MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

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End of studies project

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Speciality : Energetique

Title :

Contribution to the simulation of optimisation skin roof to improve the thermal and energy performance of « mozabit » house : case of the Beni isguen house

Promoter :	**Directed by :**
Dr. LAAFER Abdelkader	HADJOUT Mohammed TSOURI BEN TSOURI Farid

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APPRECIATION

First of all, we thank Allah for giving us the health and the ability to complete our research and our project from beginning to the end.

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Abstract

In order to reduce indoor temperature and energy consumption in traditional house located in the Ksar of Beni isgeun in southern Algeria we try to find the optimal insulation using a traditional material as a solution which was simulated by Pleiades software, and as we know that the roofs in hot and arid climate are the surfaces most exposed to intense solar radiation, and they also play an important role in improving the thermal and energy performance of the house.

Keywords: beni isguen's ksar, Pleiades, roofs, hot and arid climate, thermal and energy performance.

Résumé

Afin de réduire la température intérieure et la consommation d'énergie dans une maison traditionnelle située dans le Ksar de Beni Isgeun dans le sud de l'Algérie, nous essayons de trouver l'isolation optimale en utilisant un matériau traditionnel comme solution qui a été simulée par le logiciel Pleiades. Comme nous le savons, les toits dans un climat chaud et aride sont les surfaces les plus exposées au rayonnement solaire intense, et ils jouent également un rôle important dans l'amélioration de la performance thermique et énergétique de la maison.

Mots clés : ksar de beni isgeun, pleiades, toits, climat chaud et aride, la performance thermique et énergétique.

الملخص

من أجل تقليل درجة الحرارة الداخلية واستهلاك الطاقة في المنزل التقليدي الواقع في قصر بني إيسجن في جنوب الجزائر ، نحاول إيجاد العزل الأمثل باستخدام مادة تقليدية كحل تمت محاكاته بواسطة برنامج بلياد وكما نعلم أن الأسطح في المناخ الحار والجاف هي الأسطح الأكثر تعرضًا للإشعاع الشمسي الشديد ، كما أنها تلعب دورًا مهمًا في تحسين الأداء الحراري والطاقة للمنزل

الكلمات الدالة: قصربني ايسجن، بلياد، الاسطح، المناخ الحار و الجاف، تحسين الأداء الحراري و الطاقة.

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General introduction

In traditional cities of hot and arid climate regions like Algerian Sahara , roofs are usually the surfaces most exposed to intense sunlight in summer. This leads to high temperatures inside the houses and forces the inhabitants to escape to the terraces at night. On the other hand, some residents use air conditioning and therefore increase energy consumption. for this reason we studied the importance of insulation in roofs and their effect on inside temperature, the temperature in summer on Algerian sahara average between 44 C and 45 C so we made this project to reduce the temperature until 27 C using insulation as a solution .

1-Problem:

The having a comfortable conditions of life inside building or houses is the objective of most of people especially in summer , in hot places in the world the temperature inside houses it's so high also the needs of air conditioning .

So : how can we reduce the temperature inside buildings without the needs of air conditioning ?

2-Hypotheses:

* Roofs are the surfaces most exposed to sunlight in summer.

*Insulation is the best solution to reduce the inside temperature.

*studying the effect of roof thickness using simulation by Pleiades software

This project contain 3 chapters:

The first chapter contain a definition of traditional architecture of mozabit houses and type of roofs

The second chapter case study and climatic conditions in the mozabit houses

The third chapter contain the simulation by Pleiades software and analysis the results also studying the effect of insulation thickness in roofs and extraction the optimal solution , in the end we have o general conclusion of the project .

Chapter I

STATE OF ARTS AND PASSIF HOUSES

Introduction

The processes of globalization and technological evolution have brought complexity and ambiguity to local identities, influencing man's relationship with nature. Today, in view of limited energy resources and the increasing greenhouse effect in cities, traditional architecture appears as an essential source to be rediscovered in order to find solutions to the current alarming situation in terms of climate, without depending on energy-intensive systems. Traditional architecture is a precious tangible and intangible cultural heritage, embodying knowledge of how to design in harmony with nature, in a healthy and sustainable way. Given that climatic conditions in hot and arid regions are very specific, alternative solutions are needed to reduce energy consumption during the summer season without compromising thermal comfort. Traditional architecture has provided numerous strategies and solutions that vary from place to place, culture to culture and climate to climate. The roof is the element that receives the most solar radiation, especially in summer in hot, arid climates. Protecting the roof is therefore essential to ensure indoor thermal comfort. Roofing also plays a key role in local identity. Traditional architecture reflects the characteristics of the climate, as does roof design. The development of construction methods and new building materials has led to the emergence of many different types of roof, with different shapes and components. Whether made of stone, earth, palm, wood, concrete or other materials, the roof remains an important component of our buildings. The thermal performance of the roof can have a considerable influence on the energy consumption of buildings and the desire to minimize indoor temperatures. With this in mind, the following chapter looks in depth at traditional architecture and architectural practices, the importance of roofing in buildings, its functions, and the different types of conventional (standardized) and non-conventional (traditional) roofing in hot, arid regions around the world and in Algeria, especially in the M'Zab valley: the Ksar of Béni Isguen. This chapter also looks at the thermal performance of roofing, and its role in guaranteeing the thermal comfort of buildings[1].

I.1. Traditional architecture:

Traditional architecture, as it is known in various parts of the world, has many useful lessons to teach today's mankind in order to find appropriate solutions to the current situation. According to Professor Luca Finocchiaro, traditional and vernacular architecture represent the result of an evolutionary process in which the construction of buildings has been continually refined with the aim of adapting to the local climate and providing optimal living conditions for human habitation according to the resources available locally [2].

I.1.1. Presentation and definition of traditional architecture

Vernacular architecture is a type of architecture specific to a country, a territory and its inhabitants. It's an architecture in which people build their own homes using the materials available to them, while protecting themselves from the environment, climate and other factors. [3]

I.1.2. Factors influencing traditional architecture

Amos Rapoprt demonstrates in his book 'house, form and culture' that of all the factors influencing the form of the house, socio-cultural aspects outweigh other physical constraints such as climate, materials, site, etc. For this author, the house is unquestionably a cultural phenomenon, its form influenced by the cultural milieu to which it belongs. For this author, the house is unquestionably a cultural phenomenon, its form influenced by the cultural environment to which it belongs [4].

Some of the main factors affecting traditional architecture are shown in figure I.1.

Figure I.1: factors affecting traditional architecture [1]

I.1.3.The characteristics and identity of traditional architecture

Traditional architecture is low-cost solutions applied by local people working to better adapt to the demands imposed by the local environment. The construction of traditional buildings is not done by architects, but locals build their homes because they know exactly what they want based on their experience and experience gained from them. Ancestral, gives a natural beauty and dedicates a particular identity to this type of architecture that differs from others. [2]

I.1.4. Historical overview of traditional architecture

Overviews of traditional and vernacular architecture in Algeria in the pre-French colonial period (the aim is to take stock of the situation at the time before the changes brought about by colonization). This component includes a necessary allusion to the spatial context characterizing the territory directly linked to the training location, without being exclusively referential to it. For example, courses will preferably develop, depending on the location [5]:

1- Urban/medieval context: Casbah of Algiers / Old Town of Constantine / Derb and Arab town of Mostaganem / Spanish medieval urbanism in Oran / Medina of Tlemcen, Bejaia, etc. / Punic and Berber old towns / Military architecture in Adrar, Annaba, Bechar, etc. / dechras and fortified villages in Kabylie and Aurès / Mzab, Saoura Gourara and Souf ksour / The list is not exhaustive.

2- Spatial organization and culture (geography/environment)

3- Materials / construction techniques

4- Built landscapes.

I.2. Use of passive ventilation (cooling) systems

I.2.1. Wind towers

The wind tower is a natural ventilation device developed in the traditional architecture of Iran and certain Arab countries. Typically, it is built on the north side of the building to capture fresh air and channel it into the interior [6]. Higher wind towers can capture cooler, cleaner winds because they are more efficient than lower towers [7]. Slower wind speeds due to wind resistance generated by land masses and masonry, as lower wind towers are less efficient [8]. The wind tower is an effective strategy for passive cooling in warm-climate regions, particularly when coupled with the courtyard, as this combined arrangement can significantly increase its efficiency [9].

Figure I.2: wind towers in Yazd

Figure I.3: the wind sensor in Dolat Abad's garden, Yazd, Iran [10]

I.2.1.1.The operating principle

The wind tower uses variations in air density in and around it to operate [11]. This generates an upward or downward flow of air through the tower, depending on the season and weather conditions (day/night). Here's a summary of how it works:

During the day:

During the summer daytime, when there is no wind, the wind tower operates like an inverted chimney [12]. During the early hours of the day, the upper part of the tower remains cool after being cooled overnight, causing the air layers along the walls to cool. This creates natural convection, where the temperature difference pushes cool air downwards and into the interior rooms of the house [13]. When the temperature of the tower reaches that of the ambient air, it then functions like a conventional fireplace.

At night:

During the summer, at night, when the wind is present, the wind tower acts as a wind sensor. It captures the prevailing fresh wind through its top opening. As the wind passes over the top of the collector, the pressure difference between the base and the top of the tower helps to push warm air up towards the top and cool air down towards the base of the tower [10]. Typically, the wind tower is combined with another cooling device to further increase the cooling of the air flowing down through the tower (Figure I.4). This may include a water basin beneath the tower, as hot air in contact with water causes evaporation [8].

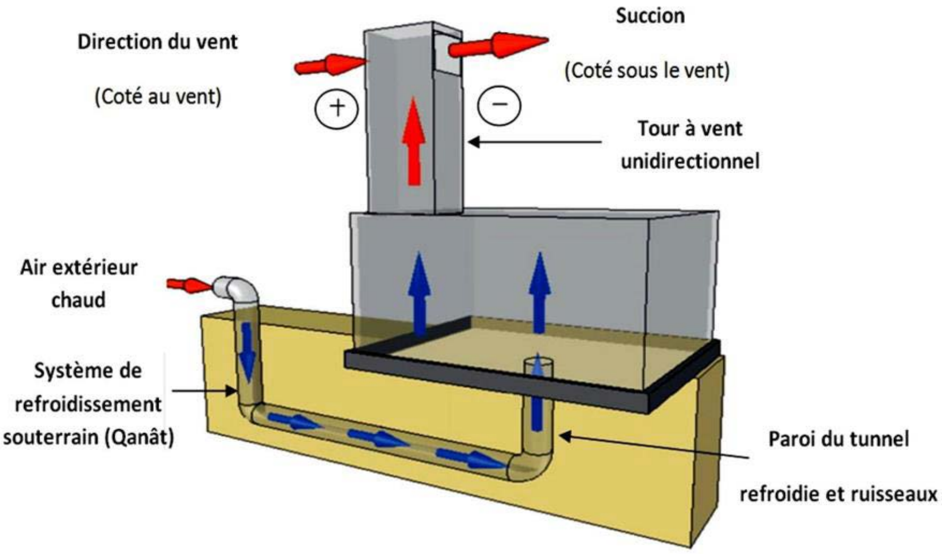


Figure I.4: Integrated wind tower with underground cooling [14].

I.3.The roofs

Roofing plays a major role in the thermal comfort of buildings. In hot, arid climates, the roof is the surface that receives the most solar radiation. Part of the heat gain comes from outside conditions in summer and part from heat loss in winter, making rooms on the upper floors of houses more uncomfortable than rooms on other floors. To ensure thermal comfort, the thermal properties of the roof must be improved. Several techniques have been developed to solve these problems: flat roofs (Figure I.5.a), vaults, domes, etc. (Figure I.5.b). This is the main focus of our work. In the following sections, we'll take a closer look at roofs and their effects on indoor thermal comfort [1].

Figure I.5: (b) Vaulted roof with cross windows in the city of Yazd [15].

Figure I.5: (a) Terrace houses in the town of Shibam [16]

I.3.1. Definition and description

The roof is the structure that covers the upper part of a building, ensuring its protection against external elements such as weather, climatic variations and atmospheric conditions. It is often referred to as a building's fifth façade, due to its aesthetic and functional importance [1]. It helps maintain a comfortable indoor temperature and reduce energy losses. The roof contributes to the overall appearance of the building. It can be made from a variety of materials such as tile, metal, wood or composites, offering a wide range of styles and finishes. In short, roofing plays a crucial role in a building's protection, insulation and aesthetic appearance. It’s essential properties include weather resistance, waterproofing, durability, thermal and acoustic insulation, and harmony with the building's overall architectural style.

I.3.2. Roofing functions: Why have a roof?

The roof is a layer between the earth and the sky, and has several distinct functions from a thermal, physical, environmental and psychological point of view, ensuring its importance in the building [1].

I.3.2.1. Physical function

Essentially, the roof acts as a shelter, protecting the inhabitants from climatic stresses such as storms, rain, wind and solar radiation. Its main purpose is to preserve the building's interior, creating a healthy environment and contributing to the structure's durability. The roof is also exposed to the sun's rays, requiring protection against the harmful effects of radiation. Structural stability, mechanical strength and thermal resistance are essential factors in ensuring the protection of the building's interior and the safety of its occupants [1].

I.3.2.2. Thermal function

Effective roof design has a direct impact on energy efficiency and indoor thermal comfort. The main thermal function of the roof is to attenuate external thermal stress on the surface, thereby reducing heat transmission to the interior. The roof's thermal characteristics are determined by the combination of the mass and thermal conductivity of the materials, the location of the insulation, and the texture and color of the exterior surface [17]. The impact of heat, energy efficiency helps to regulate the internal temperatures of non-air-conditioned buildings, minimizing the need for cooling in summer and heating in winter. This promotes energy conservation and maintains an optimal level of thermal comfort. The roof acts as a canopy, protecting and shading the building in the case of a dome or basement, gaining living space and height through its thermal role in protecting the sun and enhancing interior living spaces [1].

I.3.2.3. Environmental function

Green roofs, cool roofs, vaults, domes and evaporative roof cooling systems are examples of energy-efficient roofs that can provide thermal comfort and energy savings, depending on the type of architectural and urban [18], so improving the thermal performance of these roofs can help control greenhouse gas emissions and reduce harmful carbon emissions [1].

I.3.2.4. Psychological function

The roof has two main functions: to protect and to influence the residents' psychological state. It delimits space and houses the owner's intimate functions. Symbolizing the owner's thoughts, traditions and aspirations, it provides a sense of security by protecting the living space and the head from external threats. The roof plays the role of a helmet that protects the head and promotes a relaxed psyche [19]. Its shape, components and color have an impact on the emotional state of the inhabitants and reflect their way of building. For example, the color white creates a sense of joy, contentment and rest, positively influencing the homeowner's psychology. Similarly, a green roof offers psychological benefits such as aesthetic pleasure, [20]. improved concentration and a feeling of vitality [21]. Living on or observing a green roof also promotes good attention control [22]. The diagram in Figure I.6 summarizes the functions of the roof.

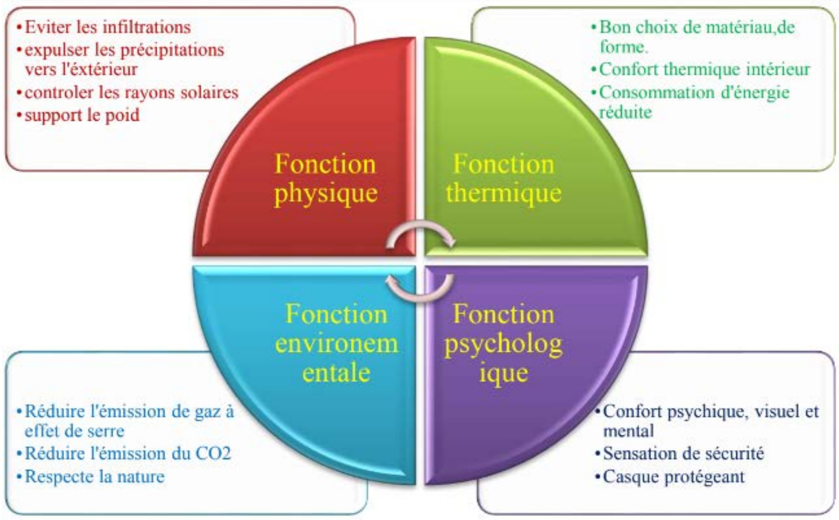


Figure I.6: Diagram summarizing the functions of a roof [1].

I.3.3 Types of roofing

Roofing can take many forms, with different shapes and components, and can be made of a variety of materials with different degrees of complexity. There are many types of roofing, differing from region to region and climate to climate. Several classifications can be studied, of which two main families can be distinguished:

conventional (standardized) and non-conventional (traditional). Classification is based on climate, shape, building materials, etc [1].

I.3.3.1. Conventional roofs

There are four main types of roof: pitched (the most common), flat, rounded and Green roof. Each type of roof can be covered with different roofing materials: tile, slate, concrete, wood or metal. The maintenance and treatment of your roof will vary according to these different characteristics. Focus on the different roof shapes with Heritage preservation [23].

I.3.3.1.A. Flat roofs

The flat roof is a more recent, and therefore more modern, type of roof. They are found mainly on new buildings, or on buildings that have undergone renovation, including the addition of an annex.

The most important aspect of a flat roof is the insulation structure you opt for. You can choose between a cold, warm, inverted or combined flat roof. In all cases, the difference between these types of insulation is the way in which you arrange the roof elements. Do you opt for insulation from the outside, or not from the inside? Will you install the insulation before the waterproofing membrane, or before the vapour barrier?

Similarly, it's essential to have an efficient drainage system. You'll need to ensure that your roof has a gentle slope of between 1% and 5%.

Finally, you can choose from a range of roofing materials: bitumen, EDPM, PVC, and so on. If this material does not contain plastic, you'll be able to collect rainwater from your roof and turn it into an ecological system. This water can then be used to water your plants, for example. Flat roofs can be accessible (Figure I.7) or inaccessible (Figure I.8). In the case of an accessible flat roof, it is transformed into a terrace as a living space. The roof terrace can be landscaped as a green roof. There are three types of flat roof [24].

Figure I.7: Flat roof: accessible flat roof [25]

Figure I.8: Flat roof: non-accessible flat roof [25]

I.3.3.1.B Hot roof

A warm roof is a flat roof where the insulation is placed on top of the substrate, with no air space between the layers.

The insulation is covered by the waterproofing membrane, which protects it. It therefore remains dry and retains all its thermal characteristics.

In most cases, a vapour-barrier membrane must be inserted between the substrate and the insulation (in the case of renovation, this may be the old waterproofing membrane that is retained) (Figure I.9).

Ballasting is not necessary. Insulation and membrane can be attached mechanically or by adhesive bonding. In the latter case, it's relatively light, and can be applied to existing structures that won't withstand an increase in load.

There are two types of warm roof: compact roof and inverted roof [26].

Compact roof

In a compact roof, the cellular glass insulation is bonded directly to the substrate in a hot bitumen bath. The joints between the sheets are filled with bitumen. The waterproofing is then fully adhered to the insulation, either with a flame or hot bitumen. (Figure I.10).

This roof forms a watertight unit, free of any layer that could carry air or water. In the event of local defects, water cannot infiltrate. Damage is limited.

A vapour barrier can generally be dispensed with, since the insulation and the joints between sheets are vapour-tight [26].

The inverted roof

An inverted warm roof is a flat roof where the waterproofing is placed on the substrate and the insulation is laid on top of the waterproofing. As a result, the insulation is wetted by rainwater, reducing its performance. The insulation is ballasted (Figure I.11) [27]. L’isolant protège l’étanchéité des rayons excessifs [28].

1. Roof support
2. Slope shape
3. Vapor barrier
4. Thermal insulation
5. Waterproofing membrane
6. Ballast if required

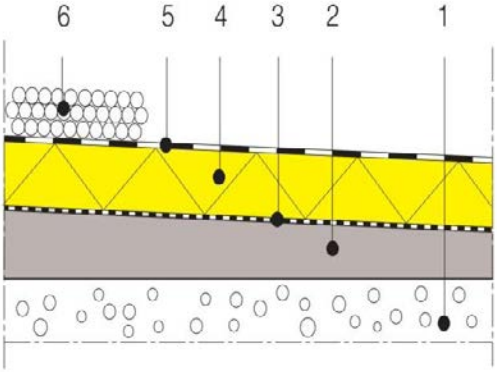


Figure I.9: Warm roof: (a) Diagram of a warm roof [29],

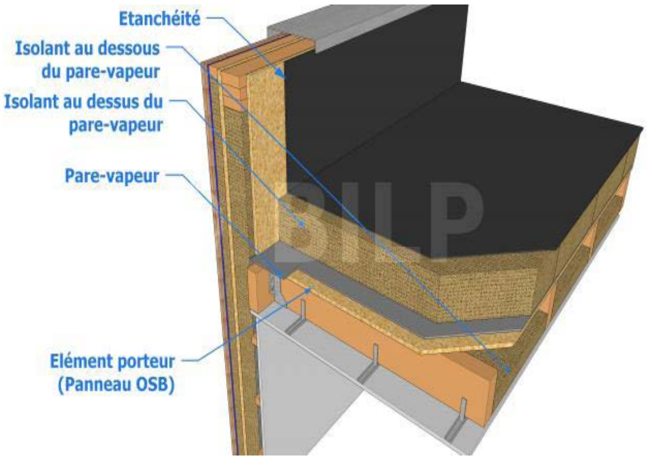


Figure I.9: (b) Warm roof: section on a warm roof [30]

1. Roof support

2: bituminous waterproofing

3: bitumen

4: cellular glass

5: support

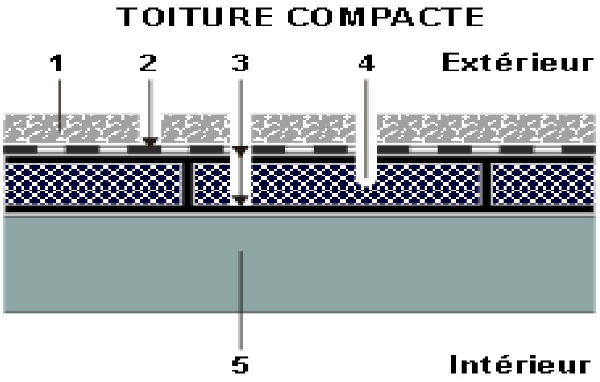


Figure I.10: diagram of a compact roof [31]

1: ballasting

2. Slope shape

3. Waterproofing membrane

4. Thermal insulation

5. Uncoupling layer, if any

6. Ballast

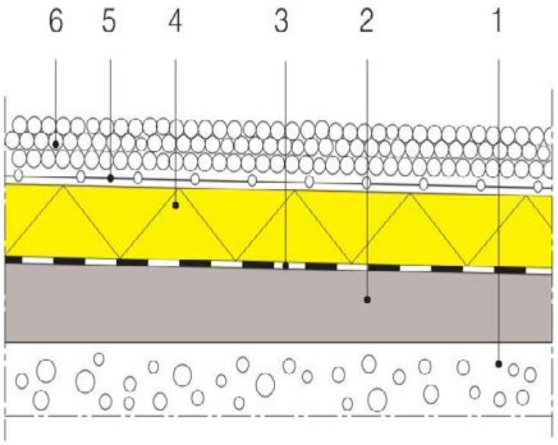


Figure I.11: diagram of an inverted roof [29]

I.3.3.1.C. Cool roof

A cold roof is a flat roof where the insulation is placed below the waterproofing support, with a ventilated air space in between. Once regularly used, this system is now completely outdated and should be avoided (Figure I.12). Insulating a flat roof with this system almost inevitably leads to internal condensation. Water vapour migrating from inside to outside condenses on the waterproofing substrate, in the insulation or in the ventilated space, and falls back onto the insulation. The actual ventilation of the air space is often less than that required. The sealing substrate is sometimes much cooler than the outside ventilation air, whose vapour condenses on the underside of the sealing (supercooling). When the ceiling is not airtight, warm indoor air is drawn into the ventilated space, where it condenses, especially if there are strong draughts [32]. This condensation can lead to the deterioration of insulation and the elimination of its effectiveness, rotting floors, freezing materials, delaminating or softening bonded materials, mold growth, etc [28].

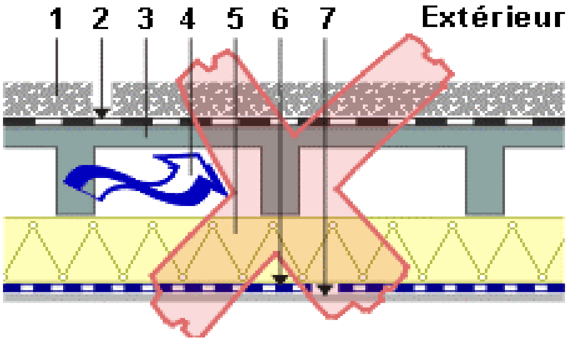


Figure I.12 (a): diagram of a cold roof [33]

1: ballast (if any)
2: waterproofing membrane
3: support
4: ventilated air space
5: insulation
6: airtight vapour barrier
7: ceiling

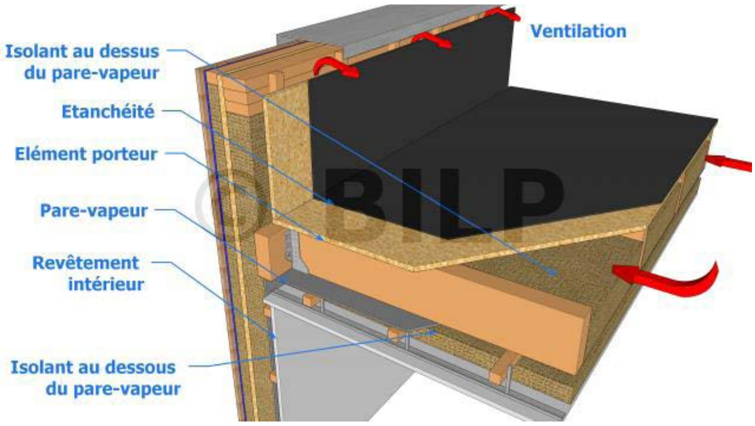


Figure I.12 (b): cross-section of a cold roof [30]

I.3.3.1.D. Combined roof ("DUO" roof)

Combination roofing is a combination of "warm roof" and "inverted roof" techniques. The insulation is installed in two layers. The first layer of insulation is covered by the waterproofing membrane. The second layer of insulation is placed on top of the waterproofing membrane [28] (Figure I.13). This combined roofing technique protects the waterproofing membrane from thermal shock and ultraviolet radiation, thereby slowing down its ageing process. A vapour barrier is sometimes inserted between the substrate and the lower insulation layer, but is not necessary when the thermal resistance of the upper layer is twice as high as that of the lower layer. Ballasting is necessary. Figure II.13 (a) shows a diagram of a DUO or combined roof, (b) the bonding of the insulation with the installation of the waterproofing membrane and (c) gravel ballast in the inverted or combined roofing technique respectively [34].

1. Support and slope
2. Vapour barrier
3. Insulation
4. Waterproofing
5. Protective layer and/or ballast
6. Protection

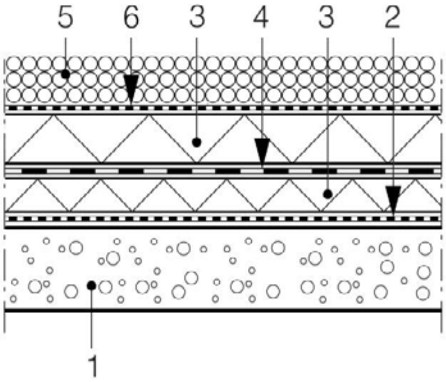


Figure I.13: (a) diagram of a combined or DUO roof [35]

Figure I.13: (b) bonding the insulation & installing the waterproofing membrane

Figure I.13: (c) Gravel ballast in the inverted or combined roofing technique [29]

I.3.3.1.E. Pitched or sloping roof

Pitched roofs are the most common type of roof in wet to cold climates. They are available in 1, 2 or 4 pitches, the most classic being the inverted-V pitch (Figure I.14).

Pitched roofs have several advantages. Their slope, more or less steep depending on the region or weather conditions, makes it easier to evacuate rain or snow. The slope also depends on the material used. Thatch, for example, requires a minimum slope of 40%, while the slope must be at least 15 degrees. It's also one of the least expensive solutions on the market!

Finally, pitched roofs are certainly the oldest roofs, beating all records for durability and offering the possibility of converting attics to gain extra space. For this reason, flat roofs are not recommended in humid regions [24].

Figure I.14: (a) Sloped roof: Danish family home with a sloped slate roof [36]

Figure I.14: (b) sloping roof of Minka house in Japan [37]

I.3.3.1.F. Curved roof

Round roofs are becoming increasingly popular with homeowners, because they give your home a very modern look and come in many different designs. This means there's something to suit every taste.

secondly, the thermal performance of a rounded roof is better than that of a flat roof. In fact, since the roof surface area is smaller with a rounded roof than with a sloped roof, and the living area is similar, you can save energy [24]. In general, rounded roofs are more commonly used in public buildings than in homes. Their construction presents challenges and requires substantial budgets due to their complexity. Thanks to advances in building materials, different types of curved and rounded roofs have emerged, such as bulbous domes, pan domes and turrets [38]. These roofs can be made of glued laminated wood, metal, concrete fleece, tiles, zinc or sheet metal.

To ensure thermal comfort and prevent energy loss, it is advisable to insulate rounded roofs. Adequate natural ventilation must also be ensured by installing small openings at the top and bottom of the ceiling, allowing fresh air to circulate to prevent dampness and mould formation. Popular with ecologists, this type of roofing makes it easy to recover rainwater through the installation of gutters and downpipes (Figure I.15) [1].

Figure I.15: Architectural projects with curved roofs

I.3.3.1.G. Green roof

Green roofing is an interesting alternative for your roof. It involves growing plants, trees, spices, herbs, etc. on the roof of your home.

There are two types of roof: intensive and extensive. On intensive roofs, you'll be able to plant trees and shrubs.

However, your home's foundations must be able to support a minimum load of 200kg. For extensive roofs, however, you won't need to check the solidity of your house's structure, as the plantings are lighter.

A green roof offers several advantages in terms of thermal comfort. Green roofs have been used in different regions of the world with varying climatic conditions (Figure I.16). However, their cooling and heating efficiency depends on the type of climate [39]. In addition, much recent research has demonstrated that green spaces have a positive impact on the well-being of city dwellers, reducing stress and promoting productivity [40].

Adopting a green roof helps to absorb carbon dioxide, release oxygen and insulate buildings. It helps combat the effects of climate change, reduce pollution and increase biodiversity in urban environments [41].

Figure I.16. (a) shows a traditional sloping green roof with native vegetation in Norway, Figure I.16. (b) and c illustrate a flat and a rounded green roof and Figure I.16. (c) flat green roofs and rounded green roofs respectively.

Figure I.16: Buildings with green roofs: (a) Traditional sloping green roof with vegetation in Norway [42]

Figure I.16: Buildings with green roofs: (b) flat green roofs and rounded green roofs respectively [43]

Figure I.16: Buildings with green roofs: (c) flat green roofs and rounded green roofs [43]

In terms of heat transfer and the functioning of a green roof, several heat exchange phenomena occur. Solar radiation is balanced by sensible and latent heat flux, resulting from convection and evaporation from soil and plant surfaces, as well as heat conduction in the substrate [44]. The main phenomena that occur in green roofs are as follows:

- The soil acts as a mass with high thermal capacity and low thermal transmittance.
- The plant layer and soil contribute to cooling through evapotranspiration.
- Foliage acts as a shading element, promoting convective heat exchange. In addition, foliage absorbs part of the sun's radiation for photosynthesis [39].

The green roof's plant layer facilitates photosynthesis processes, while the soil layer enables the absorption of precipitation, thus improving the quality of runoff water [45]. Numerous studies have indicated that green roofs are able to reflect between 20% and 30% of solar radiation, absorbing up to 60% of it through photosynthesis. As a result, less than 20% of the heat is transmitted to the substrate [39]. Figure I.17 illustrates the operating principle (a), the energy balance of green roofs (b), and a schematic structure of the cooling mechanism of an extensive and an intensive green roof during the day (c) respectively.

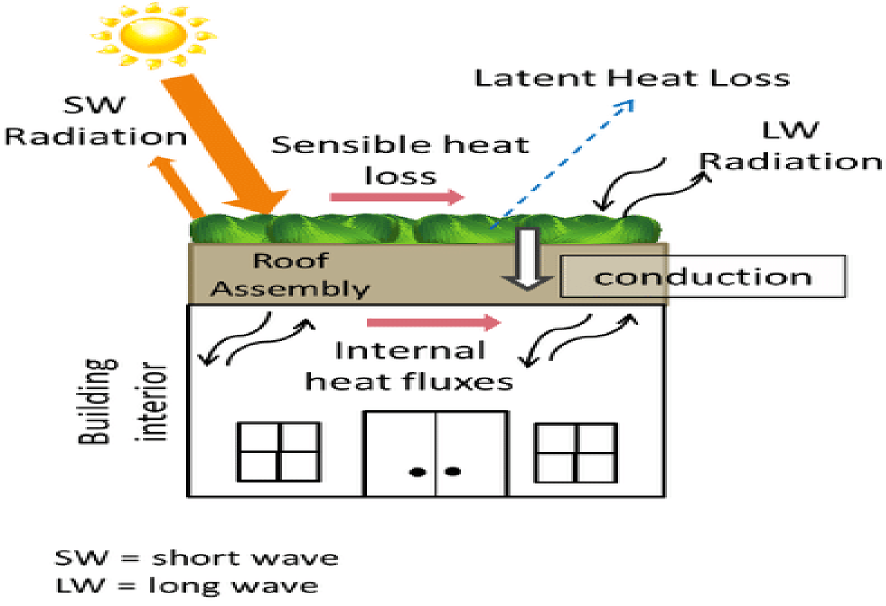


Figure I.17: (a) Schematic green roof energy balance [46]

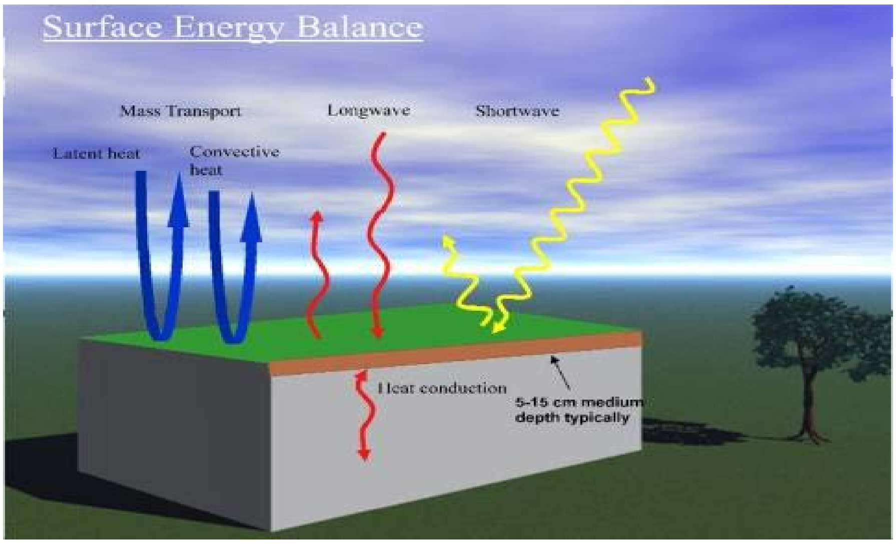


Figure I.17: (b) The figure conceptually illustrates a simplified surface energy balance for a generic green roof system [47]

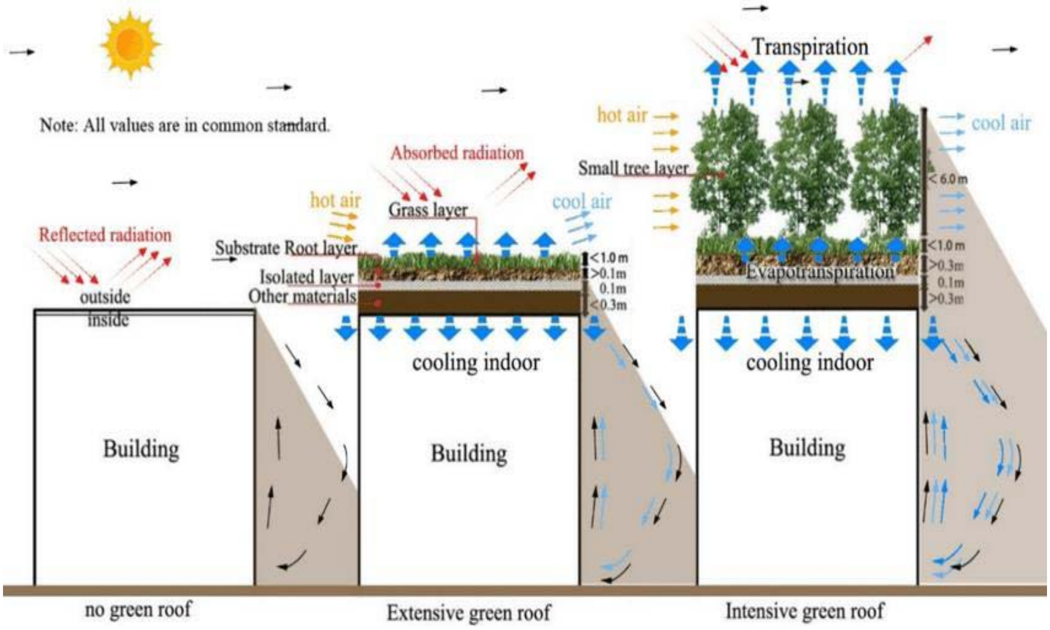


Figure I.17: (c) A schematic structure of an extensive green roof and an intensive green roof, and the cooling mechanism during the day [48]

I.3.3.2. Traditional (non-conventional) roofs

In traditional communities, the architectural image of the dwelling is generally expressed through the shape of the roof, which is the most regular element of a building. In cities, the uniformity of roofs is appreciated through aerial views [8], unlike facades, which can include several elements (windows, doors, ornamentation, etc.). In traditional cities, the design of roofs expresses the city's heterogeneity from a bird's-eye view. This gives a glimpse of a mosaic view in which the uniformity and similarity of roofs [19], are clearly apparent. In the past builders adopted several roof forms depending on the local climate and the availability of building materials such as domes and vaults. In this section, we'll look at a few types and examples of traditional roofs.

I.3.3.2.A Traditional flat roofs

Traditional flat roofs are widely adopted in older towns in hot and arid climates [49]. In hot and arid climates, they are often used on summer nights to sleep outdoors. Also, they can be used as a space for drying laundry, cereals, dates, fruit or other household functions while ensuring privacy from neighbors' glances through high walls [19]. In addition, the temperature variations between day and night in hot, arid climates are relaxed with a high thermal mass roof. These flat roofs are thickly built from local materials available on site, namely: stone, earth, mud and lime. The high thermal mass of flat roofs increases the thermal inertia of the house and protects the interior from the intense solar rays of hot summers when they are characterized by the ability to store heat during the day and release it at night [50]. There are many examples of flat roof terraces in hot regions: the roof terraces of Ghadames in Libya (Figure I.18.a), where women carry out their daily chores [51], Ksour in Morocco and Mauritania (Figure I.18.b. c), Sanaa in Yemen, etc. (Figure I.18.d).

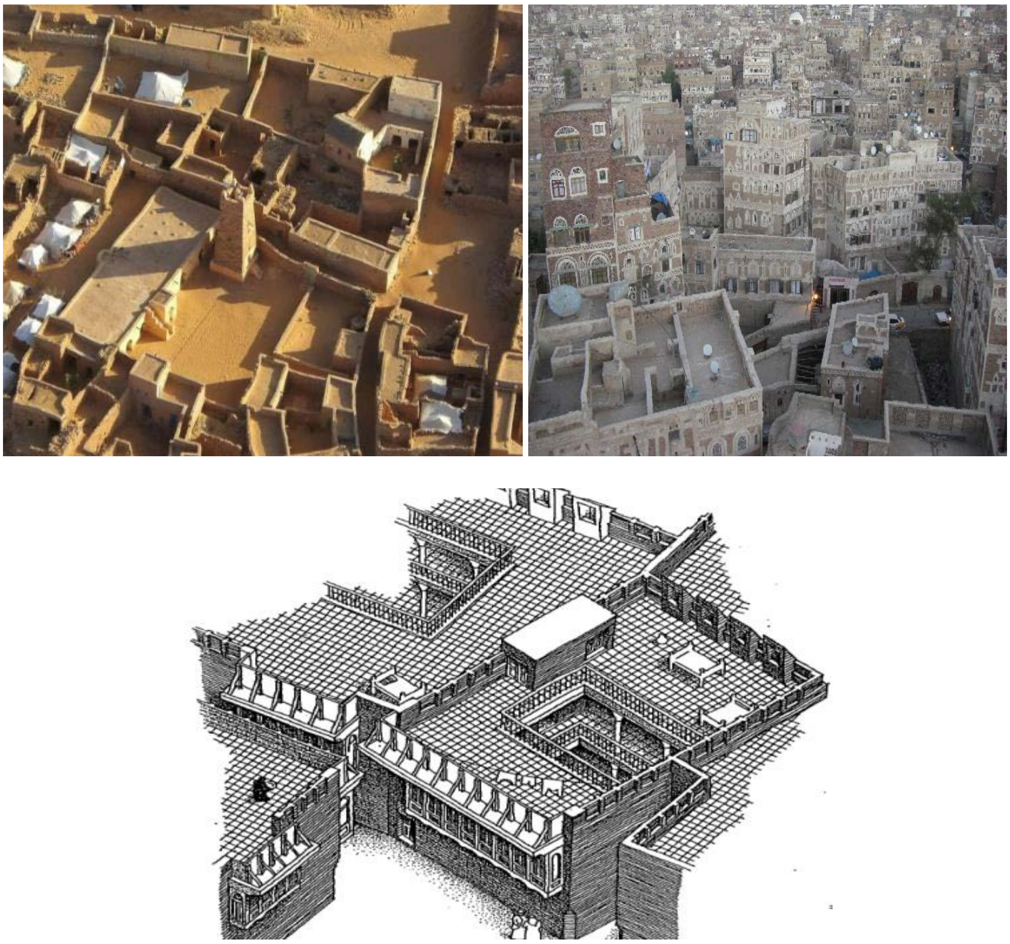


Figure I.18: View of traditional flat roofs: (a) flat roofs in the city of Ghadamès [51]; (b) Ksar Rgabi N'Ayt Hassou in Morocco [52]; (c) Aerial view of Ksar de Chinguetti and Ksar de Oualata in Mauritania respectively [53]; (d) Aerial view of the roofs of the city of Sanaa in Yemen [43]; (e) Flat roofs in Baghdad [49]

I.3.3.2.B. Domes and vaults

Curved or round roofs are not a recent innovation. In fact, many centuries ago, this configuration was already being used in the form of vaults and domes. In regions with hot, arid climates, low rainfall and a shortage of wood led to the use of adobe and mud to create arched, domed or vaulted roofs [54]

Presentation and definition

Domes and vaults have been widely used in traditional cities in hot, arid regions [55]. They are particularly common in El-oued, Algeria (the city of 1,000 domes) (Figure I.19). They can be used in residential buildings or other types of building, in cities or outside [56].

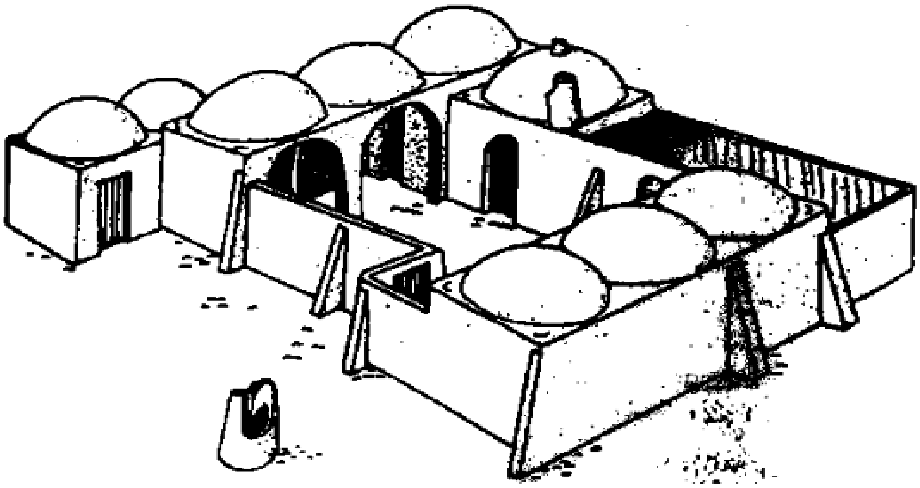


Figure I.19: Traditional towns with domed and vaulted roofs: Souf house [58]

The domed roof shape is constantly exposed to wind-driven airflow, which helps to reduce heat from intense solar radiation [57] and also cools the roof more quickly at night (Figure I.20.a and b). In the case of a domed or cylindrical roof, the projection of solar rays is not the same on all sides, so part 3 receives less heat than part 1 (Figure I.20.c). This reduces the temperature under the roof [9].

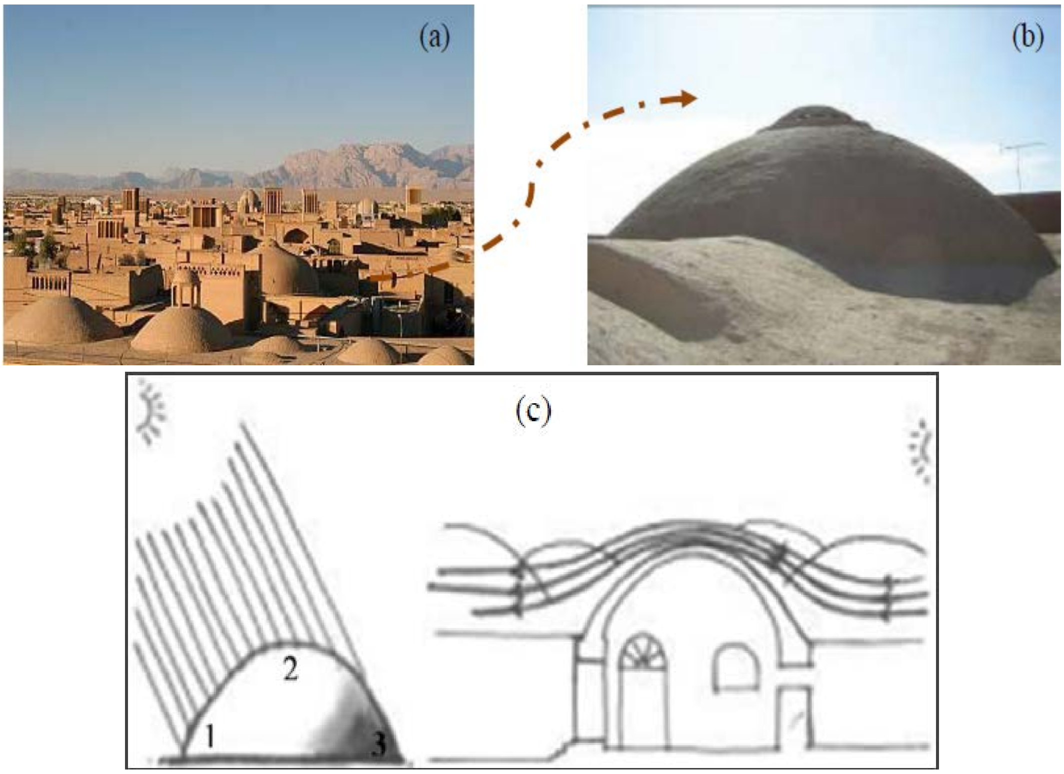


Figure I.20: Traditional roofs in Iran: (a) General view of roofs in Yazd, Iran, (b) Traditional building roof in Yazd, (c) Diagram of roof function [9]; [54]

Operating principle

During the day in summer, when the top of the dome is hot, the indoor air in contact with the dome's surfaces heats up [55]. The hot air is exhausted to the outside through the dome's window(s) [59] (i.e., air circulation takes place thanks to the pressure differentiation between the bottom and the top), (Figure I.21.a). During the night, the heat stored by the dome during the overheating hours of the day is exchanged by convection with the air and by radiation with the sky [55]. When the dome window is closed, the air inside moves towards the center and cools on contact with the dome. As a result, the air becomes denser and descends towards the side of the dome (Figure I.21.b). On mild, windless nights, when the windows are open, the inside air is warmer, while the colder outside air will enter the building through the top of the dome and descend, creating high pressure and leading to the evacuation of the warmer inside air through the building's openings [59], (Figure I.21.c).

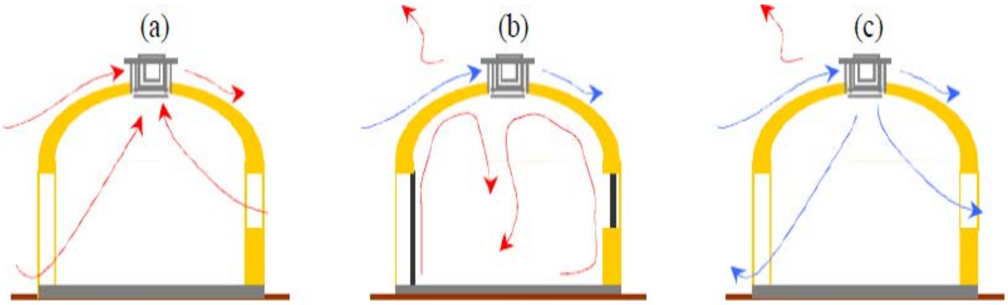


Figure I.21: The different cases of dome operation: (a) daytime: doors and windows open; (b) nighttime: all openings closed; (c) nighttime: doors and windows open [60].

In addition, water sources (fountains or pools) are sometimes placed indoors under the dome, to cool the indoor air circulating in the room. dome, to cool the indoor air circulating in the room [61] (Figure I.22).

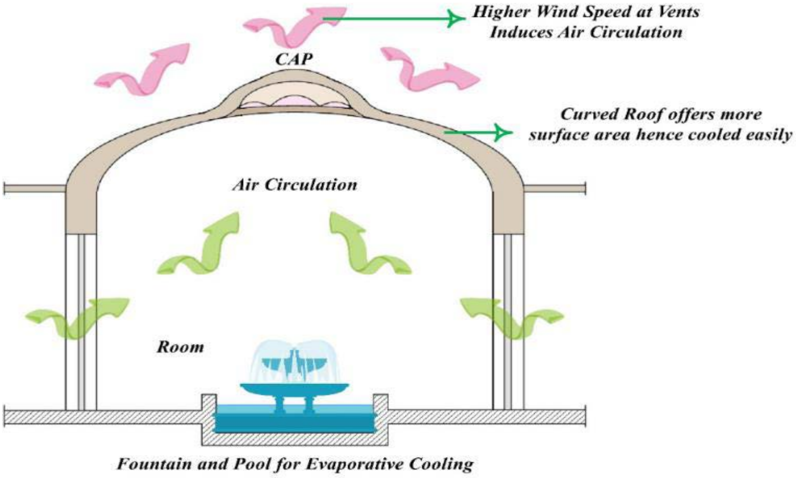


Figure I.22: Performance of domed roofs [62]: cross-section on a curved room with vent above the fountain to promote ventilation and cooling, with air circulation inside and above.

I.3.3.2.C.The Nubian vault

Nubian vaulting is an ancient architectural process, with a curved surface forming a vaulted structure. It originated in the Upper Nile, offering a technique built from local materials such as sun-dried raw earth ([63]. This construction technique does not require the use of wood, and enables local, precarious workers to be trained in a trade with a future. The Nubian vault technique was revived by Egyptian architect Hassan Fathy with the emergence and construction of the village of Gourna, near Luxor in the 1940s [64] (Figure I.23). He used vaulted roofs to repel solar radiation and ensure optimum comfort, especially as the village is located in a hot, arid climate where it is hot during the day and cold at night [65].

Figure I.23: Gourna village vault: view of the village vaults [65]

Advantages of Nubian vaulting

The Nubian vault offers a number of advantages: use of local materials, adaptation to the climate, simpler construction method, lower and more cost-effective construction costs, thermal comfort, long service life [66].

The formwork-less technique largely saves the use of wood [67], especially in warmer regions and even in deforested Sahelian regions of Africa.

It is advocated by ecologists as environmentally friendly when it uses pure earth in its structure without the need for wood.

I.4. Traditional building roofs in the M'Zab valley

The Ksour of the M'Zab valley boast many different types of roofs. Flat roofs, sloping floors, domes and vaults are just some of the types of roofs found in the Mozabite Ksour, particularly in the Ksar of Béni Isguen.

I.4.1. Flat flat roofs

Terrace roofing is the most common type of roofing used in Mozabite Ksour dwellings. Traditional terrace roofs are generally made from a mixture of clay and straw, stone or lime and local plaster, and vary in thickness from 20 to 40 cm. These thick roofs ensure high thermal inertia of the building during the day, increasing the house's insulation during periods of overheating.

Terraces in Mozabite houses are built next to each other, offering passage from one space to another without passing through the street (Figure I.24).

The ceiling is made either of flat stones, or of vaults formed by stones bonded with Timchemt (local plaster) between the joists, or by a tight lath of palm ribs [68]. This base is then covered with a layer of rammed earth, up to 30 cm thick on terraces exposed to the sun's aggressive rays.

NB: Timchemt is a traditional white plaster made from natural gypsum by the valley's ancient inhabitants.

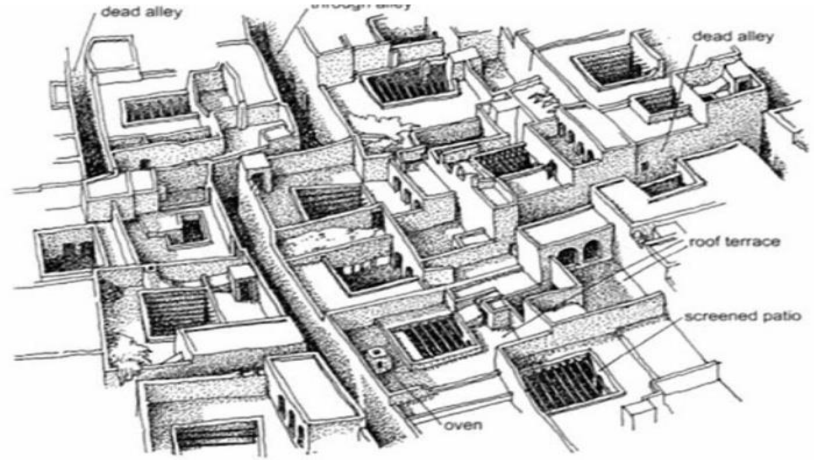


Figure I.24: The shape of roofs in the M'Zab valley, Algeria (Framework): schematic view of the roof-terrace shape of the Ksar [69].

Next, figure II.25 shows a cross-section of a traditional Mozabite house showing the various floors.

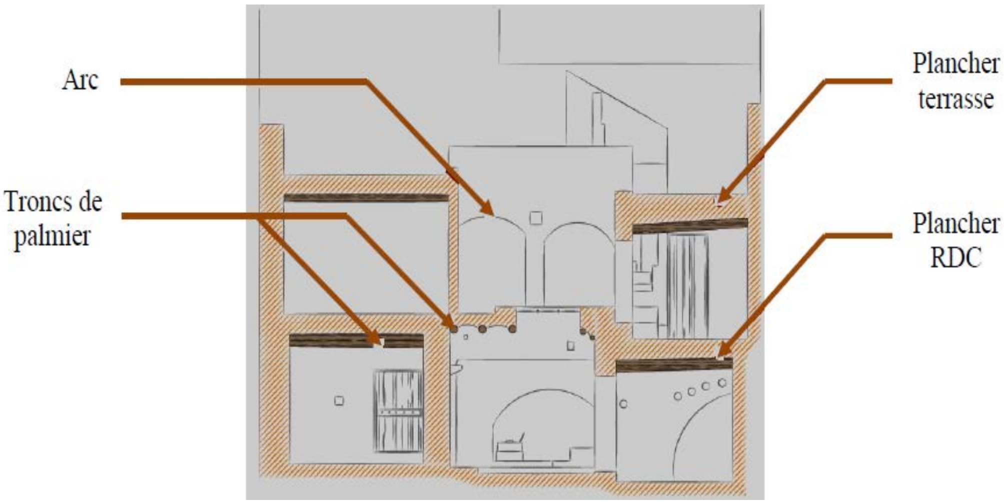


Figure I.25: Cross-section of a traditional Mozabite house showing the various floors [70]

I.4.1.1 Flat roofs made of palm trunks and branches

This type of floor was the most widely used in M'Zab until the early 20th century, given the availability of building materials such as palm trunks and branches, clay, lime and timchemt, and made it possible to create wider, larger spaces (Figure I.26) [70]. Figure I.27 shows photos of floors made from palm trunks and branches, including (a) a floor in a passageway in Ksar Al-Atteuf; (b) floors in a passageway in Ksar de Béni Isguen.

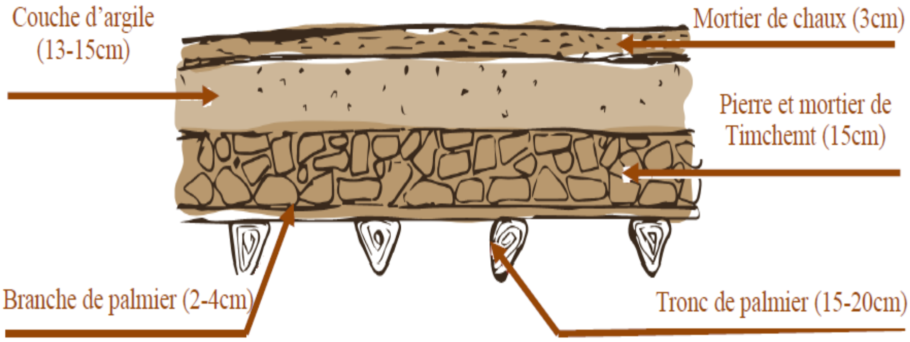


Figure I.26: Cross-section of a roof made of palm trunks and branches (case study) [70]

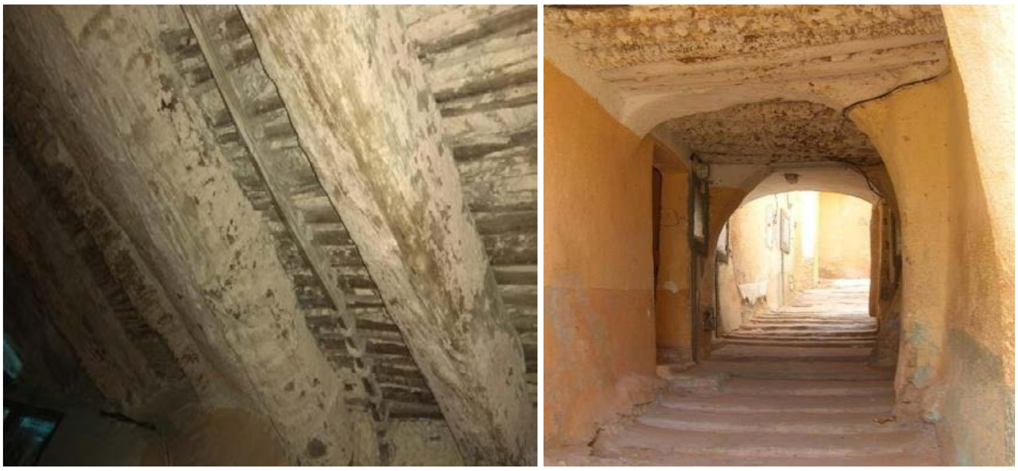


Figure I.27: Photos of a floor made of palm trunks and branches in a covered passageway of the Ksar: (a) floor in a passageway of the Ksar Al-Atteuf; (b) floor in a passageway of the Ksar of Béni Isguen [1]

A waterproofing layer of lime mortar is applied on the outside to protect the various layers. The thickness of each layer depends on whether the floor is on the first floor or the terrace (Figure I.26). In some cases, there is just a large layer of clay placed directly on the palm trunks and branches (Figure I.28). Figure I.29 shows a photograph of the different layers of palm and clay roofs.

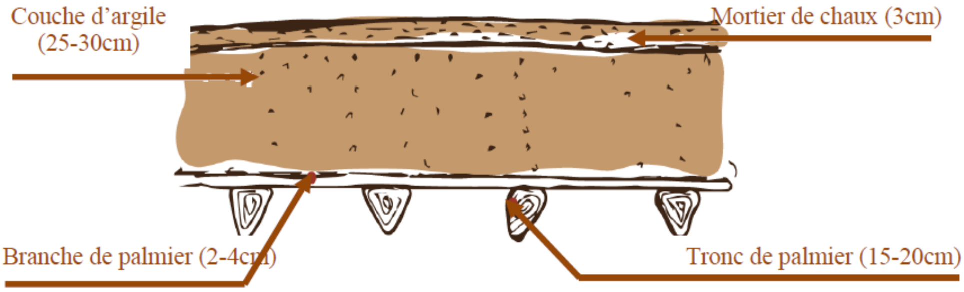


Figure I.28: Cross-section of a palm-clay roof [70]

Figure I.29: Actual photo showing the different layers of palm and clay roof [70]

Palm branches are sometimes replaced by reeds or canes, the latter working on the same principle (Figure I.30).

Figure I.30: Floor of a reed-covered passageway in the Ksar of Al Atteuf [71]

I.4.1.2 Roofs (floors) made of palm trunks and vaults

Instead of palm branches, small vaults made of stone and timchemt mortar are sometimes used, placed on the palm trunks. Wooden boards are attached at both ends as formwork to facilitate the construction of these vaults, and are then removed [70] (Figure I.31).

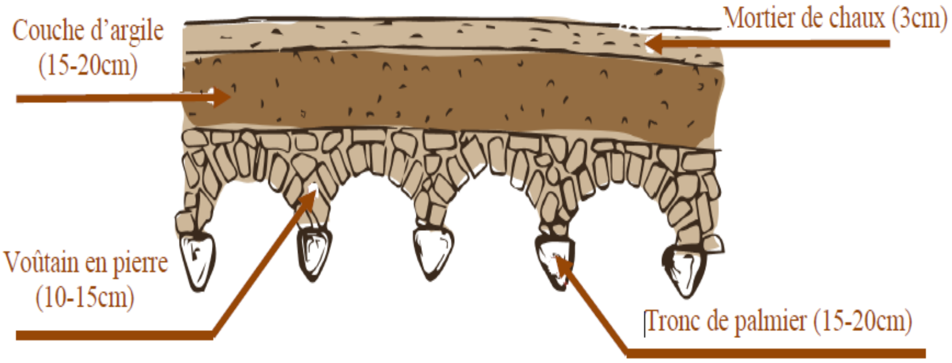


Figure I.31: Section through a roof of palm trunks and canopies [70]

I.4.1.3 Roofs (floors) made of tree trunks/palm trees and flat stones

This type of roof is made of tree trunks or palm trunks laid on the walls. Flat cut stones are sometimes used instead of palm branches and reeds.

This type of floor is rarely used, and consists of tree trunks fixed to the walls and flat stones laid on the trunks next to each other, followed by a layer of insulation and waterproofing (Figure I.32) [70].

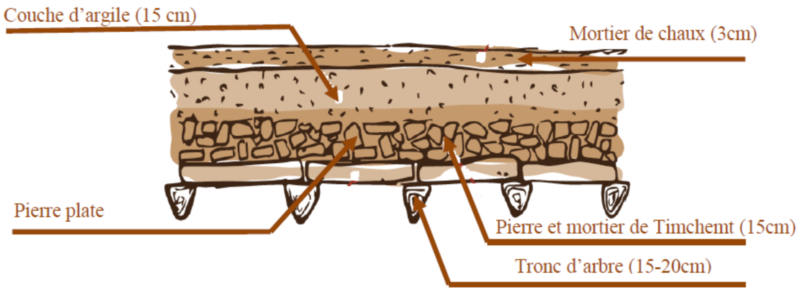


Figure I.32: Cross-section of a tree trunk and flat stone roof [70].

I.4.2. Cupolas in Mozabite constructions

The use of domes for roofing is one of the ancient techniques used to cover buildings in the M'Zab Valley, due to the absence of palm groves at the time, since the palm groves in the M'Zab Valley are artificial, and the lack of building materials that are abundant in palm groves today, such as palm and tree trunks, The domes are built using stone bonded with Timchemt mortar (local plaster), which is characterized by its solidity and rapid setting, making it easier to build. In some cases, palm branches are used as lost formwork to facilitate the laying of the stone. There are several types of dome, both circular and square, and they are used to roof mosques and funerary mausoleums, and rarely in housing, given the need to exploit terraces. the use of cupolas is considered a highly responsive solution in the hot, arid climates of the M'Zab Ksour (Figure I.33).

The domes repel the sun's aggressive rays considerably and minimize temperatures inside the buildings, which has a positive effect on indoor thermal comfort [70].

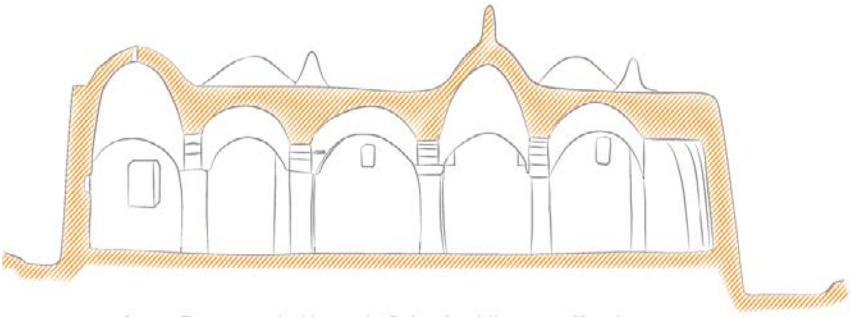


Figure I.33: Cross-section of Baba-Oueldjemma Mosque, Ghardaïa [70]

I.4.3. Vaulting in Mozabite constructions

Vaulting is an operation similar to that of arching, but it is used repeatedly in the M'Zab by builders in all types of construction (mosques, mausoleums, towers, ksar gates, dwellings, etc.) thanks to its ease of execution, its solidity, the balanced distribution and transfer of loads to the walls and the stability of the building [70]. Palm tree trunks are used to build the vaults to support the loads and stabilize the building [1].

Figure I.34: Photos showing the use of arches inside houses in Béni Isguen [72]

I.5. Thermal behaviour of a roof (thermal and radiative phenomena)

Interactions between the roof and external climatic conditions cause radiative and thermal exchanges between the roof, the external environment and the interior of the building [73]. During the day, the roof is exposed to solar radiation from the sky. Some of this radiation is reflected back outwards, and some is absorbed by the roof surface, raising its temperature. The solar radiation absorbed by the roof is transformed into heat, which is conducted inwards [59]. During the night, radiative exchange takes place between the external surface of the roof and the sky. Heat stored in the roof during the day is radiated and transmitted to the interior of the building at night [19] (Figure I.35).

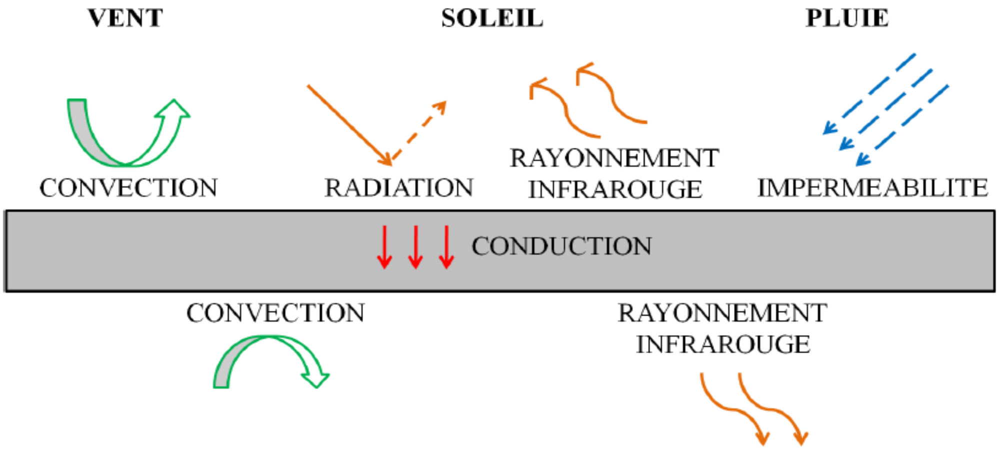


Figure I.35: Radiative behavior of the roof [8]

In summer, the roof is exposed to high levels of solar radiation, especially in hot, arid climates, resulting in high interior temperatures. The roof must therefore be well designed and protected against these aggressive influences. It is essential to control the infrared radiation generated between the roof and the sky, whether by conserving the heat generated and directing it inwards during cold seasons, or by reducing the heat and dissipating it outwards [19]; [8]. Figure I.36 illustrates a model by Kechao Tang et al, used to calculate heat absorption and emission.

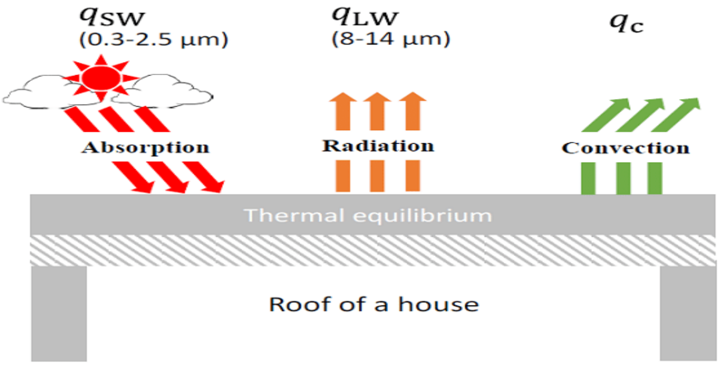


Figure I.36: Model used to calculate heat absorption and emission: Kechao Tang et al./Berkeley University [74]

In hot, dry climates, such as the Ksar of Béni Isguen, the roof's long exposure to harsh outdoor conditions is responsible for a large proportion of external heat gain in summer and heat loss in winter. As a result, rooms located under the roof are more exposed to higher heat gains, and are less comfortable than rooms on other levels due to the additional heat gain from the roof. Figure I.37 shows the heat transfer mechanisms in building roofs [1].

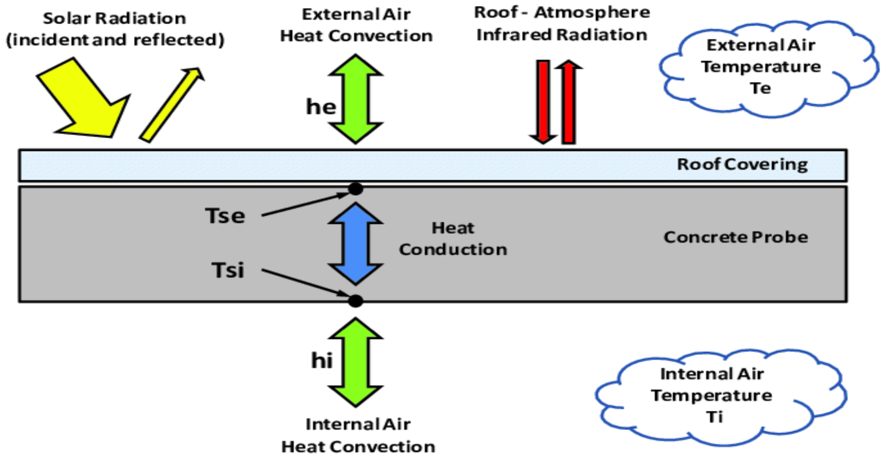


Figure I.37: Heat transfer mechanisms in building roofs [75]

I.6. Thermal performance of the roof

The roof is the surface most exposed to the sun's aggressive rays in hot and arid regions. Ensuring roof protection and reducing solar gain have become increasingly important elements in managing indoor thermal comfort levels. Several solutions have been applied to guarantee desirable protection: movable roof coverings, sunroofs, ventilated attic roofs and even warm roofs, etc. (Figure I.38). These solutions protect roofs by providing thermal insulation in summer and reducing heat loss in winter. Movable roof coverings can reduce heating/increase radiant cooling. In the case of the warm roof, as already explained, where the thermal insulation is placed on the outside, it protects the roof from strong solar radiation. In this case, roof protection is of considerable interest from an energy point of view. Roof insulation reduces a building's energy consumption, improves thermal comfort for occupants and ensures roof stability.

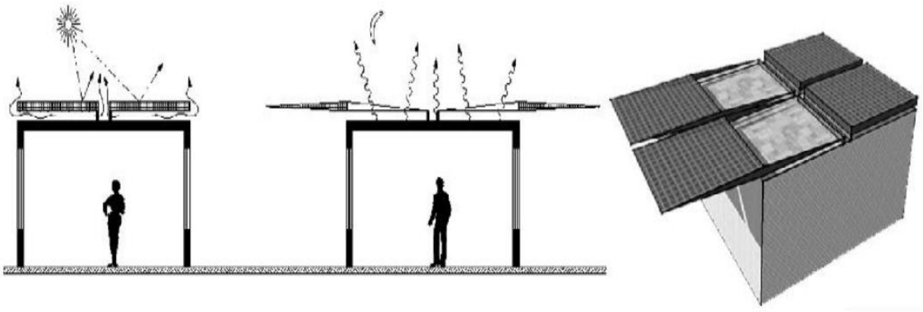


Figure I.38: Movable roof cover [76]

I.7. How does the roof affect thermal comfort?

Human comfort is the fundamental aim of any human operation or intervention. Thermal comfort is one of the most important types of comfort for a satisfying lifestyle. Reducing the temperature entering through the roof saves both heating and cooling energy. Various cooling solutions and techniques are developed and applied to the roof to ensure pleasant thermal comfort, making indoor living tolerable. So in terms of comfort, we recommend using thermal insulation from the outside (the warm roof) of the roof, which will have a positive impact on comfort in summer, precisely in the spaces under the roof. Protecting the roof from aggressive summer rays, managing external and internal solar gains, and ensuring night-time ventilation to cool the building mass are all key strategies that need to be taken into account to ensure thermal comfort [1].

I.8. State of the art

Article 1 S Pandey, DA Hindoliya, R Mod - Applied Soft Computing, 2012 - Elsevier [77]

By using Three passive cooling methods (e.g. roof pond, reflective roof cooling and using insulation over the roof) in the City of Ujjain, all three methods were effective in reducing heat flow through the roof and lowering the energy demand in the building especcialy in summer just we have to put some data like : outside temperature, relative humidity, solar intensity and wind speed.

Article 2 H Taleb, M Elsebaei, M El-Attar - Architectural Engineering and …, 2019 - Taylor & Francis [78]

In order to study The promising idea of using shipping containers as homes in a hot aride region and we used Three strategies for that, and the results showed that the most effective strategy was the use of green roofs and green walls were used to act as an insulation layer for the container envelope

Article 3 DHC Toe, T Kubota - Solar energy, 2015 - Elsevier [79]

We made investigation about vernacular passive cooling techniques and their potential application for improving indoor thermal comfort of naturally ventilated, modern brick terraced houses in Malaysia.and we saw that The small courtyards were effective to cool the high thermal mass structures through nocturnal ventilative and radiative cooling also the houses are built by wood and bamboo

Article 4 M Sebti, D Alkama, A Bouchair - Frontiers of Architectural Research, 2013 – Elsevier [80]

This investigation demonstrates that the traditional settlement of Ksar of Ouargla was a good reference of adaptation to harsh climatic conditions and that the recent morphological transformations have influenced negatively the existing favorable microclimatic conditions and resulted in increasing ambient temperatures in the transformed areas thanks to some solution like :

the compactness of urban fabric of the Ksar which minimizes the exposure of building surfaces to solar radiation in summer and cold winds of winter.

the road structure is irregular, streets are deep and twisting which create shadowed areas and reduce the radiant temperature.

Article 5 M Dabaieh, O Wanas, MA Hegazy, E Johansson - Energy and Buildings, 2015 - Elsevier [81]

In hot dry climates, it is estimated that almost half the urban peak load of energy consumption is used to satisfy air-conditioning cooling demands in summer time. Since the urbanization rate in developing countries – like the case in Egypt so we suppose t o use the cooling roof as a solution and after that our proposed solution depends mainly on protecting the roof surface from direct solar radiation so as to reduce heat gain (thus reducing R_n in Eq. (1)) and allow for air movement to help in the cooling process. At the same time we tried to design the roof section in a way that would support reducing heating days as well

Article 6 Y Zahraoui, MR Basir Khan, I AlHamrouni, S Mekhilef… - Energies, 2021 - mdpi.com [82]

Energy demand has been overgrowing in developing countries. Moreover, the fluctuation of fuel prices is a primary concern faced by many countries that highly rely on conventional power generation to meet the load demand. Hence, the need to use alternative resources, such as renewable energy, is crucial in order to mitigate fossil fuel dependency, so because of that in Algeria we have to use renewable Energy: solar, wind generation as well as geothermal and biomass technologies and after researches we saw that we can get all these energies and use them in place of fuel

Article 7 A Bouchair, A Dupagne - Building and environment, 2003 – Elsevier [83]

The vernacular building of Mzab settlements shows the optimization, over many centuries of the performance of locally available materials within the climatic conditions of southern Algeria, designed to serve the specific needs of “Ibadits” culture. Mzab demonstrates to a marked degree some peculiarities of Islamic culture, especially in town planning and dwelling design. It provides a good example of how a site may be exploited to assist defense, to benefit from summer breezes and to promote natural drainage, while providing shelter from the sun and adapting generally to severe local climate but after many years the modernization has had a negative effect at this vernacular building especially in building materials

Article 8 A Bouchair - **Building** and **environment**, **2004 –** Elsevier [84]

In the last few decades, urbanization of the valley of Mzab has exacerbated. Its impact on the natural environment and ecosystem balance has become a major preoccupation. The microenvironment of the valley is disturbed by the new urban expansions, the abolition of vegetation, the new materials employed and by industrial activities which have developed. Modifying the microenvironment will act directly on public health, thermal comfort and on the energy consumption in buildings. So as a solution we propose :

1_ Prevent further urbanization on the valley bed and establish special regulations to protect further destruction of the natural environment

2_ Trees planting as a cooling strategy

3_Use of high reflectivity surfaces

4_ Use renewable and recycled resources

5_Prevention and control of air pollution

Article 9 A Bouchair, H Tebbouche, A Hammouni, MC Lehtihet… - Energy Procedia, 2013 – Elsevier [85]

Compact settlements or “Ksar” have been commonly used in the hot dry climate of Algeria in response to imposed local environmental conditions through passive design strategies like : Size, form and orientation of the streets and overall built form should be in co-ordination with the orientation of the sun and prevailing wind direction. Linear layout of buildings and streets were avoided in all traditional settlements and this was better shading distribution within the city.

-Vegetation is a passive energy saving technique. It controls wind, solar radiation and temperature extremes of climate.

Article 10 V Costanzo, G Evola, A Gagliano… - Advances in …, 2013 - journals.sagepub.com [86]

The aim of this paper was to investigate the effectiveness of the cool roof technology for the refurbishment of an existing low-rise office building in Catania, a city in southern Italy with a hot-humid Mediterranean climate, in which the energy demand for space cooling in summer is predominant if compared to that for space heating in winter and the results shows that the using of cool paints is so important in order to reduce temperature but we shouldn't forget that Even if in this case study the overall annual energy demand is lowered by the use of a cool paint, this solution should be carefully evaluated in regions with intense or long winter period

Article 11 S Kachkouch, F Ait-Nouh, B Benhamou, K Limam - Energy and Buildings, 2018 – Elsevier [87]

Three passive techniques for air cooling in buildings are tested in the real conditions of Marrakech (Morocco) whose climate is hot semi-arid (BSh type according to the Köppen–Geiger climate classification). The passive techniques, that are white painting, shading and thermal insulation, are applied to the roofs of three outdoor test cells. Thermal performance of these techniques are assessed simultaneously via a 29 summer days monitoring of four test cells, including a reference cell with bare roof. Measurements concerned the cells indoor air temperature, the roof slab inside (ceiling) and outside surface temperature, as well as the heat flux through the roof slab. Moreover after test. The results show that the studied passive cooling techniques have a significant positive impact on the heat flux through the roof as well as the temperature of the ceiling and the cells' indoor air. The white painted roof has the highest thermal performance in terms of the ceiling and the indoor air temperature. Indeed, the former was lowered, relatively to the reference cell, by up to 13.0 °C, 9.9 °C and 8.9 °C respectively in the cells with the white painting (WP), the thermal insulation (EPS) and the shading (SH) techniques.

Article 12 S Fantucci, V Serra - Energy and Buildings, 2019 – Elsevier [88]

The energy retrofitting and conversion of attic spaces into liveable dwelling units is a widely diffused practice in EU countries, and it leads to an increment in urban density, without having to construct new buildings. Roof surfaces are the parts of buildings that are exposed the most to the sun in summer season, and for this reason, they are responsible for high cooling loads, which can determine overheating phenomena in the dwellings below the attics because of that we made an experimental study, which has dealt with the investigation of the thermal performance of a roof treated with reflective insulations, demonstrates the efficacy of the presented technology, for both the application of aluminium foil and the use of reflective paint below the roof tiles surfaces. The study, performed by means of 1D numerical simulations (verified through comparison with experimental data), has shown a reduction in the indoor summer heat gains of between ~10% and ~53%. The parameters that have been found to influence the performance the most are: the emissivity and the view factor between the treated surface and the opposite untreated surface. Moreover, the study has demonstrated that the insulation level has a negligible effect on the reduction of the percentage heat flow of a slightly ventilated roof treated with reflective insulation. Moreover, it has been shown that reflective insulation could dramatically reduce the maximum indoor summer surface temperature by ~1.2°C

Article 13 KJ Chua, SK Chou - Energy, 2010 – Elsevier [89]

Energy consumption of buildings takes up about a third of Singapore's total electricity production. In this paper, we present a pioneering study to investigate the energy performance of residential buildings. Beginning with an energy survey of households, we established the air-conditioning usage patterns and modelled residential buildings for computer simulations. An ETTV equation for residential buildings was developed. Employing this equation, we demonstrated how to achieve improved energy efficiency in residential buildings, our research has resulted in conclusive answers that demonstrate possible energy savings pegged to the ETTV. Building designers can now appreciate the relative impacts of the different parameters on the ETTV and thus the cooling energy consumption of the building.

Article 14 KT Zingre, MP Wan, SK Wong, WBT Toh, IYL Lee - Energy, 2015 – Elsevier [90]

Double-skin roof is a popular passive cooling solution to curb heat gain into buildings and cool roof is another emerging solution. This study proposed a novel CRHT (cool roof heat transfer) model for double-skin roof which is able to model the heat transfers for a double-skin roof combined with cool roof. The CRHT model was validated against experiments performed in two identically-configured, naturally ventilated apartments in Singapore. After studies we saw that The CRHT model is capable of handling the transient outdoor and indoor boundary conditions as experienced by naturally ventilated residential buildings. The CRHT model, which is generally applicable to any climate conditions, was validated against experiments in two identically configured

Conclusion

This chapter has dealt with traditional architecture and its practices for ensuring thermal comfort, particularly in hot, arid climates. The strategies discovered in this architecture have shown its performance in supporting environmentally-friendly architecture that meets the local expectations of the people. Traditional architecture constitutes an integrated system that links climatic, social and economic conditions between urban structures and interior environments. So, this architecture will remain a unique model that teaches us how to maintain a balance between human functions, social, economic and environmental values, while guaranteeing human comfort. The roof is a very important field of intervention that can help deliver significant energy savings and environmental benefits. Because of its shape, orientation, composition, surface area and high exposure to intense solar radiation, the roof is a major source of heat gain. This chapter has also covered several types of roofing used around the world and in hot and arid climates to adapt to severe climatic conditions in order to provide good resistance to heat flows from the outside in. Roof terraces, domes and vaults are just some of the roof types used in dry and arid regions.

Chapter II

Case study presentation

Introduction

The M'zab valley is a region of Algeria's northern Sahara. It takes the form of a vast rocky plateau cut by deep, tangled valleys, hence the name "chebka", meaning net. The Cretaceous plateau is formed by hard Turonian limestone. The people of the M'zab lived isolated from the outside world, with their own sociological, religious, economic, cultural and linguistic particularities. Over a period of three and a half centuries, from the 11th to the 14th century, the valley was urbanized, resulting in the creation of five cities: El-Atteuf, Bounoura, Ghardaïa, Ben-isguen and Mélika. Each town has its own palm grove, irrigation system and cemeteries. The Ksar of Béni Isguen is one of the five Ksour of the M'Zab Valley, a perfect illustration of man's ability to adapt to his environment. Despite the harsh conditions of the site, with its hot, arid climate, the Mozabites have always built their settlements according to their cultural references, their way of thinking, their religion and their way of life. The Ksar with its palm trees, the houses with their constructive and organizational details, reflect the lifestyle, customs and religion of Mozabite society par excellence.

Nevertheless, a seasonal and daily nomadism is noted by the indigenous peoples. In summer, Mozabites leave their houses inside the Ksar and occupy the houses in the palm grove. Mozabites also use the terrace during summer nights to sleep, which raises the question of thermal discomfort in the bedrooms. This study therefore aims to shed light on the problem of thermal comfort inside Mozabite houses, especially during the overheating period. This chapter will begin by presenting the context of the study and the climatic data for the Ksar of Béni Isguen.

II.1. The Ksar of Béni Isguen

II.1.1. site presentation

The Mzab city (Algeria) at 600 km south of Algiers. Unlike the other cities of the Mozabite pentapolis, Beni Isguen is not built on a rocky outcrop but on the side of a rocky hill and it is also the only city of the pentapolis not to have been built on the M'zab wadi but at the confluence of the western N'tizza and the Mzab wadi, which allowed the founders to establish the palm grove (the city's feeder garden) upstream from the N'tissas wadi, wadi essentially underground except in period of flood. The choice of this location and the erection of the city is not necessarily prior to the creation of Ghardaïa as has often been written, without any references being given. As we shall see later, another city (Tafilelt) may have been prior to Beni Isguen. Over the centuries, the occupation of the land by palm groves and their intensive exploitation has gradually dried up the underground course of the Oued Mzab; the construction of Bou Noura, Melika and Ghardaïa cannot be explained in any other way than by the search for wells that could be exploited by going upstream [1].

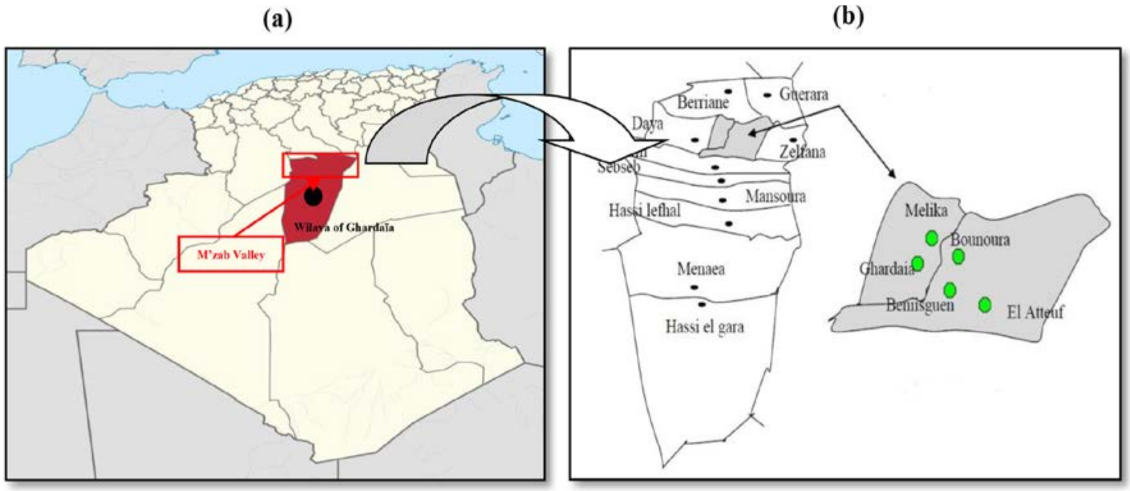


Figure II.1: (a) Situation of the M’zab Valley in the map of Algeria; (b) Situation of the Ksar of Beni Isguen in the M’zab Valley.

II.2. Composition of the Valley the 5 Ksour

Five ksour make up the M'Zab valley, located on the banks of the Oued M'Zab and form what is commonly known as the M'Zab pentapolis consisting of Beni-Isguen (1347), Bounoura (1046), El Atteuf (1012), Ghardaïa (1053) and Melika (1124) [2].

The Béni Isguen ksar, one of the valley's five ksour, is located on the side of a piton equidistant between the Melika and Bounoura ksars, at the confluence of the Oued M'Zab and Oued N'tissa.

The overall surface area of this ksar is estimated at 16.5 ha and the total number of its dwellings is 1010 houses [3].

II.1.3. Territorial resources of the Ksar

The Ksar de Béni Isguen area has three main resources: cultural resources, the environmental landscape and a specific local economy. Cultural resources are the most important, as they possess significant tangible and intangible potential. [4]

II.1.4 Urbanization of the Ksar

The ksour of southern Algeria are characterized by their specific architecture and unique socio-spatial organization, reflecting the way of life of local society. The M'zab Valley in Ghardaïa, for example, is home to a number of ksour and palm groves, classified as UNESCO World Heritage Sites for their distinctive architectural and urban features. However, this heritage is under threat from decades of urban development aggression [5].

II.1.5 Principle of urban organization in the Ksar

The Ksar of Béni Isguen is built on a piton around a mosque [6]. Around the mosque, the houses are harmoniously arranged in terraces (Figure II.2). The urban layout of the Béni Isguen ksar is based on a compact urban fabric with narrow streets [7] (Figure II.3).

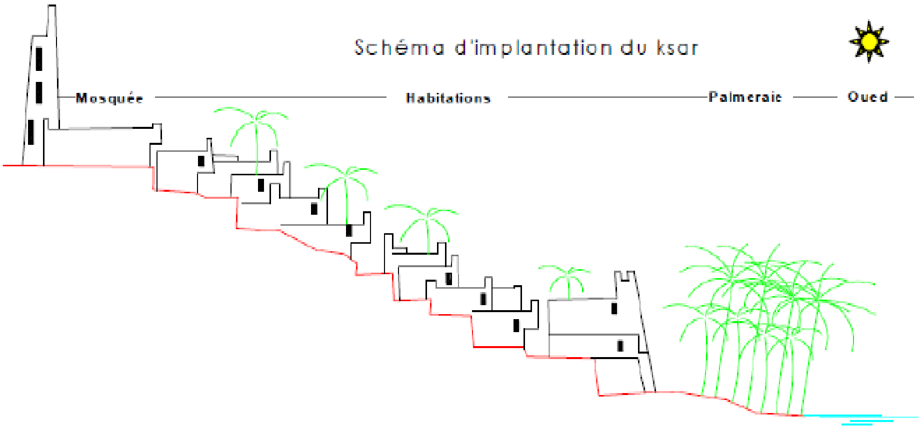


Figure II.2: Layout of the ksar [8]

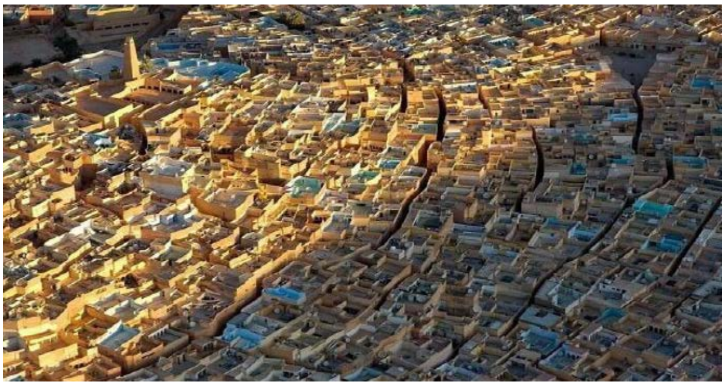


Figure II.3: Photo showing the compact urban fabric of the ksar [4]

II.2. Climatic study of the Ksar of Béni Isguen

It's well known that southern Algeria is one of the driest lands in the world. The prevailing environmental conditions that affect the comfort of the inhabitants are of four main types: high temperatures and intense solar radiation, glare from direct and reflected light, and dust storms.

In general, southern Algeria, and the Ksar of Béni Isguen in particular, has a typical desert climate, with variations between seasons and between day and night temperatures. The climate is hot and dry in summer, with cold nights and mild days in winter. Rain occurs mainly in winter (a few days a year) and relative humidity is low, especially in summer. Storms occur at certain times of the year, usually in March and April [4].

II.2.1. Climatic data

The Ksar of Beni Isguen is located in a desert site characterized by hot and dry climate [10]. It is located on the side of a peak equidistant between the Ksar of Melika and that of Bounoura, at the confluence of the Oued M'Zab and the Oued N'tissa. This Ksar is organized around the mosque which is the central and highest point of the city. It has two main gates located in the north-east and south-west, connected by a street, as well as three other gates leading to the various cemeteries [11].All the alleys end at the market square. The urban fabric of this Ksar is compact with narrow streets.

The climate in the Ksar de Béni Isguen region is of the hot, dry Saharan type that covers much of North Africa.

The fundamental character of the climate in Beni Isguen's Ksar is the dryness of the air combined with low rainfall, but microcli- mates play a considerable role due to the relief or the vegetation, which locally modify the climatic conditions [12].

The Tables 1 and 2 represent the climatic data of temperature and relative humidity of Beni Isguen’s Ksar from the year of 2011 to 2017.

Month/year	2011	2012	2013	2014	2015	2016	2017
January	12.6	10.8	12.7	12.3	11	13.8	9.8
February	12.4	9.7	12.6	14.4	11.5	14.7	14.7
March	15.2	16.1	18.7	15.8	16.4	17	18.1
April	21.8	21	21.5	22.7	23	22.7	21.3
May	24.6	27.8	25.6	26.8	27.9	26.8	28.5
June	29.4	34	30	30.1	30.6	31.3	31.4
July	35.1	26.4	34.6	35.5	33.4	34.2	33.9
August	23.6	27.4	32.1	35.6	33.7	33	33.7
September	31.2	29.1	29.5	31.4	29.3	29.3	28.1
October	20.9	24.7	26.9	24.4	23.7	25.2	21.8
November	16.3	17.1	16.5	17.5	16.4	16.6	16
December	12.6	12.6	10.5	11.4	12.4	12.6	11.5

Table II.1: Monthly average temperature of Beni Isguen’s Ksar in C_ [13].

Month/year	2011	2012	2013	2014	2015	2016	2017
January	48	34	32	49	43	40	32
February	44	31	39	38	42	36	39
March	53	28	36	33	31	27	12
April	43	20	35	22	24	30	29
May	36	18	31	24	20	22	23
June	35	16	28	22	22	21	23
July	24	14	25	13	19	20	17
August	26	24	31	17	28	25	34
September	33	33	40	26	35	35	32
October	59	39	36	28	40	38	42
November	55	59	46	43	51	45	40
December	60	55	66	51	54	65	49

Table II.2: Monthly average of relative humidity of Beni Isguen’s Ksar in % [13].

II.2.2. A reading of the Ksar climate

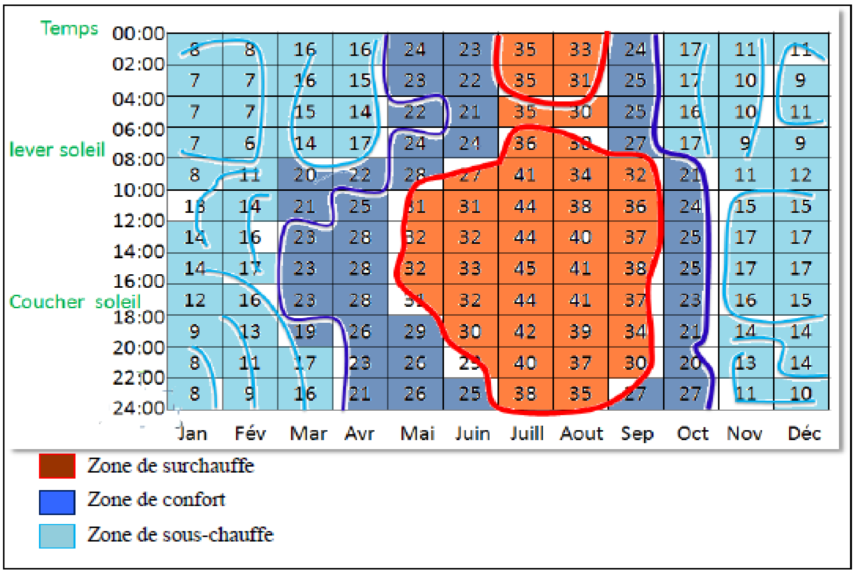
The annual temperature distribution is apparently uniform; or the summer season is marked by very high temperatures, with a great amplitude between daytime and night-time temperatures.

The hot period begins in May and lasts until September. The highest temperature is recorded in July, with an average of 39.8°C and a very low relative humidity of 14.2%. While, for the winter period, the lowest average temperature is noted in January with 11°C and a relative humidity of 75.9%.

There has, however, been a marked increase in the average temperatures recorded in recent years, the result of global warming, which is a reality strongly felt in Algeria. The Ksar of Béni Isguen, on the other hand, has a hot, dry climate. The best months to visit the Ksar are: April, May, September and October [4].

II.2.3. The isotherms

The isotherms are based on 12 months of climate data (°C) for the year 2018 from the online site: Climat Win: Figure II.4 shows the isotherms for the Ksar of Béni Isguen [4].



Temps	Jan	Fév	Mar	Avr	Mai	Juin	Juill	Aout	Sep	Oct	Nov	Déc
00:00	8	8	16	16	24	23	35	33	24	17	11	11
02:00	7	7	16	15	23	22	35	31	25	17	10	9
04:00	7	7	15	14	22	21	35	30	25	16	10	11
06:00	7	6	14	17	24	24	36	[illegible]	27	17	9	9
08:00	8	11	20	22	28	27	41	34	32	21	11	12
10:00	13	14	21	25	31	31	44	38	36	24	15	15
12:00	14	16	23	28	32	32	44	40	37	25	17	17
14:00	14	17	23	28	32	33	45	41	38	25	17	17
16:00	12	16	23	28	31	32	44	41	37	23	16	15
18:00	9	13	19	26	29	30	42	39	34	21	14	14
20:00	8	11	17	23	26	25	40	37	30	20	13	14
22:00	8	9	16	21	26	25	38	35	27	27	11	10

Figure II.4: Isotherms showing the different thermal zones [4].

II.3. Presentation of house

The case study is based upon a house located in Beni Isguen’s Ksar. It has a single facade from which there is the only entrance to the house (Figure II.5). The facade surface is small which reduces exposure to intense sunlight. The houses of Beni Isguen’s Ksar are characterized by the existence of a cellar, ground floor, floor and terrace. So, like the majority of ‘Mozabit’ houses, this house has a cellar (basement) where there is water well. Then, the ground floor contains the living rooms namely: the Tizefri (Living room), a bedroom, the kitchen, toilet and two stairwells. In addition, on the first floor are the bedrooms: parents, girls and boys and the bath-room. For the terrace, there is a corner reserved for storage with the existence of ‘Chebek’ to let in the light. The plans of the house are shown in (Figure II.6). The ceiling consists either of a lath tightened with palm ribs, or of flat stones, or of vaults made of stones linked with Timchemt (local plaster) between the joists [14]. This base is covered with a layer of clay up to 30 cm thick, and above this layer a lime mortar screed is applied. As for the vaults, their construction is based on the same technique as that of the arches, which stones mounted with a ‘‘timchemt” on formwork of palm ribs. This type of roof is widely used in homes due to the availability of construction raw materials such as palm trunks and branches, clay, lime and ‘tim-chemt’.In the rooms, the ‘Mozabits’ use small stone vaults and lime mortar placed on the trunks of palm trees (Figure II.7) [15].

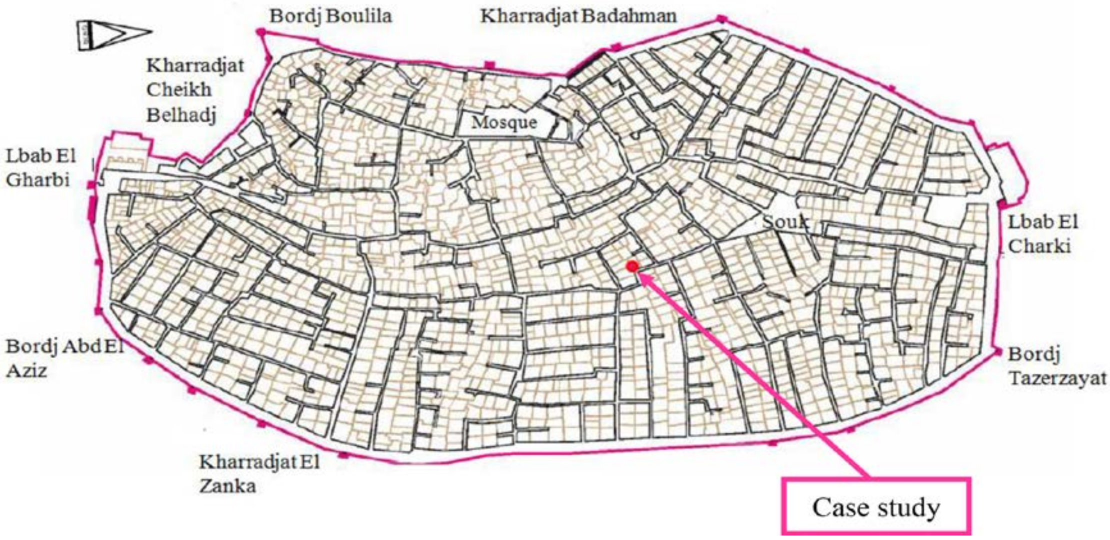


Figure II.5: Case study on the map of Beni Isguen’s Ksar.

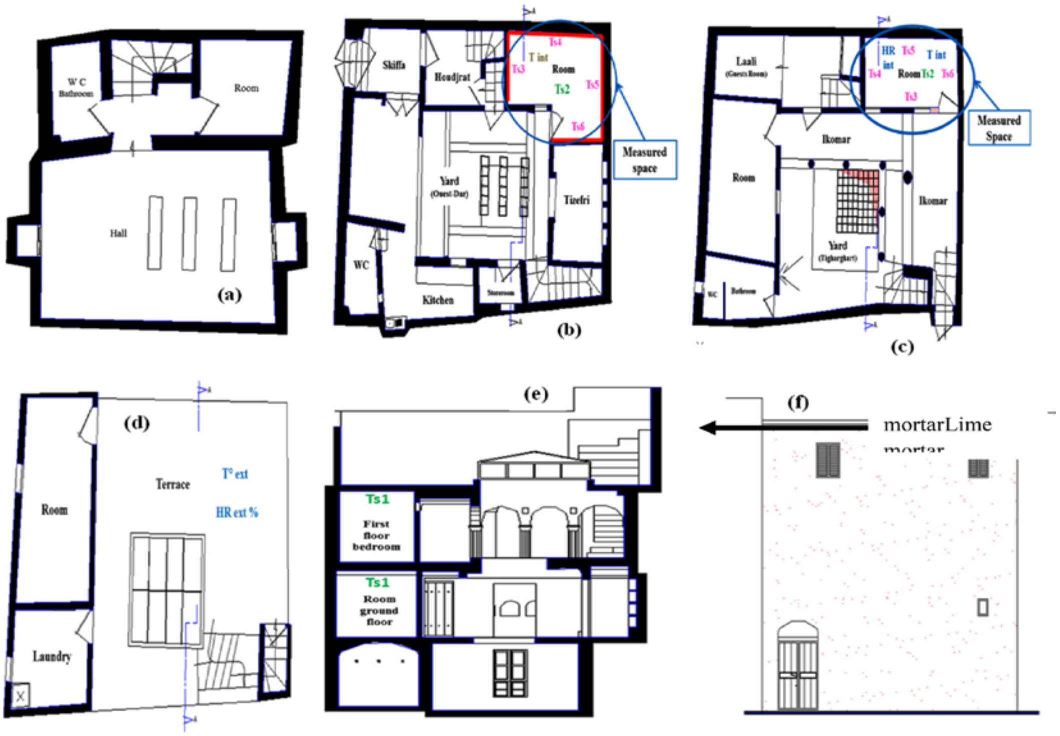


Figure II.6: House plan: (a) Basement plan, (b) Ground floor plan, (c) First floor plan, (d) Terrace plan, (e) Section AA, (f) Façade.

Figure II.7 Photos showing roof of palm tree trunks and vaults in the room of the case study [15].

II.3.1 Wall characteristics

II.3.1.1 Wall materials

Table II.3

Materials	Conductivity (W/mK)	Capacity Thermal (j/kg.°C)	Density (kg/m ^{3})	Thickness (cm)
Hard stone	2.4	936	2350 a 2580	38
Lime mortar	0.87	1080	1800	For gluing
Sand	0.6	823	1300	\

II.3.1.2 Ground materials

Table II.4

Materials	Conductivity (W/mK)	Capacity Thermal (j/kg.°C)	Density (kg/m ^{3})	Thickness (cm)
Palm tree trunk	0.7	3	850	15 a 20
Pierre	1.4	936	1840 a 2340	13
Timchemt mortie	0.75	1080	100 a 1300	\
Clay	1.15	936	1700 a 2000	10
Lime mortar	0.87	1080	1800	5

II.3.1.3 Roof materials

Table II.5

Materials	Conductivity (W/mK)	Capacity Thermal (j/kg.°C)	Density (kg/m ^{3})	Thickness (cm)
Palm tree trunk	0.08 (0.122)	\	850	15 a 20
Pierre	1.4	936	1840 a 2340	15
Timchemt mortie	0.7	1080	100 a 1300	For coating
Clay layer	1.15	936	1700 a 2000	14
Lime	0.87	1080	1800	8

Conclusion

The urban and architectural practices observed in the Ksar of Béni Isguen offer alternative solutions for meeting the social and cultural needs of the Mozabites, while coping with the challenges imposed by a hot, dry climate. The Ksour are also equipped with passive strategies to better manage construction space, benefit from natural ventilation, and design with local means and materials, introducing local solutions to highlight a quality living space.

These practices can be summed up in the following points: the best way to cope with the harsh conditions of a hot, dry climate is to compact the urban fabric.

Small streets with a sinuous shape and an appropriate orientation towards prevailing winds can improve outdoor comfort conditions.

They control prevailing winds and high temperatures, and provide a source of dates and food. since the Ksar of Béni Isguen is built with very narrow streets, the roof is the problematic surface that largely causes thermal discomfort. It has been noted that the horizontal surfaces expressed by the roofs are the most exposed to intense solar rays during the summer period, especially in July and August, and that the inhabitants of the Ksar use the terrace to sleep at night. It is undeniable that there is a real problem of thermal discomfort and high temperatures, particularly in the upstairs areas.

Chapter III

Simulation, results, and discussion

Introduction

By The simulation in this chapter, we will try to identify the effect of roof insulation on the house temperature and the need of air conditioning by changing the thickness of each material in the roof in every time using pléiades program which we will use it to draw the house and enter the material of walls and roofs and all the calculations to get a good simulation, after that we tried to have the best solution for this problem.

III.1.Definition of simulation

The dynamic thermal simulation simulates the metabolism of the building during the days of year depending on the weather and the occupation of the building, the simulation gives us three answers:

1- Temperature evolution.
2- Discomfort
3- Needs and consumption in heating air conditioning

The simulation makes it possible to identify and quantify the impact of the various energy leaks (thermal bridges, infiltration, ventilation....) in order to validate the concepts and technical solutions adapted.

III.2. Presentation of ‘Pleiadeslogiciel’

Pleiade provides the various calculation modules with an efficient; it also allows the entry of libraries, the detailed description of building and calculates, analysis of results.

Pleiade also can be used for:

*bioclimatic design and thermal comfort analysis and calculate energy needs and consumption and comfort also.

* Verification of regulatory requirements

* The sizing of heating or air conditioning systems

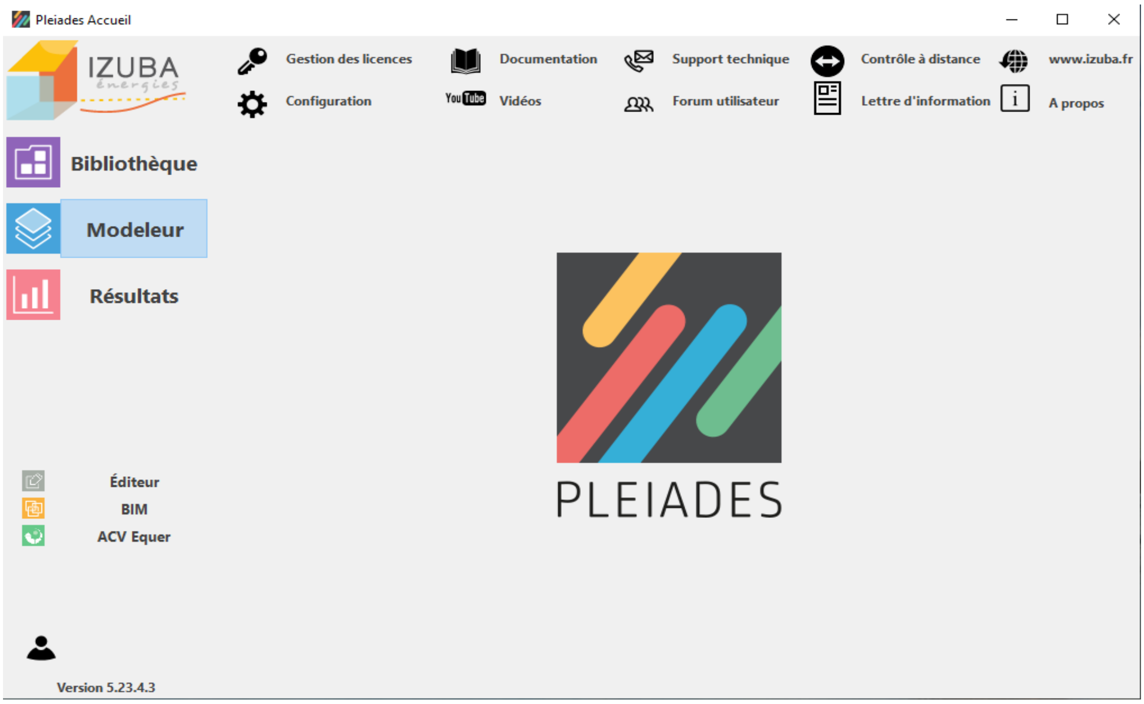


Figure III.1: Pleiades

Meteonorm 8

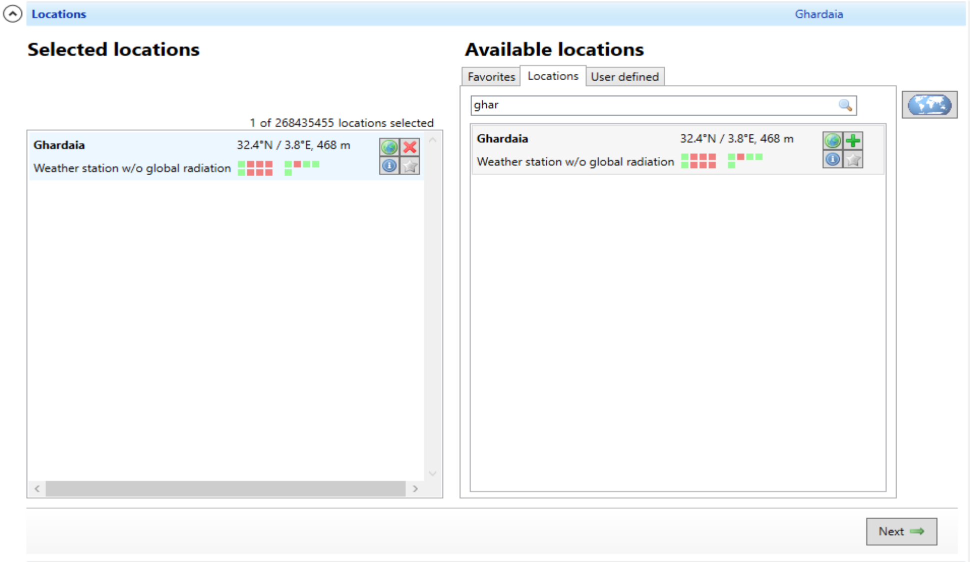
Is a reference tool based on more than 25 years of experience in weather databases

This software contains a very comprehensive database of meteorological data but also algorithms making it possible to create, from the measured values, weather files in any place in the world.

III.3.steps of simulation

III.3.1.Creation of meteorological file in Meteonorm 8

We have to follow the following steps:



Locations — Ghardaia

Selected locations

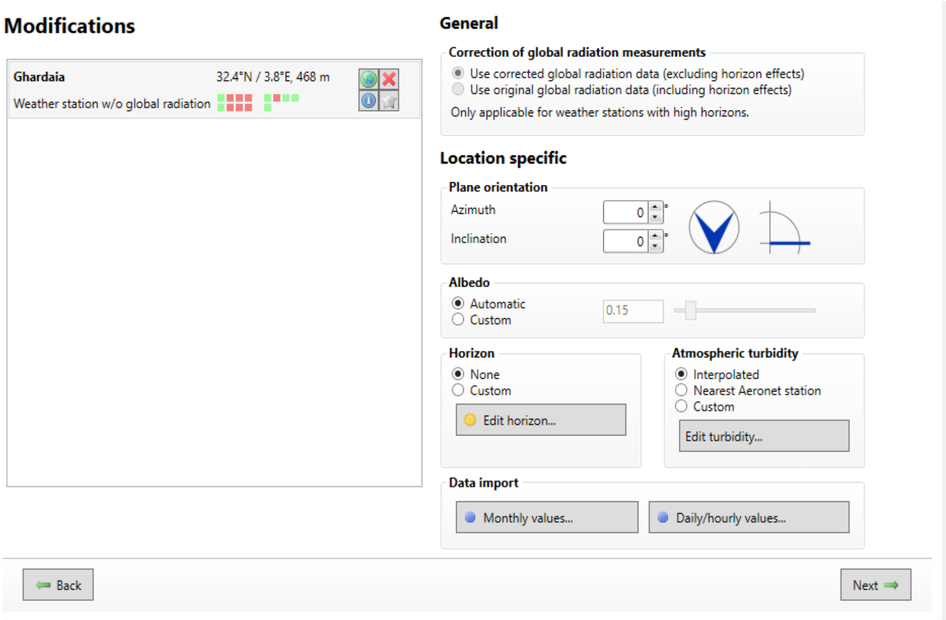
1 of 268435455 locations selected

Ghardaia 32.4°N / 3.8°E, 468 m
Weather station w/o global radiation

Available locations

ghar

Ghardaia 32.4°N / 3.8°E, 468 m
Weather station w/o global radiation



Modifications

Ghardaia 32.4°N / 3.8°E, 468 m
Weather station w/o global radiation

General

Correction of global radiation measurements
● Use corrected global radiation data (excluding horizon effects)
○ Use original global radiation data (including horizon effects)
Only applicable for weather stations with high horizons.

Location specific

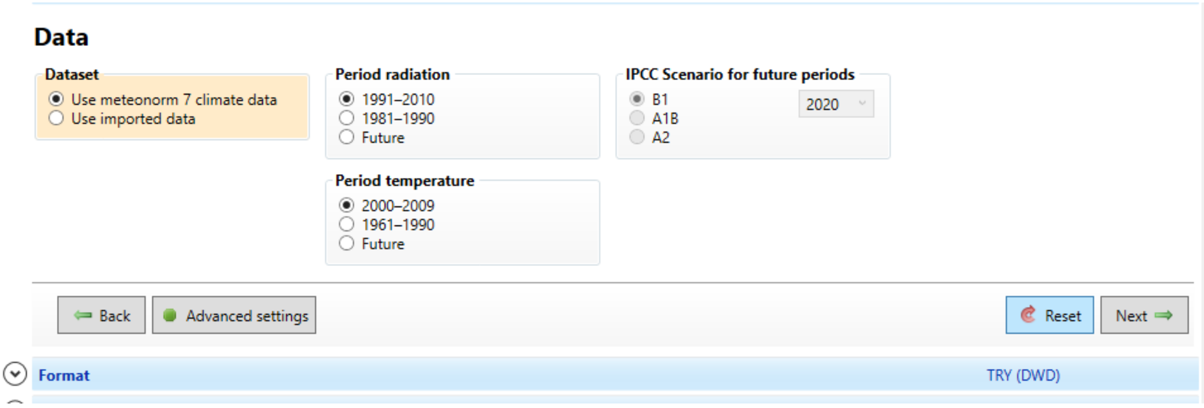
Plane orientation
Azimuth 0°
Inclination 0°

Albedo
● Automatic
○ Custom 0.15

Horizon
● None
○ Custom

Atmospheric turbidity
● Interpolated
○ Nearest Aeronet station
○ Custom

Data import



Data

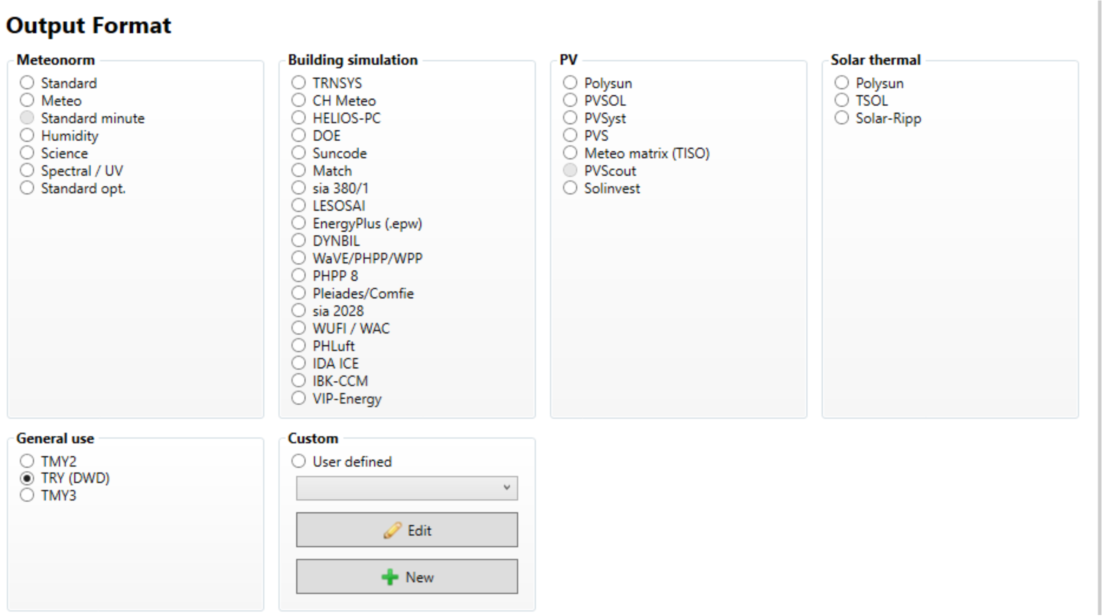
Dataset
● Use meteonorm 7 climate data
○ Use imported data

Period radiation
● 1991–2010
○ 1981–1990
○ Future

IPCC Scenario for future periods
● B1
○ A1B
○ A2
2020

Period temperature
● 2000–2009
○ 1961–1990
○ Future

Format TRY (DWD)



Output Format

Meteonorm
○ Standard
○ Meteo
○ Standard minute
○ Humidity
○ Science
○ Spectral / UV
○ Standard opt.

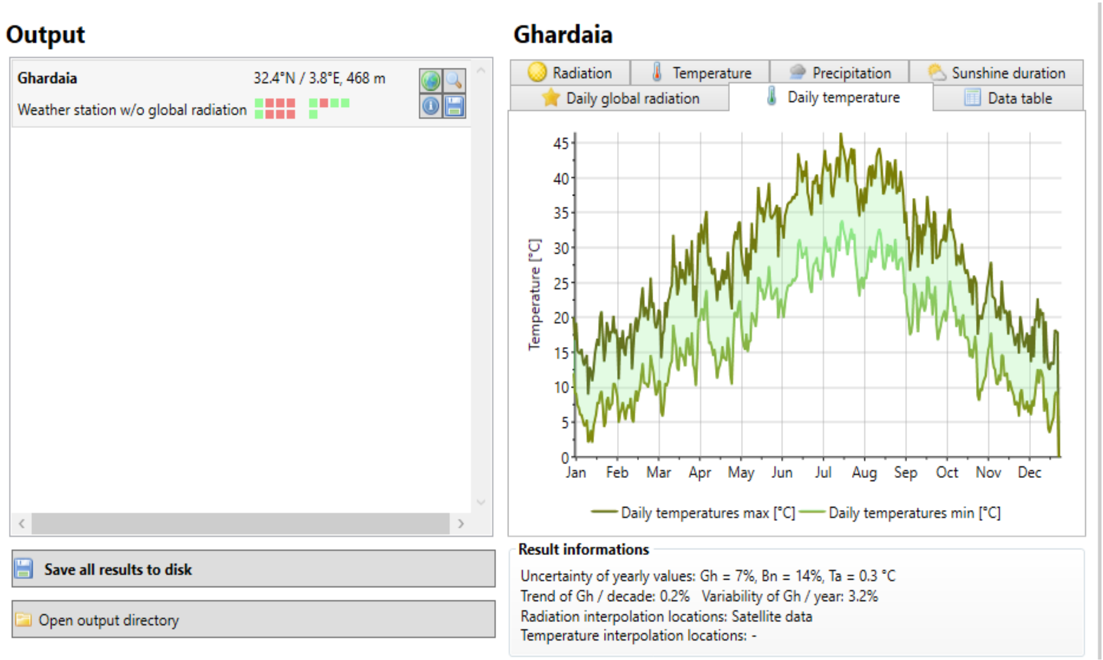
Building simulation
○ TRNSYS
○ CH Meteo
○ HELIOS-PC
○ DOE
○ Suncode
○ Match
○ sia 380/1
○ LESOSAI
○ EnergyPlus (.epw)
○ DYNBIL
○ WaVE/PHPP/WPP
○ PHPP 8
○ Pleiades/Comfie
○ sia 2028
○ WUFI / WAC
○ PHLuft
○ IDA ICE
○ IBK-CCM
○ VIP-Energy

PV
○ Polysun
○ PVSOL
○ PVSyst
○ PVS
○ Meteo matrix (TISO)
○ PVScout
○ Solinvest

Solar thermal
○ Polysun
○ TSOL
○ Solar-Ripp

General use
○ TMY2
● TRY (DWD)
○ TMY3

Custom
○ User defined



Ghardaia 32.4°N / 3.8°E, 468 m

Weather station w/o global radiation

Result informations

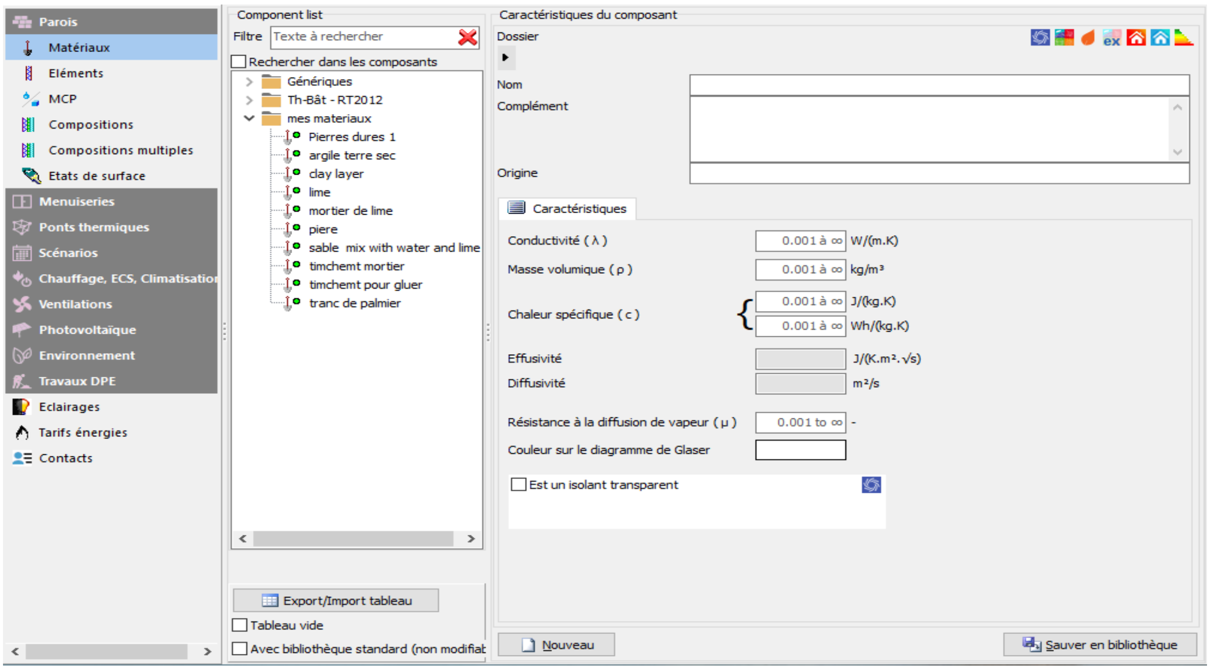
Uncertainty of yearly values: Gh = 7%, Bn = 14%, Ta = 0.3 °C
Trend of Gh / decade: 0.2% Variability of Gh / year: 3.2%
Radiation interpolation locations: Satellite data
Temperature interpolation locations: -

Figure III.2 weather station identification

Next step we import the file to pleiade

III.3.2. material entry

First step we go to the library and we put the materials we need for construction also the elements if we didn't find them in library

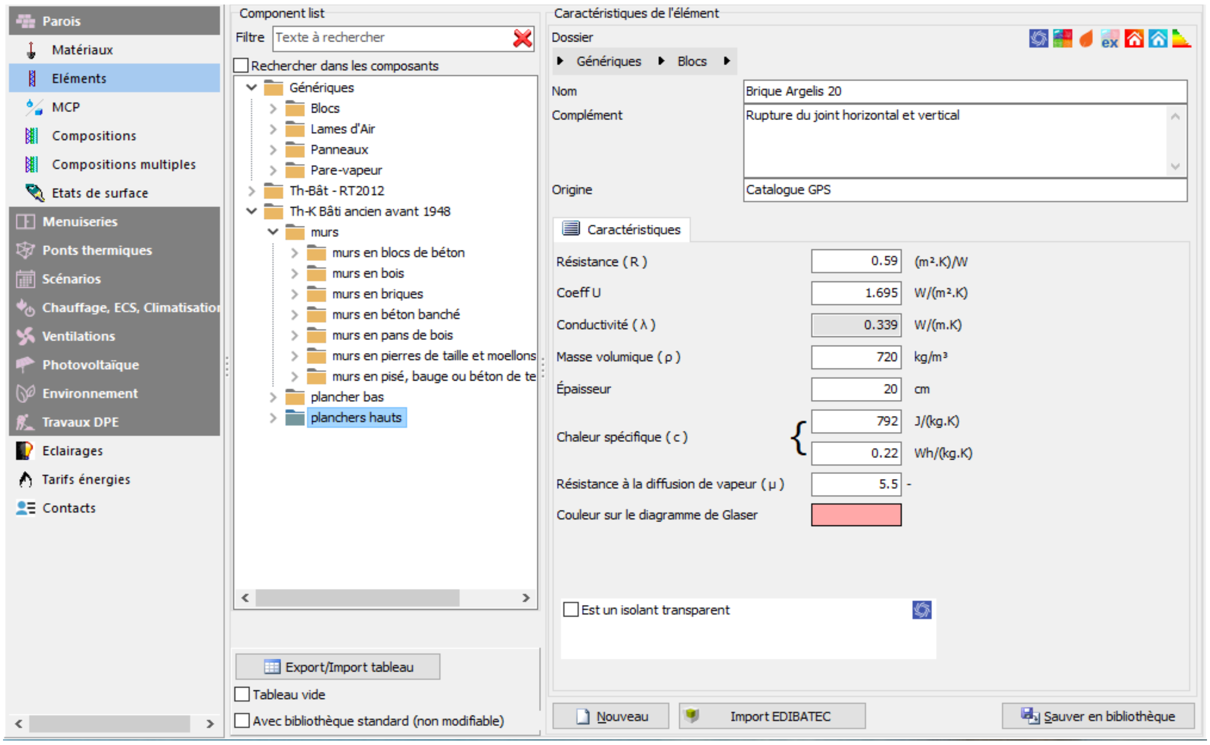


☐ Rechercher dans les composants

- Génériques
- Th-Bât - RT2012
- mes materiaux
  - Pierres dures 1
  - argile terre sec
  - clay layer
  - lime
  - mortier de lime
  - piere
  - sable mix with water and lime
  - timchemt mortier
  - timchemt pour gluer
  - tranc de palmier

☐ Tableau vide
☐ Avec bibliothèque standard (non modifiab

Conductivité (λ) 0.001 à ∞ W/(m.K)
Masse volumique (ρ) 0.001 à ∞ kg/m³
Chaleur spécifique (c) 0.001 à ∞ J/(kg.K) ; 0.001 à ∞ Wh/(kg.K)
Effusivité J/(K.m².√s)
Diffusivité m²/s
Résistance à la diffusion de vapeur (μ) 0.001 to ∞ -
Couleur sur le diagramme de Glaser
☐ Est un isolant transparent



Nom: Brique Argelis 20

Complément: Rupture du joint horizontal et vertical

Origine: Catalogue GPS

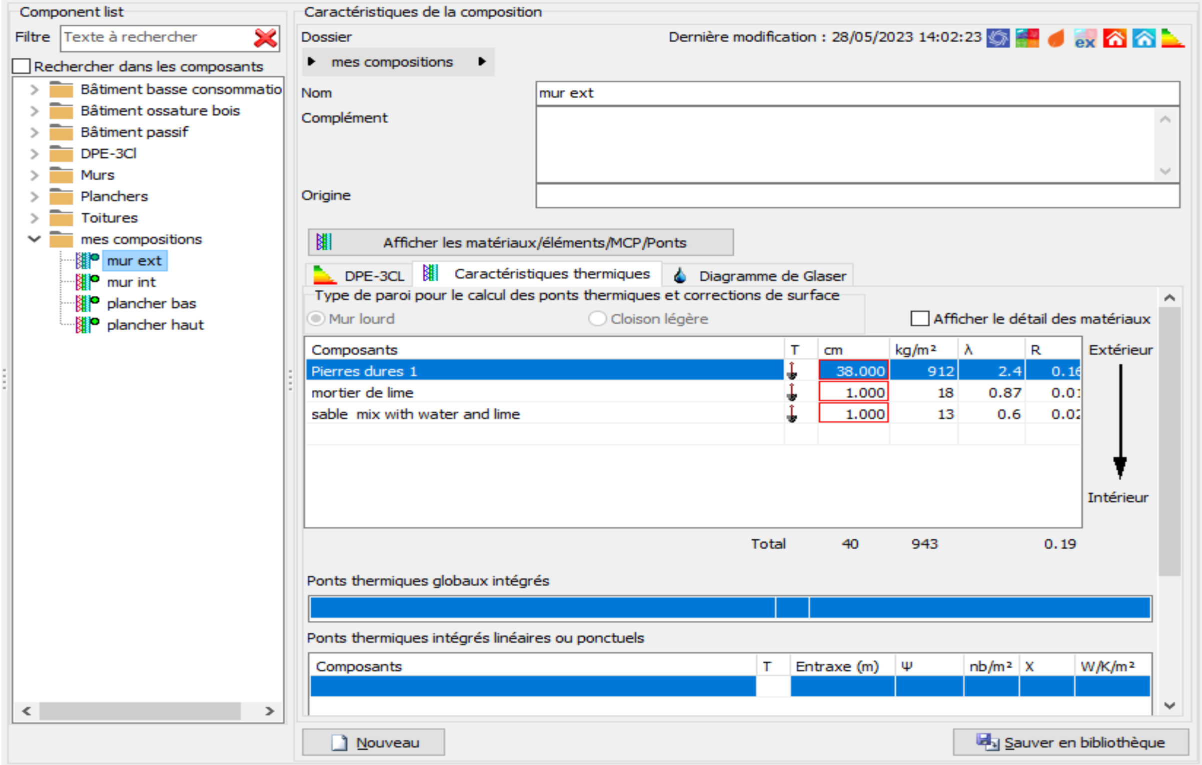
Résistance (R)	0.59	(m².K)/W
Coeff U	1.695	W/(m².K)
Conductivité (λ)	0.339	W/(m.K)
Masse volumique (ρ)	720	kg/m³
Épaisseur	20	cm
Chaleur spécifique (c)	792	J/(kg.K)
	0.22	Wh/(kg.K)
Résistance à la diffusion de vapeur (μ)	5.5	-
Couleur sur le diagramme de Glaser	🟥	

Figure III.3: Enter materials and Elements

and for each material and elements (palm trunk ,clay layer,lime,sotnes ,hard stones ......) we add their :(coif U, conductivity ,.....)

III.3.3.creation of walls, roof and floor composition

We can choose the class of walls: wall,roof,floor.... give a name to the composite wall ,then we drag into the table on the right the constructive elements or materials of the wall theat are visible on the left of the window for each material in the composition ,it’s necessary to define the thickness. And the walls are defined from the outside to the inside ,and we save them in library.



Dernière modification : 28/05/2023 14:02:23

Nom: mur ext

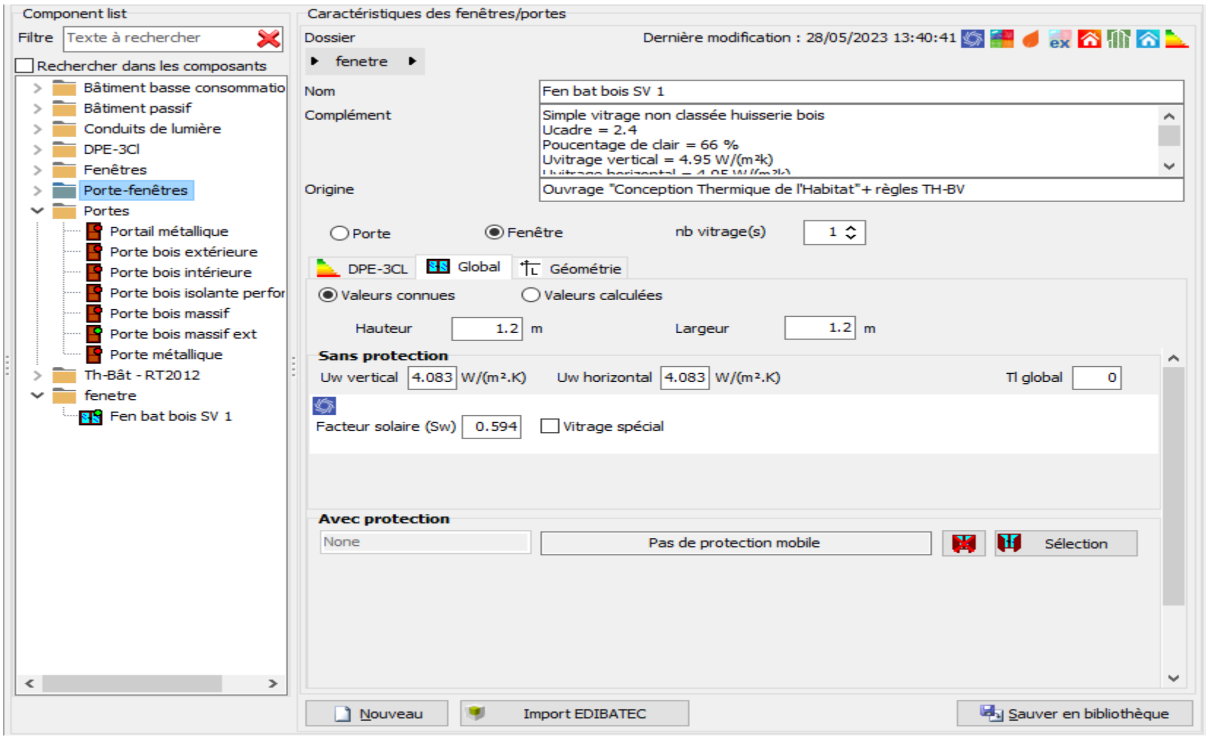
Composants	T	cm	kg/m²	λ	R
Pierres dures 1		38.000	912	2.4	0.1
mortier de lime		1.000	18	0.87	0.0
sable mix with water and lime		1.000	13	0.6	0.0
Total		40	943		0.19

Composants	T	Entraxe (m)	Ψ	nb/m²	X	W/K/m²

Figure III.4: Creation of walls composition

III.3.4. search in the library

our next step is to search in the library the necessary joinery, save and send it to the project and we can modify their length and width.



Filtre: Texte à rechercher

☐ Rechercher dans les composants

Dossier: fenetre

Dernière modification : 28/05/2023 13:40:41

Nom: Fen bat bois SV 1

Complément:
Simple vitrage non classée huisserie bois
Ucadre = 2.4
Poucentage de clair = 66 %
Uvitrage vertical = 4.95 W/(m²k)

Origine: Ouvrage "Conception Thermique de l'Habitat"+ règles TH-BV

○ Porte ● Fenêtre nb vitrage(s) 1

● Valeurs connues ○ Valeurs calculées

Hauteur 1.2 m Largeur 1.2 m

Sans protection

Uw vertical 4.083 W/(m².K) Uw horizontal 4.083 W/(m².K) Tl global 0

Facteur solaire (Sw) 0.594 ☐ Vitrage spécial

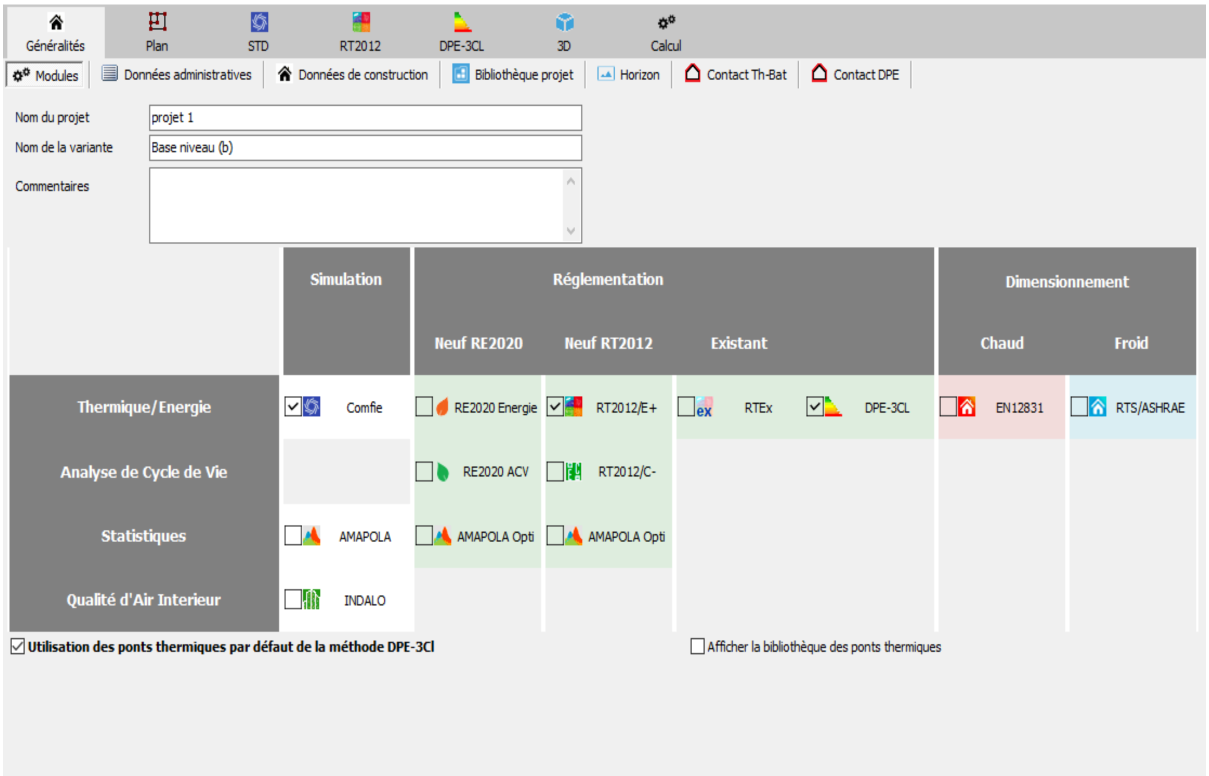
Avec protection

None Pas de protection mobile

Figure III.5: create the necessary joinery

III.3.5. modeleur to build the house

after saving the created walls and joinery we go to modeleur to build the house. And define the dimensions and doors and windows, also we define the bed rooms and WC and living rooms



Nom du projet: projet 1

Nom de la variante: Base niveau (b)

Commentaires:

	Simulation	Réglementation				Dimensionnement	
		Neuf RE2020	Neuf RT2012	Existant		Chaud	Froid
Thermique/Energie	☑ Comfie	☐ RE2020 Energie	☑ RT2012/E+	☐ RTEx	☑ DPE-3CL	☐ EN12831	☐ RTS/ASHRAE
Analyse de Cycle de Vie		☐ RE2020 ACV	☐ RT2012/C-				
Statistiques	☐ AMAPOLA	☐ AMAPOLA Opti	☐ AMAPOLA Opti				
Qualité d'Air Interieur	☐ INDALO						

☑ **Utilisation des ponts thermiques par défaut de la méthode DPE-3Cl**

☐ Afficher la bibliothèque des ponts thermiques

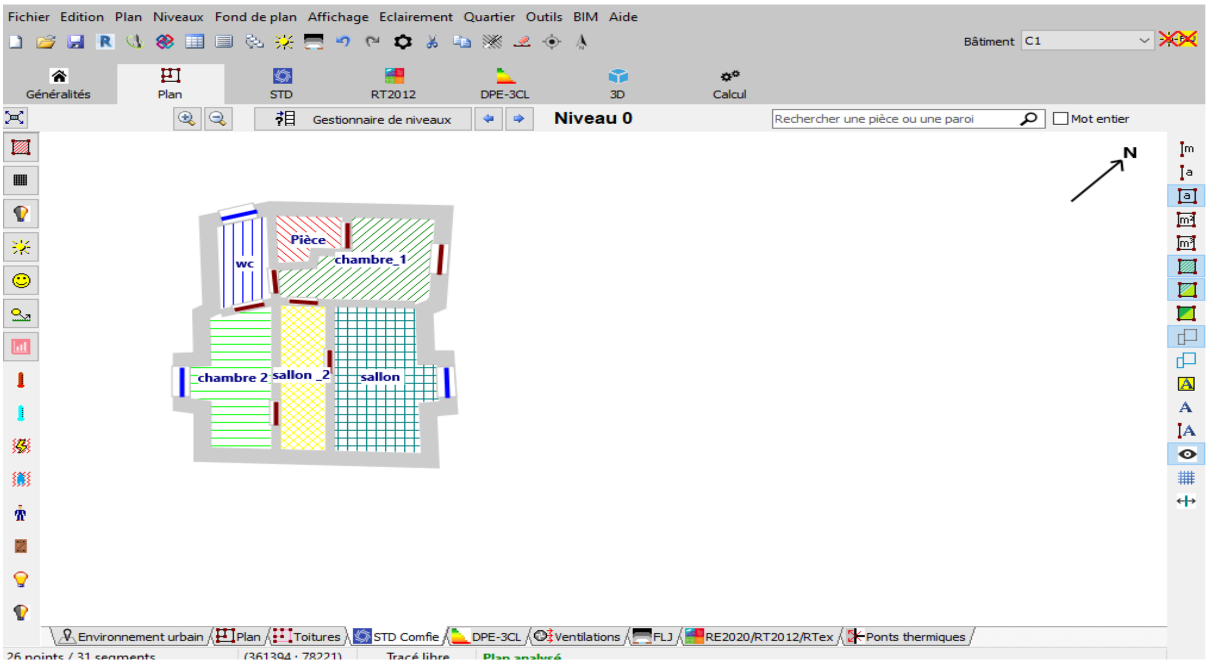
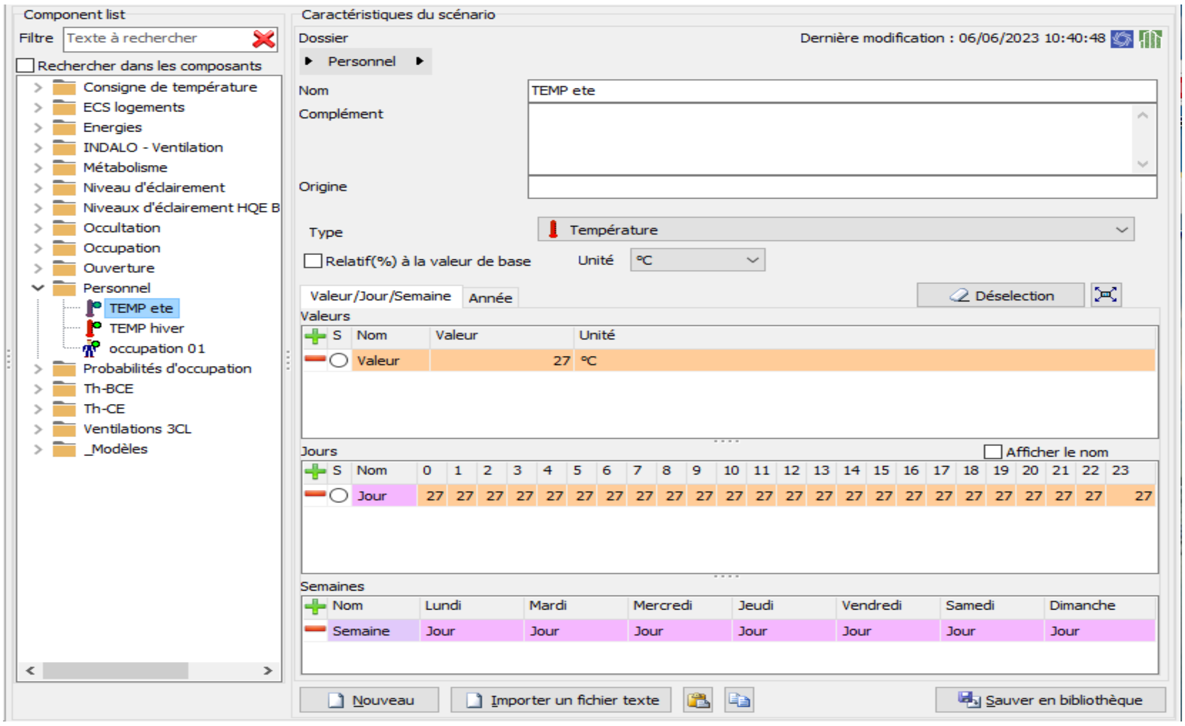


Figure III.6: Building the House

III.3.6. scenarios

we define scenarios of the building : scenarios of ventilation , concealment and occupation (how many people in the house ,their occupation house in week) also the temperature in summer (**27** C) also the metabolism we defined it between (**0.8** and **1.6**) during the week .



Dernière modification : 06/06/2023 10:40:48

Nom: TEMP ete

Complément:

Origine:

Type: Température

☐ Relatif(%) à la valeur de base

Unité: °C

Valeurs

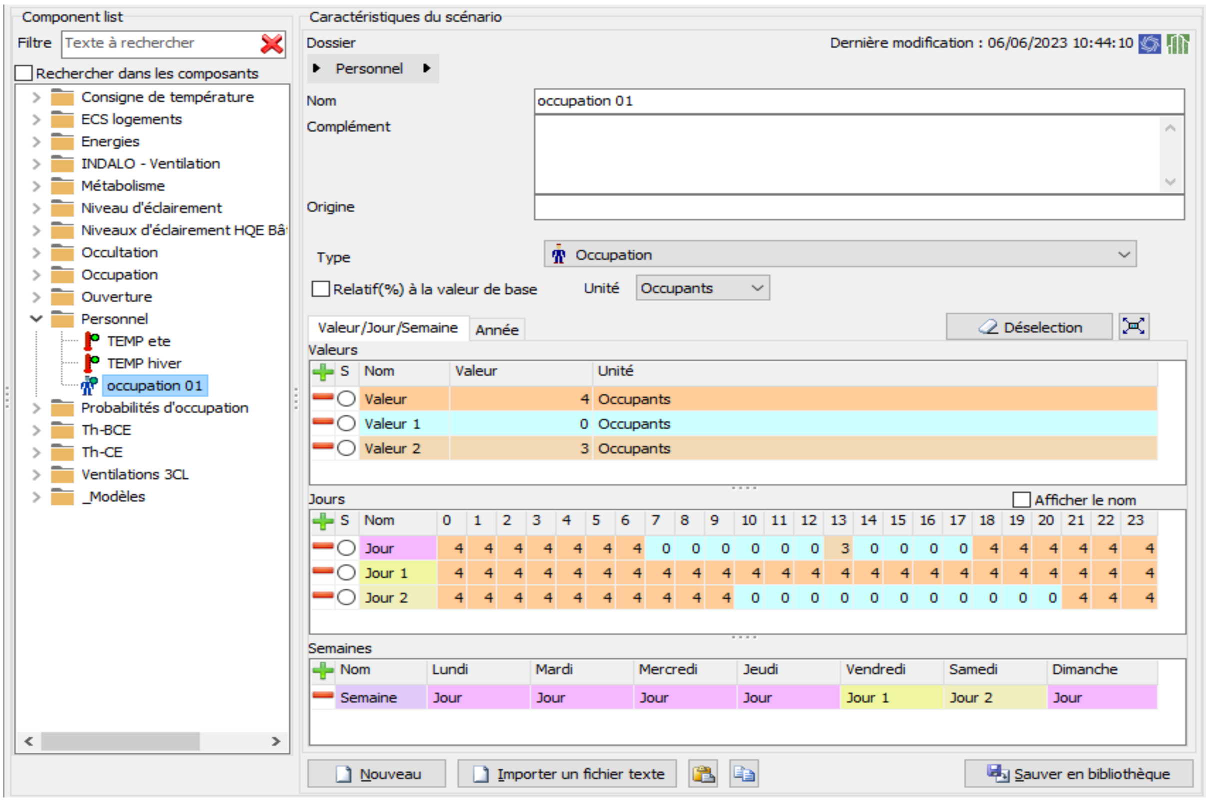
S	Nom	Valeur	Unité
○	Valeur	27	°C

Jours ☐ Afficher le nom

S	Nom	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
○	Jour	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

Semaines

Nom	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Semaine	Jour	Jour	Jour	Jour	Jour	Jour	Jour



Dossier: Personnel

Dernière modification : 06/06/2023 10:44:10

Nom: occupation 01

Complément:

Origine:

Type: Occupation

☐ Relatif(%) à la valeur de base — Unité: Occupants

Valeur/Jour/Semaine | Année

Valeurs

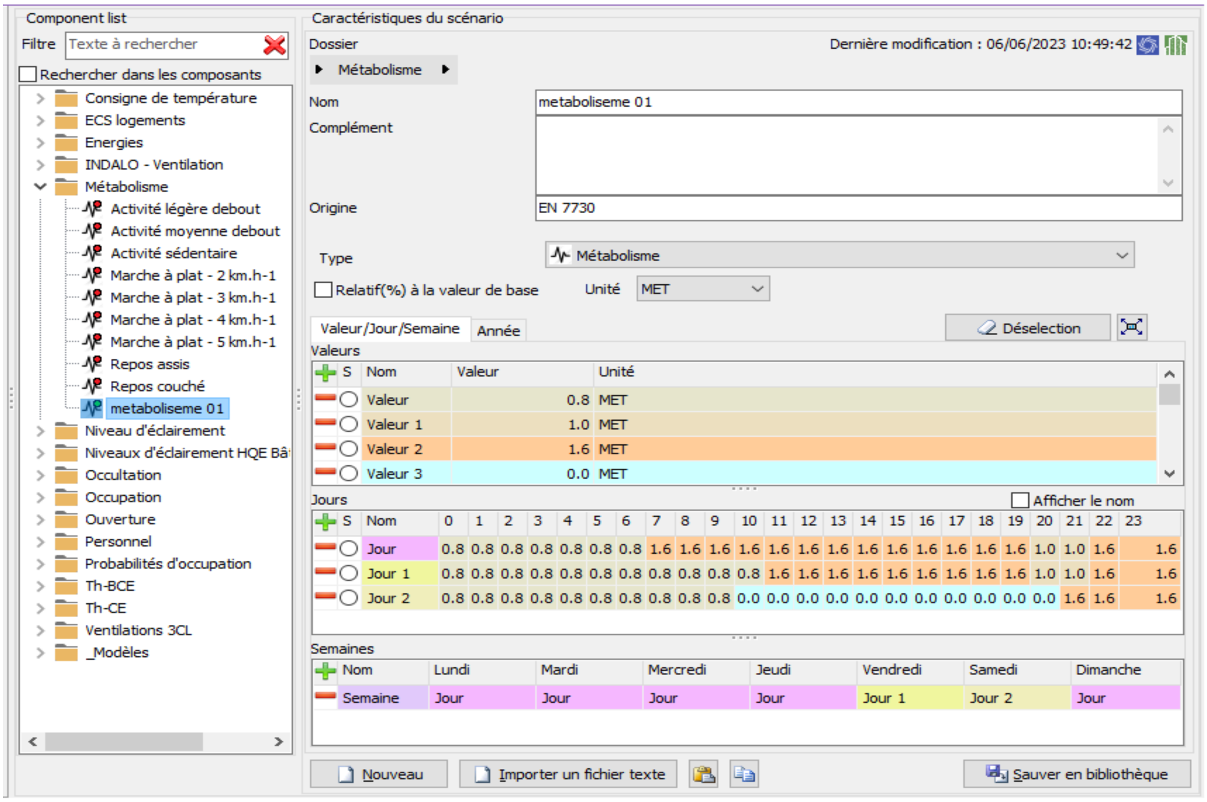
S	Nom	Valeur	Unité
○	Valeur	4	Occupants
○	Valeur 1	0	Occupants
○	Valeur 2	3	Occupants

Jours — ☐ Afficher le nom

S	Nom	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
○	Jour	4	4	4	4	4	4	4	0	0	0	0	0	0	3	0	0	0	0	4	4	4	4	4	4
○	Jour 1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
○	Jour 2	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	4	4	4

Semaines

Nom	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Semaine	Jour	Jour	Jour	Jour	Jour 1	Jour 2	Jour



Dossier: Métabolisme

Dernière modification : 06/06/2023 10:49:42

Nom: metaboliseme 01

Complément:

Origine: EN 7730

Type: Métabolisme

☐ Relatif(%) à la valeur de base — Unité: MET

Valeur/Jour/Semaine | Année

Valeurs

S	Nom	Valeur	Unité
○	Valeur	0.8	MET
○	Valeur 1	1.0	MET
○	Valeur 2	1.6	MET
○	Valeur 3	0.0	MET

Jours — ☐ Afficher le nom

S	Nom	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
○	Jour	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.6	1.6
○	Jour 1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.0	1.0	1.6	1.6
○	Jour 2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.6	1.6

Semaines

Nom	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Semaine	Jour	Jour	Jour	Jour	Jour 1	Jour 2	Jour

Figure III.7**:** Define the scenarios and metabolism

III.3.7. start the simulation

We start by our first case without thermostat set point

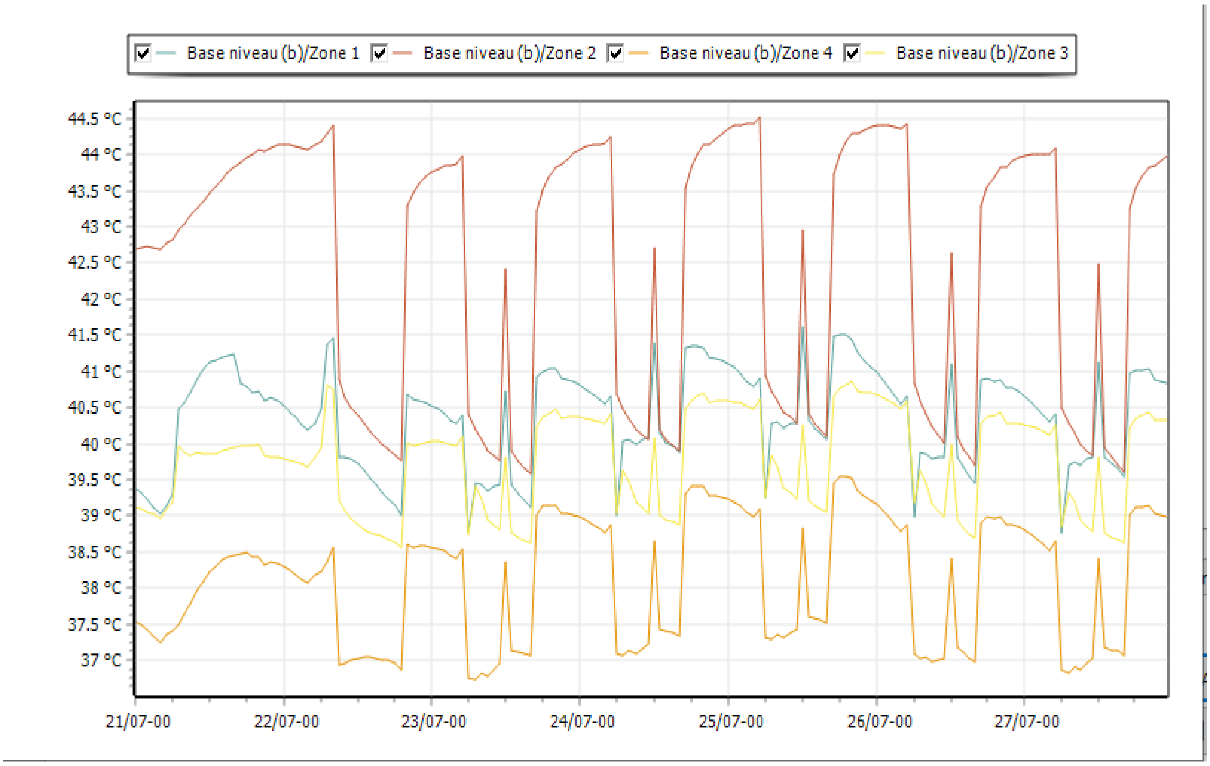
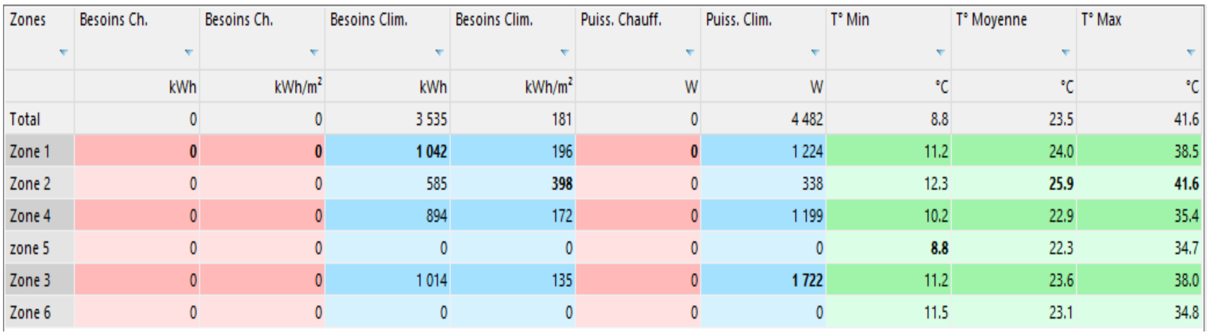


Figure III.8: Firstcase without thermostat set point

We see that the temperature is **44.3 C** in the zone which located in the south while it averages between 36 **C** and 36.5 **C** in the zone which located in the north.

There is also a temperature difference between day and night, which indicates that the thermal inertia of this building is low.

Next step is adding to this case the thermostat set point to see the deference between them so we notice that the maximal temperature is less than the first case now it's **41.6 C** and the minimal is **8.8 C,** also we notice that the Air conditioning needs are so high in zone 1 is **1042 kWh.**

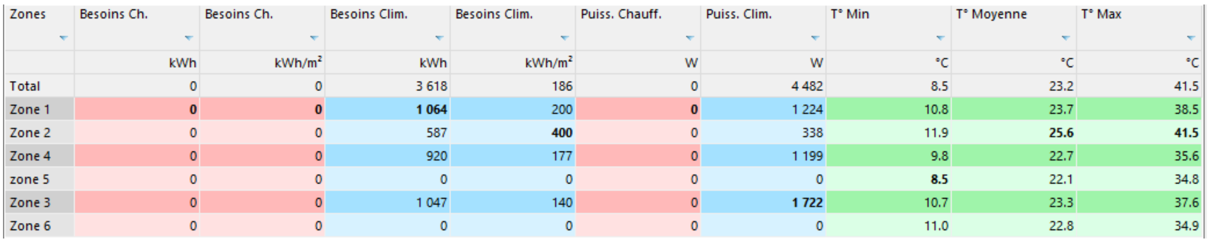


Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 535	181	0	4 482	8.8	23.5	41.6
Zone 1	**0**	**0**	**1 042**	196	**0**	1 224	11.2	24.0	38.5
Zone 2	0	0	585	**398**	0	338	12.3	**25.9**	**41.6**
Zone 4	0	0	894	172	0	1 199	10.2	22.9	35.4
zone 5	0	0	0	0	0	0	**8.8**	22.3	34.7
Zone 3	0	0	1 014	135	0	**1 722**	11.2	23.6	38.0
Zone 6	0	0	0	0	0	0	11.5	23.1	34.8

Figure III.9: First case with thermostat set point

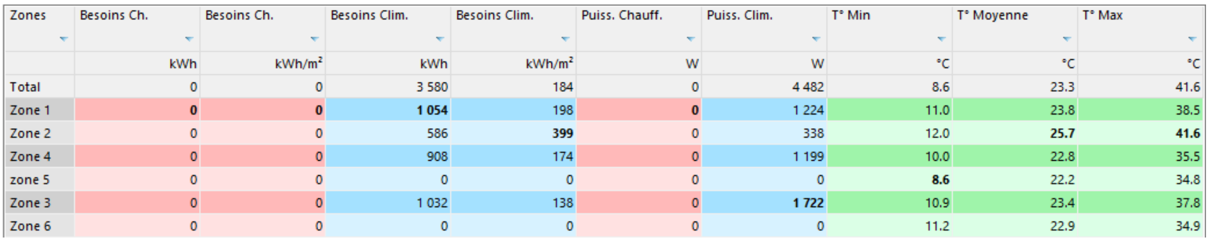
After seeing the results we add in every time **3 cm** of **palm trunk** in the roof in order to see the changes in Air conditioning needs

From 5 cm:



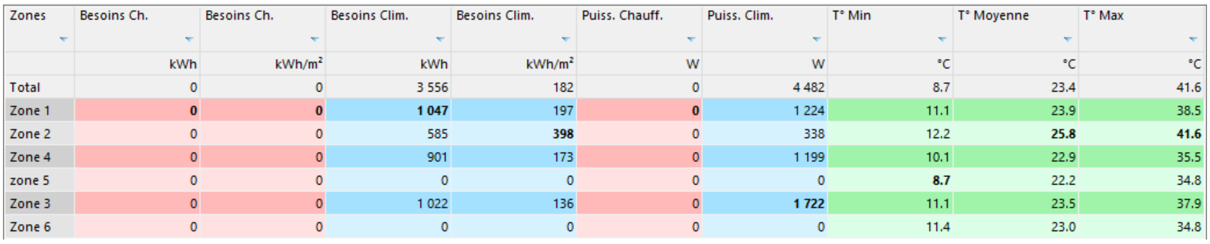
Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 618	186	0	4 482	8.5	23.2	41.5
Zone 1	**0**	**0**	**1 064**	200	**0**	1 224	10.8	23.7	38.5
Zone 2	0	0	587	**400**	0	338	11.9	**25.6**	**41.5**
Zone 4	0	0	920	177	0	1 199	9.8	22.7	35.6
zone 5	0	0	0	0	0	0	**8.5**	22.1	34.8
Zone 3	0	0	1 047	140	0	**1 722**	10.7	23.3	37.6
Zone 6	0	0	0	0	0	0	11.0	22.8	34.9

From 8 cm:



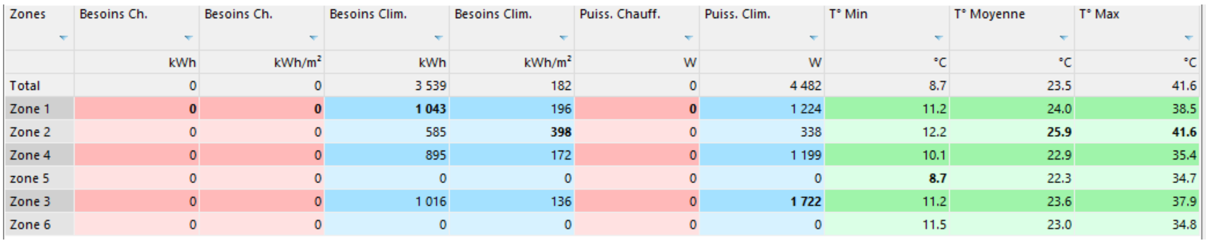
Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 580	184	0	4 482	8.6	23.3	41.6
Zone 1	**0**	**0**	**1 054**	198	**0**	1 224	11.0	23.8	38.5
Zone 2	0	0	586	**399**	0	338	12.0	**25.7**	**41.6**
Zone 4	0	0	908	174	0	1 199	10.0	22.8	35.5
zone 5	0	0	0	0	0	0	**8.6**	22.2	34.8
Zone 3	0	0	1 032	138	0	**1 722**	10.9	23.4	37.8
Zone 6	0	0	0	0	0	0	11.2	22.9	34.9

From 11 cm:



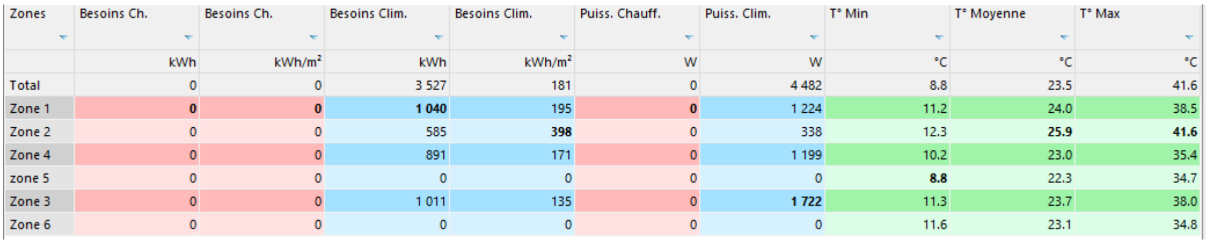
Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 556	182	0	4 482	8.7	23.4	41.6
Zone 1	**0**	**0**	**1 047**	197	**0**	1 224	11.1	23.9	38.5
Zone 2	0	0	585	**398**	0	338	12.2	**25.8**	**41.6**
Zone 4	0	0	901	173	0	1 199	10.1	22.9	35.5
zone 5	0	0	0	0	0	0	**8.7**	22.2	34.8
Zone 3	0	0	1 022	136	0	**1 722**	11.1	23.5	37.9
Zone 6	0	0	0	0	0	0	11.4	23.0	34.8

From 14 cm:



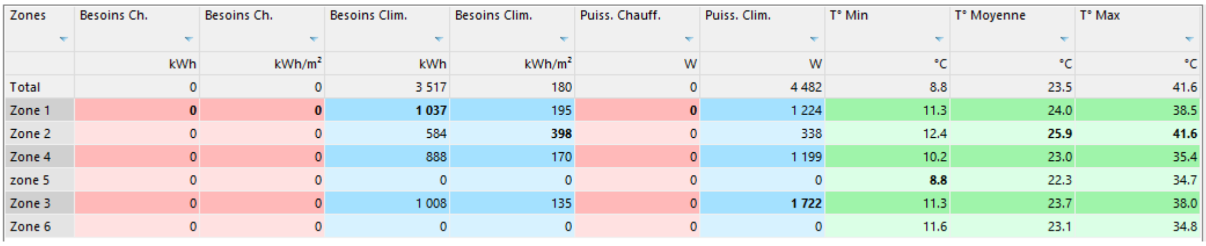
Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 539	182	0	4 482	8.7	23.5	41.6
Zone 1	**0**	**0**	**1 043**	196	**0**	1 224	11.2	24.0	38.5
Zone 2	0	0	585	**398**	0	338	12.2	**25.9**	**41.6**
Zone 4	0	0	895	172	0	1 199	10.1	22.9	35.4
zone 5	0	0	0	0	0	0	**8.7**	22.3	34.7
Zone 3	0	0	1 016	136	0	**1 722**	11.2	23.6	37.9
Zone 6	0	0	0	0	0	0	11.5	23.0	34.8

From 17 cm:



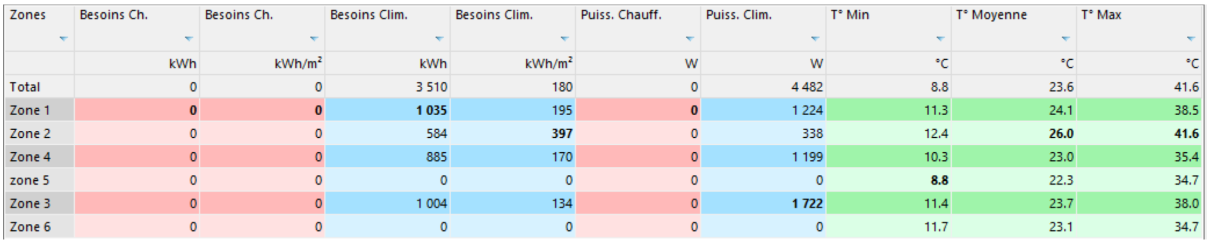
Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 527	181	0	4 482	8.8	23.5	41.6
Zone 1	**0**	**0**	**1 040**	195	**0**	1 224	11.2	24.0	38.5
Zone 2	0	0	585	**398**	0	338	12.3	**25.9**	**41.6**
Zone 4	0	0	891	171	0	1 199	10.2	23.0	35.4
zone 5	0	0	0	0	0	0	**8.8**	22.3	34.7
Zone 3	0	0	1 011	135	0	**1 722**	11.3	23.7	38.0
Zone 6	0	0	0	0	0	0	11.6	23.1	34.8

From 20 cm:



Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 517	180	0	4 482	8.8	23.5	41.6
Zone 1	**0**	**0**	**1 037**	195	**0**	1 224	11.3	24.0	38.5
Zone 2	0	0	584	**398**	0	338	12.4	**25.9**	**41.6**
Zone 4	0	0	888	170	0	1 199	10.2	23.0	35.4
zone 5	0	0	0	0	0	0	**8.8**	22.3	34.7
Zone 3	0	0	1 008	135	0	**1 722**	11.3	23.7	38.0
Zone 6	0	0	0	0	0	0	11.6	23.1	34.8

From 23 cm:

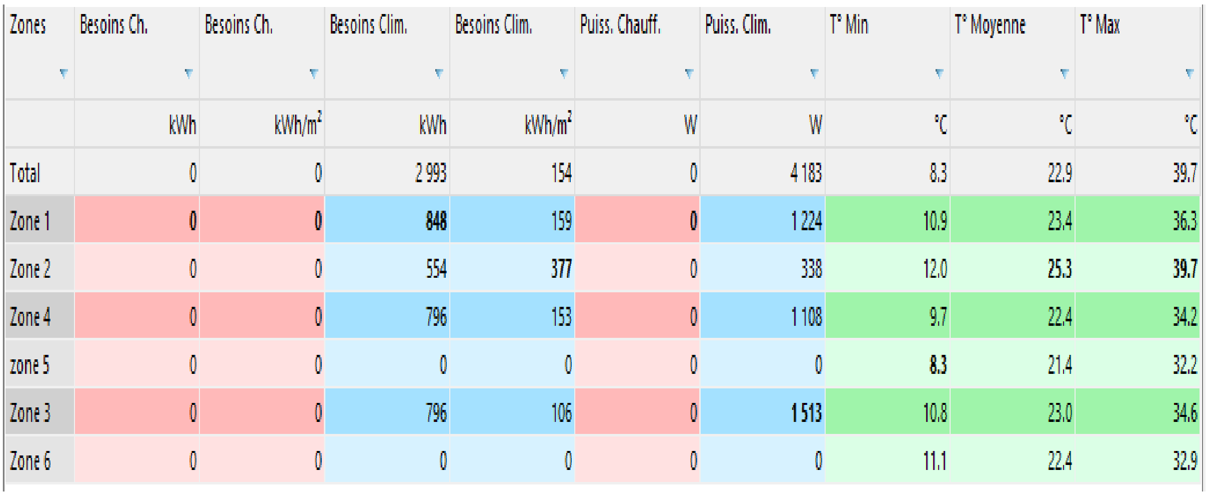


Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	3 510	180	0	4 482	8.8	23.6	41.6
Zone 1	**0**	**0**	**1 035**	195	**0**	1 224	11.3	24.1	38.5
Zone 2	0	0	584	**397**	0	338	12.4	**26.0**	**41.6**
Zone 4	0	0	885	170	0	1 199	10.3	23.0	35.4
zone 5	0	0	0	0	0	0	**8.8**	22.3	34.7
Zone 3	0	0	1 004	134	0	**1 722**	11.4	23.7	38.0
Zone 6	0	0	0	0	0	0	11.7	23.1	34.7

Figure III.10: Results of adding 3 cm of isolation

After seeing the results we can say that the best isolation is the isolation from **20 cm** because after that when we add 3 cm more we didn’t get more temperature less so the **optima lsolution** is from **20 cm** of palm trunk isolation.

The last step is taking the optimal solution and make it without thermostat set point but we add **Masks surround the house** to see how will it effect in the Air conditioning needs



Zones	Besoins Ch.	Besoins Ch.	Besoins Clim.	Besoins Clim.	Puiss. Chauff.	Puiss. Clim.	T° Min	T° Moyenne	T° Max
	kWh	kWh/m²	kWh	kWh/m²	W	W	°C	°C	°C
Total	0	0	2 993	154	0	4 183	8.3	22.9	39.7
Zone 1	**0**	**0**	**848**	159	**0**	1 224	10.9	23.4	36.3
Zone 2	0	0	554	**377**	0	338	12.0	**25.3**	**39.7**
Zone 4	0	0	796	153	0	1 108	9.7	22.4	34.2
zone 5	0	0	0	0	0	0	**8.3**	21.4	32.2
Zone 3	0	0	796	106	0	**1 513**	10.8	23.0	34.6
Zone 6	0	0	0	0	0	0	11.1	22.4	32.9

Figure III.11: The optimal solution without thermostat set point but with masks sur round the house.

So we notice that the masks surround the house made the heat get down from **44.3 C** to **39.7 C**, and also get down the air conditioning needs until **848 kWh**.

Conclusion:

After simulation and seeing the results, we can say that the masks surround the house made the heat get down remarkably, for this reason the Mozabites were building next to each other and making narrow roads to avoid the high temperature inside the houses and reduce the use of source of cooling.

General Conclusion

In arid areas, the use of palm trunks as roofing material can have a number of important benefits:

Insulation: palm trunks provide natural insulation because of their fibrous structure. They help reduce the transmission of solar heat into buildings when used in roofs. This can help maintain a cooler indoor temperature. This reduces the need for air conditioning and saves energy.

Protection from the sun: Palm trunk roofs can act as a shield against direct sunlight. They absorb some of the sun's energy, reducing the impact of direct sunlight on the roof surface. This can help extend the life of the roof by reducing the damage caused by UV rays.

Durability in dry conditions: Palm trunks are naturally adapted to dry conditions and can withstand high heat, drought and strong winds. When used in roofs, they can withstand the extreme weather conditions of arid zones, providing a durable and resilient solution.

Local aesthetics: Using palm trunks in roofs allows buildings to blend in with the natural landscape of arid zones. This can help preserve local aesthetics by using natural materials that reflect the cultural identity of the region.

Use of renewable resources: Palms are fast-growing plants and are often grown for economic purposes in arid areas. Using palm trunks for roofing promotes the use of renewable and sustainable resources, reducing the environmental impact of construction.

However, it is important to note that the use of palm trunks for roofing must be done responsibly. The sustainable availability of palm resources must be ensured, as well as regular maintenance of the roofs to ensure their durability and safety.

Reference

[1] Thèse de Doctorat LMD Kadri Meryem , 2021 The contribution of double skin roof coupled with thermo reflective paint to improve thermal and energy performance for the 'Mozabit'houses: Case of Beni Isguen's Ksar in southern Algeria.

[2] **Finocchiaro, L. (2019).** Enhancing Environmental Performance of Vernacular Architecture. A Case Study *Sustainable Vernacular Architecture* (pp. 257-273): Springer, Cham.

[3] https://mediaculture.info/larchitecture-traditionnelle-dite-vernaculaire-des-constructions-elegantes-et-bioclimatiques/

[4] [Rapoport. A, 1972]

[5] https://facsct.univ-annaba.dz/?p=2993

[6] **Salkini, H., Greco, L., & Lucente, R. (2017).** Towards adaptive residential buildings traditional and contemporary scenarios in bioclimatic design (the case of Aleppo). *Procedia Engineering, 180*, 1083-1092.

[7] **Bouchair, A. (1989).** *Solar induced ventilation in the Algerian and similar climates.* Doctoral thesis, University of Leeds.

[8] **Sayigh, A. (2019).** *Sustainable Vernacular Architecture: How the Past Can Enrich the Future*: Springer.

[9] **Keshtkaran, P. (2011).** Harmonization between climate and architecture in vernacular heritage: a case study in Yazd, Iran. *Procedia Engineering, 21*, 428-438.

[10] **Maleki, B. A. (2011).** Traditional sustainable solutions in Iranian desert architecture to solve the energy problem. *International Journal on Technical and Physical Problems of Engineering (IJTPE), 6*, 84-91.

[11] **Santamouris, M., & Asimakopoulos, D. (1996).** *Passive cooling of buildings*: Earthscan.

[12] **Saadatian, O., Haw, L. C., Sopian, K., & Sulaiman, M. Y. (2012).** Review of windcatcher technologies. *Renewable and Sustainable Energy Reviews, 16*(3), 1477-1495.

[13] **Zarandi, M. M. (2009).** Analysis on Iranian wind catcher and its effect on natural ventilation as a solution towards sustainable architecture (Case Study: Yazd). *Eng Technol, 54*, 574-579.

[14] **Hughes, B. R., Calautit, J. K., & Ghani, S. A. (2012).** The development of commercial wind towers for natural ventilation: A review. *Applied energy, 92*, 606-627.

[15] (https://dwarchive.com/archive/vaulted-roof-cross-windows-yazd-city)

[16] **Hadhramaut, W. (2016).** Rehabilitation of the City of Shibam.

[17] **Hwaish, A. N. A. (2015).** Impact of heat exchange on building envelope in the hot climates. *International Journal of Emerging Technology and Advanced Engineering, 5*(2), 47-57.

[18] **Sadineni, S. B., Madala, S., & Boehm, R. F. (2011).** Passive building energy savings: A review of building envelope components. *Renewable and Sustainable Energy Reviews, 15*(8), 3617-3631.

[19] **Lopez-Besora, J., Coch, H., & Pardal, C. (2019).** Contemporary roof design concepts: learning from vernacular architecture *Sustainable Vernacular Architecture* (pp. 357-376): Springer.

[20] **Williams, K. J., Lee, K. E., Sargent, L., Johnson, K. A., Rayner, J., Farrell, C., . . . Williams, N. S. (2019)**. Appraising the psychological benefits of green roofs for city residents and workers. *Urban Forestry & Urban Greening, 44*, 126399.

[21] **Hartig, T., Mitchell, R., De Vries, S., & Frumkin, H. (2014).** Nature and health. *Annual review of public health, 35*, 207-228.

[22] **Lee, K. E., Williams, K. J., Sargent, L. D., Williams, N. S., & Johnson, K. A. (2015).** 40-second green roof views sustain attention: The role of micro-breaks in attention restoration. *Journal of Environmental Psychology, 42*, 182-189.

[23] https://www.preservationdupatrimoine.fr/toiture-les-differentes-formes/

[24] **https://www.guide-travaux-toiture.be/types-de-toitures/**

[25] **Encyclopédie libre, W. (2016).** Toit-terrasse.

[26] https://energieplus-lesite.be/techniques/enveloppe7/techniques-d-isolation/toiture-plate4/toiture-chaude/#Generalites

[27] https://energieplus-lesite.be/techniques/enveloppe7/techniques-d-isolation/toiture-plate4/toiture-inversee/

[28] **Guide pratique pour les architectes, G. (2013).** L'isolation thermique de la toiture plate

[29] **Guide. (2015).** Toiture plate, from https://www.guidebatimentdurable.brussels/fr/toiture-plate.html?IDC=9164

[30] (https://toiture.bilp.fr/toiture-terrasse-12/mise-en-oeuvre/structure-bois/toiture-chaude-froide)

[31] (https://energieplus-lesite.be/techniques/enveloppe7/techniques-d-isolation/toiture-plate4/toiture-chaude/)

[32] https://energieplus-lesite.be/techniques/enveloppe7/techniques-d-isolation/toiture-plate4/toiture-froide/

[33] (https://mobic-autoconstruction.fr/2017/05/02/isoler-sa-toiture-plate/)

[34] https://energieplus-lesite.be/techniques/enveloppe7/techniques-d-isolation/toiture-plate4/toiture-combinee/

[35] (https://www.guidebatimentdurable.brussels/fr/isolation-d-une-toiture-plate.html?IDC=2214)

[36] (https://www.cupapizarras.com/fr/actualite/10-maisons-contemporaines-toits-en-pente/)

[37] **Singh, R. P. (2019).** Continuing culture and meeting modernity: The World Heritage villages of Shirakawa-Gō and Gokayama, Japan *Routledge Companion to Global Heritage Conservation* (pp. 128-151): Routledge.

[38] **Szalapaj, P. (2014).** *Contemporary architecture and the digital design process*: Routledge.

[39] **La Roche, P., & Berardi, U. (2014).** Comfort and energy savings with active green roofs. *Energy and Buildings, 82*, 492-504.

[40] (Cooper, 2008)

[41] **Kafafy, N. A. (2009).** Thinking out of the Box: Approaches for Facing the Under-Supplied Green Spaces in Over-Urbanized Compact Cities, with Application on Cairo City. *Urban Design Research: Method and Application, 3*, 165.

[42] **Ayata, T., Tabares-Velasco, P. C., & Srebric, J. (2011).** An investigation of sensible heat fluxes at a green roof in a laboratory setup. *Building and environment, 46*(9), 1851-1861.

[43] (Google image, 2021)

[44] **Sailor, D. J., Elley, T. B., & Gibson, M. (2012).** Exploring the building energy impacts of green roof design decisions–a modeling study of buildings in four distinct climates. *Journal of Building Physics, 35*(4), 372-391.

[45] **Bates, A. J., Sadler, J. P., & Mackay, R. (2013).** Vegetation development over four years on two green roofs in the UK. *Urban Forestry & Urban Greening, 12*(1), 98-108.

[46] **Osma, G., Ordóñez, G., Hernández, E., Quintero, L., & Torres, M. (2016).** The impact of height installation on the performance of PV panels integrated into a green roof in tropical conditions. *Energy Production and Management in the 21st Century II: The Quest for Sustainable Energy, 205*, 147.

[47] **Gaffin, S. R., Khanbilvardi, R., & Rosenzweig, C. (2009).** Development of a green roof environmental monitoring and meteorological network in New York City. *Sensors, 9*(4), 2647-2660.

[48] **Zhang, G., He, B.-J., Zhu, Z., & Dewancker, B. J. (2019).** Impact of morphological characteristics of green roofs on pedestrian cooling in subtropical climates. *International journal of environmental research and public health, 16*(2), 179.

[49] **Ragette, F. (2003).** *Traditional domestic architecture of the Arab region*: Edition Axel Menges.

[50] **Olgyay, V. (2015).** *Design with climate: bioclimatic approach to architectural regionalism-new and expanded edition*: Princeton university press.

[51] **Shibub, M. M. (2017).** Sustainable Architecture: Learned scientific lessons from Ghadames, a Traditional Libyan City. *INTERNATIONAL TRANSACTION JOURNAL OF ENGINEERING MANAGEMENT & APPLIED SCIENCES & TECHNOLOGIES, 8*(4), 233-241.

[52] **Wikipédia. (2021b)**. Liste des ksour au Maroc.

[53] **Wikipédia. (2021a).** Anciens ksour de Ouadane, Chinguetti, Tichitt et Oualata *Encyclopédie libre*.

[54] **Saljoughinejad, S., & Sharifabad, S. R. (2015).** Classification of climatic strategies, used in Iranian vernacular residences based on spatial constituent elements. *Building and environment, 92*, 475-493.

[55] **Faghih, A. K., & Bahadori, M. N. (2009).** Solar radiation on domed roofs. *Energy and Buildings, 41*(11), 1238-1245.

[56] **Azil, C., Djebri, B., & Rovero, L. (2018).** *Desert rose: building material of cupolas in the Souf in Algeria.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

[57] **Moradi, S. (2005).** Environmental control system. *Ashiyan: Tehran, Iran*, pp.128.

[58] (Côte, 2006)

[59] **Bencheikh, H. (2007).** *Etude et réalisation d'un système de refroidissement passif en utilisant une toiture radio-évaporative dans les climats chauds et arides.*

[60] **Bahadori, M., & Haghighat, F. (1985).** Passive cooling in hot, arid regions in developing countries by employing domed roofs and reducing the temperature of internal surfaces. *Building and environment, 20*(2), 103-113.

[61] **Alp, A. V. (1991).** Vernacular climate control in desert architecture. *Energy and Buildings, 16*(3-4), 809-815.

[62] **Kamal, M. A. (2012).** An overview of passive cooling techniques in buildings: design concepts and architectural interventions. *Acta Technica Napocensis: Civil Engineering & Architecture, 55*(1), 84-97.

[63] **Sadeghi, N. H. (2018).** Conservation and safety assessment of vaulted Adobe Architecture in Yazd, Iran.

[64] **Fathy, H. (2010).** *Architecture for the poor: an experiment in rural Egypt*: University of Chicago press.

[65] **Shaheen, M. (1975).** Hassan Fathy, Architecture for the Poor: An Experiment in Rural Egypt (Chicago and London, University of Chicago Press, 1973). Pp. 232 text, 132 illustrations, 6 appendices and a glossary of terms. $10.95. *International Journal of Middle East Studies, 6*(4), 511-514.

[66] **Lepik, A. (2010).** *Small scale, big change: new architectures of social engagement*: The Museum of Modern Art.

[67] **Oliver, P. (2003).** *Technology transfer–a vernacular view*: Wiley: Hoboken, NJ.

[68] **Didillon, H., & Donnadieu, C. (1977).** *Habiter le désert: les maisons mozabites: recherches sur un type d'architecture traditionnelle pré-saharienne* (Vol. 6): Editions Mardaga.

[69] **Trombadore, A., & Visone, F. (2019).** Vernacular architecture as model to design a prototype for affordable housing in mosul *Sustainable Vernacular Architecture* (pp. 181-205): Springer.

[70] **OPVM. (2013).** Planchers des constructions traditionnelles dans la vallée du M'zab. *brochure*. Retrieved from www.opvm.dz website:

[71] (A, 2018)

[72] **OPVM. (2018).** collecte d'informations et de données réelles suite à la demande de l'auteur, *Office de protection de la vallée du M'zab*. Rue ELdjazair, Ghardaia.

[73] **Chen, J., & Lu, L. (2021).** Comprehensive evaluation of thermal and energy performance of radiative roof cooling in buildings. *Journal of Building Engineering, 33*, 101631.

[74] (https://trustmyscience.com/revetement-toit-capable-reguler-temperature-maisons-toute-annee/)

[75] **Lucero-Álvarez, J., Martin-Dominguez, I. R., Rubín-Zacarías, F., Ledezma-Gallegos, A., & Alarcón-Herrera, M. (2011).** *Experimental comparison of heat flow through concrete roofing flagstones with different coatings.* Paper presented at the ISES Solar World Congress. Kassel, Alemania.

[76] **Lavaf Pour, Y., & Surat, M. (2012).** Towards new approaches for converting principles of vernacular architecture into energy efficient buildings in hot and dry climates. *Journal of Building Performance*.

[77] S Pandey, DA Hindoliya, R Mod - Applied Soft Computing, 2012 - Elsevier

[78] H Taleb, M Elsebaei, M El-Attar - Architectural Engineering and …, 2019 - Taylor & Francis

[79] DHC Toe, T Kubota - Solar energy, 2015 - Elsevier

[80] M Sebti, D Alkama, A Bouchair - Frontiers of Architectural Research, 2013 - Elsevier

[81] M Dabaieh, O Wanas, MA Hegazy, E Johansson - Energy and Buildings, 2015 - Elsevier

[82] Y Zahraoui, MR Basir Khan, I AlHamrouni, S Mekhilef… - Energies, 2021 - mdpi.com

[83] A Bouchair, A Dupagne - Building and environment, 2003 - Elsevier

[84] A Bouchair - **Building** and **environment**, **2004** – Elsevier

[85] A Bouchair, H Tebbouche, A Hammouni, MC Lehtihet… - Energy Procedia, 2013 – Elsevier

[86] V Costanzo, G Evola, A Gagliano… - Advances in …, 2013 - journals.sagepub.com

[87] S Kachkouch, F Ait-Nouh, B Benhamou, K Limam - Energy and Buildings, 2018 – Elsevier

[88] S Fantucci, V Serra - Energy and Buildings, 2019 – Elsevier

[89] KJ Chua, SK Chou - Energy, 2010 – Elsevier

[90] KT Zingre, MP Wan, SK Wong, WBT Toh, IYL Lee - Energy, 2015 – Elsevier

Chapter II

[1] https://journals.openedition.org/encyclopedieberbere/1676

[2] **Bensalah, I., Yousfi, B., Menaa, N., & Bougattoucha, Z. (2018).** Urbanisation de la vallée du M’zab et mitage de la palmeraie de Ghardaïa (Algérie): un patrimoine oasien menacé. *Belgeo. Revue belge de géographie*(2).

[3] **OPVM. (2018).** collecte d'informations et de données réelles suite à la demande de l'auteur, *Office de protection de la vallée du M'zab*. Rue ELdjazair, Ghardaia.

[4] Thèse de Doctorat LMD Kadri Meryem , 2021 The contribution of double skin roof coupled with thermo reflective paint to improve thermal and energy performance for the ‘Mozabit’houses: Case of Beni Isguen’s Ksar in southern Algeria.

[5] https://journals.openedition.org/belgeo/24469#tocto1n1

[6] **Chabi, M. (2009).** *Etude bioclimatique du logement socio-participatif de la vallée du M'zab: cas du ksar Tafilelt.*

[7] **Bouchair, A., Tebbouche, H., Hammouni, A., Lehtihet, M., & Blibli, M. (2013).** Compact cities as a response to the challenging local environmental constraints in hot arid lands of Algeria. *Energy Procedia, 42,* 493-502.

[8] **Chabi, M., & Dahli, M. (2011).** Une nouvelle ville saharienne sur les traces de l’architecture traditionnelle: Communication-Rouen, ksour.

[9] O.N.M, G.m.s., Climatic data of the M’zab valley, 2018: Noumret, Ghardaia.

[10] M.E.H.D. Lamrhari, Comportement thermique et économie d’énergie dans un appartement avec différentes mesures d’efficacité énergétique dans les six zones climatiques du Maroc, 2018, Université Cadi Ayyad Marrakech (Maroc).

[11] R. Guechchati, et al., Simulation de l’effet de l’isolation thermique des bâtiments Cas du centre psychopédagogique SAFAA à Oujda. J. Renew. Energies, 2010 13(2) 223–232.

[12] DTR3.2, thermal regulation of residential buildings, 2011, CNERIB: Alger.

[13] K. ALMI, Développement et caractérisation de matériaux à base du bois de palmier dattier adaptés aux applications de développement durable en Algérie, 2018, UNIVERSITE MOHAMED KHIDER BISKRA.

[14] Article M. Kadri, A. Bouchair and A. Laafer Energy & Buildings 256 (2022) 111746