirt or blouse** | **1** | **1** |
| **Short sleeved pullover** | **1** | **1** |
| **Long dress** | **1** | **1** |
| **Knee length dress** | **1** | **1** |
| **Skirt** | **1** | **1** |
| **Thin tights** | **1** | **1** |
| **Standard underwear** | **1** | **1** |
| **Other major item** | **1** | **1** |

**30.** What has been your activity level in the last 15 minutes?

| Watching TV | Cooking | Standing | Walking | Washing | Reading |
|---|---|---|---|---|---|
| | | | | | |

If "Other", please state: ______________________

**31.** Approximately, what are your energy bills/ month (electricity)?

| | Jan | Feb | Mar | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Monthly Amount (N)** | | | | | | | | | | | | |
| **kWh** | | | | | | | | | | | | |

# DAILY DIARY

# (Comfort Survey)

**A daily diary designed for thermal comfort evaluation of occupants in residential buildings in Algeria: A case study of Ghardaia. Please fill, tick or circle as many as you can**

**1.** Address (Location):_______________________________________________________

**2.** Date:___________________

**3.** Time:___________________

| Morning: | Afternoon: | Evening: |
|---|---|---|

**4.** Gender:

| Male | Female |
|---|---|
| | |

**5.** Age of respondent:

| 18 – 30 years | 31 – 45 years | 46 – 59 years | 60 and above |
|---|---|---|---|
| | | | |

**6.** In what room are you currently filling in this survey?

| Living room | Bedroom | Kitchen | Dining room |
|---|---|---|---|
| | | | |

**7.** Where have you spent most of your time in the last hour?

| Living room | bedroom | Kitchen |
|---|---|---|
| | | |

If "Other", please state: ____________________

**8.** Have you just come into the building in the last…?

| 15 minutes | 30 minutes | 45 minutes | 1 hour | More than 1 hr. |
|---|---|---|---|---|
| | | | | |

**9.** What has been your activity within the last hour?

| Watching TV | Cooking | Standing | Walking | Washing | Reading |
|---|---|---|---|---|---|
| | | | | | |

If "Other", please state: ____________________

**10.** Do you feel comfortable now?

| Very uncomfortable | Uncomfortable | Slightly uncomfortable | Neutral | Slightly comfortable | Comfortable | Very comfortable |
|---|---|---|---|---|---|---|
| | | | | | | |

**11.** Would you like to be:

| Cooler | No change | Warmer |
|---|---|---|
| | | |

**12.** How would you rate the overall acceptability of the temperature at this moment?

| Acceptable | Not acceptable |
|---|---|
| | |

**13.** How do you feel about the thermal sensation in your building at this moment?

| Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot |
|---|---|---|---|---|---|---|
| | | | | | | |

**14.** How do you feel about the air movement (ventilation) in your building at this moment?

| Very Little | Little | Slightly little | Neutral | Slightly much | Much | Very much |
|---|---|---|---|---|---|---|
| | | | | | | |

**15.** How do you feel about the air (humidity) in the building at this moment?

| Very dry | Dry | Slightly dry | Neutral | Slightly humid | Humid | Very humid |
|---|---|---|---|---|---|---|
| | | | | | | |

**16.** How do you feel about the day lighting level at this moment?

| Very dim | Dim | Slightly dim | Neutral | Slightly bright | Bright | Very bright |
|---|---|---|---|---|---|---|
| | | | | | | |

**17.** How do you feel about the air quality at this moment?

| Very stuffy | Stuffy | Slightly stuffy | Neutral | Slightly good | Good | Very good |
|---|---|---|---|---|---|---|
| | | | | | | |

**18.** How do you prefer air temperature at this moment?

| Much cooler | Slightly cooler | No change | Slightly warmer | Much warmer |
|---|---|---|---|---|
| | | | | |

**19.** Occupant's activity level during the last 15 minutes?

| Watching TV | cooking | Standing | Walking | Washing | reading |
|---|---|---|---|---|---|
| | | | | | |

If "Other", please state: ______________________

**20.** In the last 30 minutes please identify the kind of drinks you have taken

| Cold drinks | Hot drinks | No drinks |
|---|---|---|
| | | |

If "Other", please state: ______________________

**Control vote**

**21.** Are you using anything to keep yourself comfortable at this moment, if yes where are you using it?

| Space/ Control | Open Windows | Open Doors | Electric fan | A/C | Hand fan |
|---|---|---|---|---|---|
| Living room | | | | | |
| Bedroom | | | | | |
| Dining room | | | | | |

**22.** How often do you use these controls stated in (21) above at this moment?

| Very little | Little | Slightly little | Neutral | Slightly much | Much | Very much |
|---|---|---|---|---|---|---|
| | | | | | | |

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**23.** Are you satisfied with the level of control at this moment?

| Very dissatisfied | Dissatisfied | Slightly dissatisfied | neutral | Slightly satisfied | Satisfied | Very satisfied |
|---|---|---|---|---|---|---|
| | | | | | | |

**24.** Please circle the clothing you are wearing at the moment. <circle all that apply>

| ITEM OF CLOTHES: | SCORE |
|---|---|
| **Shorts** | 1 |
| **Singlet** | 1 |
| **Track/ Jogging suits** | 1 |
| **Trousers/ slacks** | 1 |
| **Jeans** | 1 |
| **Short sleeved shirt or blouse** | 1 |
| **Long sleeved pullover** | 1 |
| **Short sleeve pullover** | 1 |
| **Long dress** | 1 |
| **Knee length dress** | 1 |
| **Skirt** | 1 |
| **Thin tights** | 1 |
| **Standard underwear** | 1 |
| **Other major item** | 1 |

**25.** Do you feel well at the moment?

| Yes | No |
|---|---|
| | |

If No, (**25a**) is this making you feel hot or cold?

| Yes | No |
|---|---|
| | |

(**25b**) for how many days have you been feeling unwell?

(1-7)? ______

**26.** Please make any further comment about the comfort in this building, i.e. indoor air temperature, humidity, air freshness, etc.

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

# APPENDIX 2: QUESTIONNAIRE IN ARABIC

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## مسح الراحة السكنية

**استبيان مصمم لتقييم ما بعد الإشغال في المباني السكنية في الجزائر :دراسة حالة في غرداية .من فضلك املأ ، ضع علامة أو ضع دائرة حول أكبر عدد ممكن من الأشخاص**

**القسم أ :معلومات أساسية**

**الموقع**

**التاريخ**

**الوقت**

| صباحا | مع الظهيرة | مساءا |
|---|---|---|

**الجنس**

| انثى | ذكر |
|---|---|
| | |

**العمر**

| او اكثر 60 | 46 – 59 | 31 – 45 | 18 – 30 |
|---|---|---|---|
| | | | |

**الحالة العائلية**

| افضل عدم القول | متزوج | اعزب |
|---|---|---|
| | | |

**الوضع الوظيفي**

| عاطلين عن العمل | طالب علم | لحسابهم الخاص | موظف خاص | موظف حكومي |
|---|---|---|---|---|
| | | | | |

**الوضع الاجتماعي – الاقتصادي**

| الدخل المرتفع | الدخل المتوسط | دخل منخفض |
|---|---|---|
| | | |

**ما هو أعلى مستوى من التحصيل العلمي الخاص بك؟**

| المرحلة الجامعية | المرحلة الثانوية | المرحلة المتوسطة | المرحلة الابتدائية | لا تعليم رسمي |
|---|---|---|---|---|
| | | | | |

**ما هي وضعية سكنك الحالية**

| شاغل مالك | مؤجر (إيجار) |
|---|---|
| | |

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**القسم ب :خصائص البناء /استهلاك الطاقة**

**ما هو نوع منزلك؟**

| دوبلكس | مبنى شبه منفصل | منفصل | مسكن شبه منفصل | بنجالو عائلي واحد |
|---|---|---|---|---|
| | | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ______________________

**كم غرفة نوم لديك في شقتك؟**

| أكثر من 4 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|
| | | | | |

**كم عدد الاشخاص الذين يعيشون في هذه الشقة؟**

| أكثر من 4 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|
| | | | | |

**منذ متى وانت تعيش في شقتك؟**

| أكثر من4 سنوات | سنوات 5 – 4 | سنوات 3 – 1 | أقل من 1 سنة |
|---|---|---|---|
| | | | |

**في المتوسط ، كم تنفق على فاتورة الكهرباء شهريًا من الشبكة الوطنية؟**

| فوق DZD 20,000 (£129.94) | DZD 15,000- DZD 20,000 (£97.46- £129.94) | DZD 10,000 – DZD 15,000 (£64.97- £97.46) | DZD 5,000 – DZD 10,000 (£32.49- £ 64.97) | أقل DZD5,000 (£32.49) |
|---|---|---|---|---|
| | | | | |

**ما هو مصدرك البديل للكهرباء إن وجد؟**

| لا أحد | آخر | الألواح الشمسية (الكهروضوئية) | محطة توليد الطاقة في الحي | مجموعات توليد الطاقة الشخصية |
|---|---|---|---|---|
| | | | | |

**في المتوسط ، كم تنفق شهريًا على مصدر بديل للكهرباء؟**

| فوق DZD 20,000 (£129.94) | DZD 15,000- DZD 20,000 (£97.46- £129.94) | DZD 10,000 – DZD 15,000 (£64.97- £97.46) | DZD 5,000 – DZD 10,000 (£32.49- £ 64.97) | أقل DZD5,000 (£32.49) |
|---|---|---|---|---|
| | | | | |

**ما هو المصدر الرئيسي لوقود الطهي؟**

| كهرباء | غاز | الكيروسين | الحطب | آخر |
|---|---|---|---|---|
| | | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ______________________

**ما هو المصدر الرئيسي لإمدادك بالمياه؟**

| خطوط العامة | الآبار | مياه الامطار | بائعي المياه |
|---|---|---|---|
| | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ______________________

**القسم ج :الظروف الحرارية الداخلية**
**تصويت المقيم**

**هل تستخدم أي شيء للحفاظ على راحتك ، إذا كانت الإجابة بنعم ، فما هي المساحة التي تستخدمها؟**

| الفضاء /التحكم | النوافذ المفتوحة | أبواب مفتوحة | مروحة كهربائية | تكييف | مروحه اليد |
|---|---|---|---|---|---|
| غرفة المعيشة | | | | | |
| غرفة نوم | | | | | |
| غرفة العشاء | | | | | |

**كم مرة تستخدم الضوابط المذكورة في )20 (أعلاه؟**

| قليل جدا | قليل | جد قليلا | متعادل | جد كثير | كثير | كثير جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**هل أنت راض عن مستوى السيطرة؟**

| غير راض جدا | غير راض | غير راض قليلاً | متعادل | راض قليلاً | راض | راض جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**الإحساس الحراري**

| ما رأيك في الإحساس الحراري في الغرفة :)الغرف (خلال | بارد كثيرا<br>1 | بارد<br>2 | بارد قليلاً<br>3 | متعادل<br>4 | دافي قليلاً<br>5 | حار<br>6 | حار كثيرا<br>7 |
|---|---|---|---|---|---|---|---|
| احساس بالجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في الليل؟ | | | | | | | |
| ممطر في النهار؟ | | | | | | | |
| ممطر في الليل؟ | | | | | | | |
| درجة الحرارة الداخلية العامة | | | | | | | |

**ضوء النهار**

| | قاتمة جدا | قاتمة | قاتمة قليلا | متعادل | ساطع قليلا | ساطع | مشرق جدا |
|---|---|---|---|---|---|---|---|

| ما رأيك في الإضاءة النهارية في الغرفة )الغرف (أثناء: | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| موسم الجفاف في النهار؟ | | | | | | | |
| موسم الأمطار في النهار؟ | | | | | | | |

**الرطوبة**

| ما رأيك في نسبة الرطوبة في الغرفة )الغرف (خلال: | جاف جدا | جاف | جافة قليلاً | متعادل | رطب قليلا | رطب | رطب جدا |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| موسم الجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في الليل؟ | | | | | | | |
| ممطر في النهار؟ | | | | | | | |
| ممطر في الليل؟ | | | | | | | |

**حركة الهواء**

| ما رأيك في حركة الهواء في الغرفة / الغرف خلال: | قليل جدا | قليل | جد قليلا | متعادل | جد كثير | كثير | كثير جدا |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| موسم الجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في الليل؟ | | | | | | | |
| ممطر في النهار؟ | | | | | | | |
| ممطر في الليل؟ | | | | | | | |
| حركة الهواء عامة | | | | | | | |

**جودة الهواء**

| ما رأيك بجودة الهواء في الغرفة )الغرف (خلال: | خانق جدا | خانق | خانق قليلا | متعادل | حسن | حسن جدا | جيد جدا |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| موسم الجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في الليل؟ | | | | | | | |
| ممطر في النهار؟ | | | | | | | |
| ممطر في الليل؟ | | | | | | | |
| حركة الهواء عامة | | | | | | | |

**التصنيف البيئي الداخلي**

| ما رأيك في البيئة في الغرفة )الغرف (خلال: | غير مريح للغاية | غير مريح | غير مريح إلى حد ما | متعادل | مريحة قليلاً | مريحة | مريحة كثيرا |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| موسم الجفاف في النهار؟ | | | | | | | |
| احساس بالجفاف في الليل؟ | | | | | | | |
| ممطر في النهار؟ | | | | | | | |
| ممطر في الليل؟ | | | | | | | |
| الراحة الحرارية الشاملة | | | | | | | |

**التفضيل الحراري**

| كيف تفضل درجة حرارة الهواء أثناء: | أكثر برودة | أبرد قليلاً | لا تغيير | أدفأ قليلا | أكثر دفئا |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| موسم الجفاف في النهار؟ | | | | | |
| احساس بالجفاف في الليل؟ | | | | | |
| ممطر في النهار؟ | | | | | |
| ممطر في الليل؟ | | | | | |
| الرضا العام | | | | | |

**الملابس النموذجية التي ترتديها في الداخل في المنزل**

**باستخدام الجدول أدناه ، يرجى تحديد عناصر الملابس التي سترتديها عادةً في الداخل .الرجاء اختيار مجموعة واحدة فقط تميز ملابسك الداخلية في الوقت المذكور من العام.**

| عنصر الملابس: | فصل الجاف | الموسم الممطر |
|---|---|---|
| شورت | 1 | 1 |
| القميص | 1 | 1 |
| لباس رياضي | 1 | 1 |
| بنطلون | 1 | 1 |
| جينز | 1 | 1 |
| قميص أو بلوزة بأكمام قصيرة | 1 | 1 |
| قميص أو بلوزة بأكمام طويلة | 1 | 1 |
| كنزة صوفية بأكمام قصيرة | 1 | 1 |
| فستان طويل | 1 | 1 |
| فستان بطول الركبة | 1 | 1 |
| تنورة | 1 | 1 |
| الجوارب رقيقة | 1 | 1 |
| الملابس الداخلية | 1 | 1 |
| ملابس اخرى | 1 | 1 |

ما هو مستوى نشاطك في آخر 15 دقيقة؟

| قراءة | غسل | المشي | الوقوف | طبخ | مشاهدة التليفزيون |
|---|---|---|---|---|---|
| | | | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ____________________

تقريبًا ما هي فواتير الطاقة الخاصة بك /شهر )كهرباء(؟

| | Jan | Feb | Mar | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| المبلغ | | | | | | | | | | | | |
| kWh | | | | | | | | | | | | |

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# مذكرات يومية

# (استبيان الراحة الحرارية)

**هاته اليومية مصممة لتقييم الراحة الحرارية لشاغلي المباني السكنية في الجزائر :دراسة حالة في غرداية .من فضلك املأ أو ضع علامة أو ضع دائرة حول أكبر عدد ممكن من الأشخاص**

**-الموقع**

**التاريخ**

**الوقت**

| صباحا | مع الظهيرة | مساءا |
|---|---|---|

**الجنس**

| انثى | ذكر |
|---|---|
| | |

**العمر**

| او اكثر 60 | 46 – 59 | 31 – 45 | 18 – 30 |
|---|---|---|---|
| | | | |

**في أي غرفة تملأ هذا الاستبيان حاليًا؟**

| غرفة الاكل | مطبخ | غرفة نوم | غرفة المعيشة |
|---|---|---|---|
| | | | |

**أين قضيت معظم وقتك في الساعة الماضية؟**

| مطبخ | غرفة نوم | غرفة المعيشة |
|---|---|---|
| | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ________________________

**هل أتيت للتو إلى المبنى في آخر ...؟**

| .أكثر من 1 ساعة | ساعة 1 | دقيقة 45 | دقيقة 30 | دقيقة 15 |
|---|---|---|---|---|
| | | | | |

**ما هو نشاطك خلال الساعة الماضية؟**

| قراءة | غسل | المشي | الوقوف | طبخ | مشاهدة التليفزيون |
|---|---|---|---|---|---|
| | | | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ________________________

**هل تشعر بالراحة الآن؟**

| مريحة كثيرا | مريحة | مريحة قليلاً | متعادل | غير مريح إلى حد ما | غير مريح | غير مريح للغاية |
|---|---|---|---|---|---|---|
| | | | | | | |

**هل تود أن تكون**

| اكثر دفىء | متعادل | اكثر برودة |
|---|---|---|
| | | |

**كيف تقيم القبول العام لدرجة الحرارة في هذه اللحظة؟**

| غير مقبول | مقبول |
|---|---|
| | |

**ما هو شعورك حيال الإحساس الحراري في المبنى الخاص بك في هذه اللحظة؟**

| حار كثيرا | حار | دافي قليلاً | متعادل | بارد قليلاً | بارد | بارد كثيرا |
|---|---|---|---|---|---|---|
| | | | | | | |

**ما هو شعورك حيال حركة الهواء )التهوية (في المبنى الخاص بك في هذه اللحظة؟**

| كثير جدا | كثير | جد كثير | متعادل | جد قليلا | قليل | قليل جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**ما هو شعورك حيال الهواء )الرطوبة (في المبنى في هذه اللحظة؟**

| رطب جدا | رطب | رطب قليلا | متعادل | جافة قليلاً | جاف | جاف جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**ما هو شعورك حيال مستوى الإضاءة في النهار في هذه اللحظة؟**

| مشرق جدا | ساطع | ساطع قليلا | متعادل | قاتمة قليلا | قاتمة | قاتمة جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**ما هو شعورك حيال جودة الهواء في هذه اللحظة؟**

| جيد جدا | حسن جدا | حسن | متعادل | خانق قليلا | خانق | خانق جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**كيف تفضل درجة حرارة الهواء في هذه اللحظة؟**

| أكثر دفئا | أدفأ قليلا | متعادل | أبرد قليلاً | أكثر برودة |
|---|---|---|---|---|
| | | | | |

**مستوى نشاط الشاغل خلال آخر 15 دقيقة؟**

| قراءة | غسل | المشي | الوقوف | طبخ | مشاهدة التليفزيون |
|---|---|---|---|---|---|
| | | | | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ____________________

University of Kent

**يرجى تحديد نوع المشروبات التي تناولتها في آخر 30 دقيقة**

| المشروبات الباردة | مشروبات ساخنة | لا مشروبات |
|---|---|---|
| | | |

:إذا كان "غير ذلك "، يرجى تحديد ما يلي ______________________

**التفضيل الحراري**

**هل تستخدم أي شيء للحفاظ على راحتك في هذه اللحظة ، إذا كانت الإجابة بنعم ، فأين تستخدمه؟**

| الفضاء /التحكم | النوافذ المفتوحة | أبواب مفتوحة | مروحة كهربائية | تكييف | مروحه اليد |
|---|---|---|---|---|---|
| غرفة المعيشة | | | | | |
| غرفة نوم | | | | | |
| غرفة العشاء | | | | | |

**كم مرة تستخدم عناصر التحكم المذكورة في )21 (أعلاه في هذه اللحظة؟**

| قليل جدا | قليل | جد قليلا | متعادل | جد كثير | كثير | كثير جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**هل أنت راضٍ عن مستوى التحكم في هذه اللحظة؟**

| غير راضٍ جدا | غير راضٍ | غير راضٍ قليلاً | متعادل | راضٍ قليلاً | راضٍ | راضٍ جدا |
|---|---|---|---|---|---|---|
| | | | | | | |

**يرجى وضع دائرة حول الملابس التي ترتديها في الوقت الحالي ضع دائرة حول كل ما ينطبق**

**باستخدام الجدول أدناه ، يرجى تحديد عناصر الملابس التي سترتديها عادةً في الداخل .الرجاء اختيار مجموعة واحدة فقط تميز ملابسك الداخلية في الوقت المذكور من العام.**

| عنصر الملابس: | فصل الجاف | الموسم الممطر |
|---|---|---|
| شورت | 1 | 1 |
| القميص | 1 | 1 |
| لباس رياضي | 1 | 1 |
| بنطلون | 1 | 1 |
| جينز | 1 | 1 |
| قميص أو بلوزة بأكمام قصيرة | 1 | 1 |
| قميص أو بلوزة بأكمام طويلة | 1 | 1 |
| كنزة صوفية بأكمام قصيرة | 1 | 1 |
| فستان طويل | 1 | 1 |
| فستان بطول الركبة | 1 | 1 |
| تنورة | 1 | 1 |
| الجوارب رقيقة | 1 | 1 |
| الملابس الداخلية | 1 | 1 |
| ملابس اخرى | 1 | 1 |

**هل تشعر بتحسن في هذه اللحظة؟**

| لا | نعم |
|---|---|
| | |

**إذا كانت الإجابة لا ، )25 أ (هل هذا يجعلك تشعر بالحر أو البرودة؟**

| لا | نعم |
|---|---|
| | |

**كم عدد الأيام التي كنت تشعر فيها انك غير مرتاح؟ (ب 25)**

.يُرجى تقديم أي تعليق إضافي حول الراحة في هذا المبنى ، مثل درجة حرارة الهواء الداخلي ، والرطوبة ، ونضارة الهواء ، وما إلى ذلك