



## Scientific article

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## Consideration of climatic conditions in the design of dwellings in the Sahara desert

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**Abstract.** Climate is one of the important factors in architecture. The historical architecture experience of the inhabitants of the desert zones has created invaluable knowledge on the design of residential environments in these aggressive conditions. Climate also is an important ecological component in the formation of vernacular architecture in the Saharan desert, it had a strong influence on the formation of desert settlements, the Saharan traditional dwellings are an indispensable source for studying organizations and architectural typologies and the adaptation to the harsh climate. The article discusses the climatic conditions in which the dwellings in the Sahara desert were built and the important strategies and passive climatization techniques of the design of the dwellings and presents a review of the various techniques developed. These various passive methods and strategies give the Saharan dwellings, adaptation, efficiency, and durability in these hot-arid conditions of the desert and can be a great source of architectural inspiration for new projects.

**Keywords:** Sahara, climate, residential buildings, environment, vernacular architecture

### Introduction

Since old times every population has created its own habitation in accordance with its needs and its environment. The Great Sahara is a land of old humanity, of great historical thickness, of human creations as beautiful as the creations of nature. Every era, every nation, has left its imprint on the vast backdrop of the Desert light trace or powerful mark, each one is a human signature, rich of all meaning [1]. The study of climatology is important to understand the relations between the buildings and the climate to determine the urban and architectural characteristics in the Saharan area [2]. The Saharan climate is characterized by the weakness and the irregularity of the precipitations, an intense luminosity, a strong evaporation and big differences of temperature [3].

Today, hot deserts are the most challenging regions in terms of energy consumption in buildings due to the intensive demand for cooling, as they experiences an extreme maximum air temperature of over 50 °C, there is increasing consumption of energy also buildings are responsible for more than 40% of global energy consumption [4], climate had a strong influence on the formation of desert habitations, for these reasons the problems of the dwellings design and her climate adaptation are strongly imposed.

The purpose of this study is explore and understand the relation between climate and architecture and draw lessons from vernacular architecture for applying sustainable energy concepts which help in the reduce of energy using.

The present work discuss the consideration of climatic conditions in the architecture design, for that we chose cities located in different geographical situations in different countries (Algeria, Libya, Morocco, Mali).

Now the most cities in Sahara have high power consumption and with high energy prices, these problems led to a rethinking of the way homes are designed. Now there are too many research study the possibilities for developing new techniques, for saving more energy as sustainable options for buildings through their improved energy, environmental and thermal performance.

### **Methodology**

In order to achieve the stipulated aim, the study in this paper traces the following steps:

1. Analyses of the climate in the Saharan area (Ghardaïa, Timbuktu) cities.
2. General overview of the vernacular architecture.
3. Defining the relation between the architecture and climate.
3. Analyses of the morphologies and structure of two Saharan cities (Ghardaïa, Ghadames).
4. Analyses of passive climatization techniques and strategies used in patio house.
5. Defining the benefits of the use of these passive climatization techniques.

### **Climatic conditions in the Saharan area**

In the Great Sahara desert, an average effective duration of insolation of more than 3, 978 hours in each year is regularly recorded, more than 10 hours per day, but in the central Sahara more than 4,000 hours of annual daylight (more than 11 hours a day) [5].

The word “Sahara” certainly refers to geographical reality [6], and in the arid zones, there is usually less than 250 mm of precipitation a year, there are several deserts of the hot deserts (figure 1) in the world like such as the Great Sahara (figure 2), Arabian Desert, Kalahari Desert, Syrian Desert, the only thing that is typical for all deserts is their aridity, translated by the weakness and rarity of precipitation. The important aridity called hyper-aridity, elevation, and soil, with variations in with mean annual temperatures exceeding 30 °C (86 °F). Other general features are dust, dry vegetation, and most importantly, temperature decreases quickly just after sunset and increases after sunrise [7]. With an area of 9,065,000 km<sup>2</sup> and extends over more than ten countries: Algeria, Chad, Mali, Egypt, Senegal, Mauritania, Morocco, Niger, Libya, Sudan, Tunisia, and Western Sahara, the Great Sahara is the largest desert hot in the world’s lowest supply area and considered as the best illustration of hot deserts in the world, the extensive hot desert located in the northern part of the African continent [8].

In the hottest months (figure 3) temperatures can rise over 50 °C (122 °F). A single daily variation of 0.5 °C (31.1 °F) to 37.5 °C (99.5 °F) has been recorded [9]. The two graphs down show the climate in Timbuktu and Ghardaïa cities within a year (figure 4), the climate graphs depict monthly average temperatures, precipitation, wet days, sunlight hours, relative humidity and wind speed.



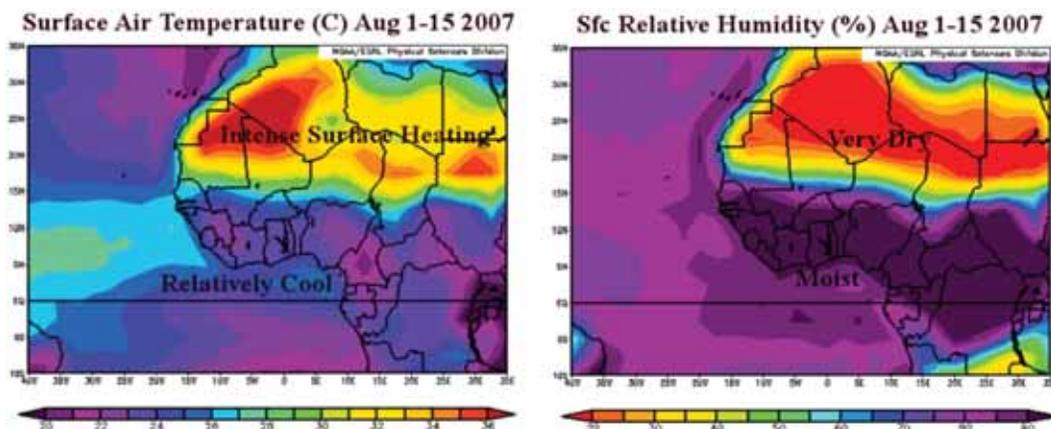
**Figure 1.** The map of Köppen — Geiger, climate classification “Köppen” BWh

Source: [https://upload.wikimedia.org/wikipedia/commons/e/e4/Koppen\\_World\\_Map\\_BWh.png](https://upload.wikimedia.org/wikipedia/commons/e/e4/Koppen_World_Map_BWh.png)



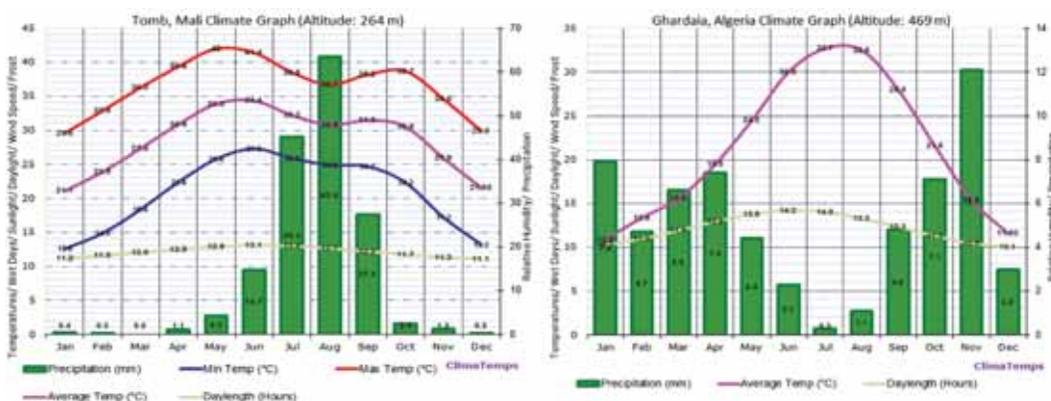
**Figure 2.** The Great Sahara desert

Source: <https://www.britannica.com/place/Sahara-desert-Africa>



**Figure 3.** National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis of Northern Africa during August 1—15, 2007 showing the temperature (*left*) and moisture (*right*) gradients

Source: <http://maps.wunderground.com/blog/Weather456/archive.html?year=2010&month=06>



**Figure 4.** Timbuktu city (Mali), Ghardaia city (Algeria), Climate Graphs

Source: <http://www.smara.climateemps.com/map.php>

In addition, the climate has a strong sunshine with a large portion of the direct radiation. The clear night sky can cause great differences between day and night temperatures, and the potential for radiative cooling is high. Winter nights are cold in certain regions [10]. The Saharan population, within the limits of the Sahara countries (Algeria, Morocco, Mauritania, Mali, Niger, Tunisia, and Chad), is estimated at 1.7 million inhabitants in 1948, 2 million in 1966 and 10 million in the mid-1994 [10]. Moreover, there is a large growth in population in the last 10 years.

### ***The vernacular architecture and Saharan urbanization***

The vernacular or traditional architecture has achieved through trial and error through the years inherently provides the aesthetic qualities, the climatic adaptability, and the economic feasibility, with a respect of surrounding nature that today's sensitive architects

search for. Indigenous urban and rural fabric and individual building structures demonstrate endlessly such ingenuities of past architecture. Climatic control commences with community planning on the urban scale. It initiates through the way buildings agglomerate and shelters each other from the heat, the way serpentine-like streets denounce the harsh sun and pull the cool breeze through while keeping dust and sand out [12]. The term “vernacular architecture” is used to refer to traditional buildings that have been designed and built to match the local climate and culture and what built in the desert areas differed in the composition and construction material than built in other areas. Urbanization in the Sahara has a historical dimension, in this territory, characteristic type of residential buildings has developed with these conditions and inhabited spaces are integrated with the Saharan environment, with a unique harmony and homogeneity between buildings and nature because of the use of local natural resources as building materials [13]. The architecture and construction of clay has ancient historical roots and is of great importance in the modern world [14].

### ***The keys of the adaptation of desert habitations***

Desert habitation has always been effective in terms of adaptation to the harsh conditions of the terrain and climate. Cities are made in the forms of traditional architecture, largely due to the influence of the environment. However, there many vernacular techniques that have been developed for hot desert climates to seek cooling and comfort and day-lighting. To ensure the comfort of the habitat in such hot and arid environment there’s many strategies used we can observe on three levels: territory level, urban level, architectural level.

**1. Geographical location.** The most of Saharan cities are located near to a valley or Oases, a good geographical location is important for the architecture buildings, and to the adaptation of the climate conditions, the location near to Oases will allow for constant moderate climates in the city. In the Sahara we can find several distinct ecoregions. With their variations in climate, elevation, and soil quality, these regions harbor distinct communities of plants and animals, and the most of cities are situated in those ecoregions.

**2. Compact form of cities.** The second adaptation to climate conditions is start by the density of buildings (figure 5). Houses are compact with a closed outer face. The road layout of cities is narrow and is similar in most of the cities [15]. The streets, long and winding are shadowy most of the day [16]. The buildings are so tightly pressed against each other that they leave a minimum of the area of the external surfaces that are not protected from the marching rays of the sun and the hot winds-dry winds.

The planning structure of the complex is characterized by integrity and unity, almost complete absence of separately standing material volumes, high density and heat resistance of all residential buildings. In Saharan areas the climatic performance of urban forms begins at the scale of the city. This type of urban fabric has been relied upon to avoid heat and to obtain shade in addition to that, the narrowing of streets and alleys to reduce their exposure to the sun. Climatic performance of buildings in hot arid regions starts at the scale of the city, in a dense urban context, there is little space for dust swirls, for sand and for direct or diffuse solar radiation.

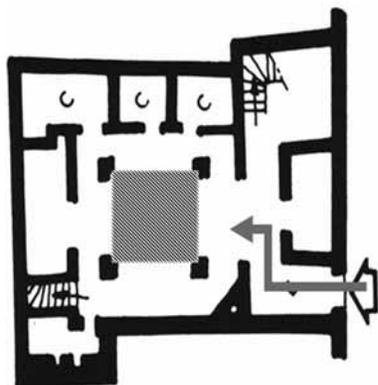


**Figure 5.** Urban view of Ghardaïa, M'Zab Valley, Algeria (left);  
City of Ghadames, Libya (George Steinmetz) (right)

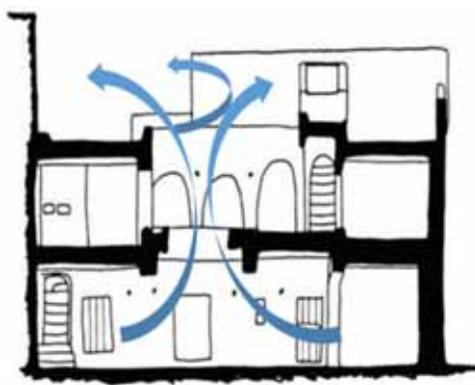


**Figure 6.** Marrakech, part of the medina  
shown the houses with courtyards  
(Friedrich Ragette)

Plans of houses are about 8—15 m width (figure 7), the patio can be a kind of microcosm (figure 8) that connects the house with nature, sky, sun, fresh air, earth, and sometimes water and vegetation. The spatial configuration of the cup-shaped patio creates a kind of microclimate [18].



**Figure 7.** Traditional house plan, with central patio,  
Ghardaïa, Algeria (J. Eshalie)



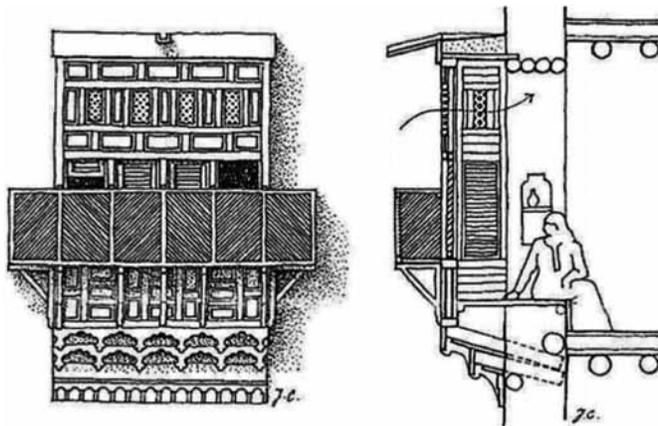
**Figure 8.** Section of Mozabite house in Ghardaïa,  
patio and the natural ventilation (Christian Bouquet)

**4. Vegetation and fountain.** For the ensure the comfort of the habitat, many of the inhabitants create a green courtyard with a fountain and plants as a traditional methods of natural refreshment, with natural ventilation, when the wind passes and contacts the wet surfaces of the fountain or basins diffuse their freshness inside the house, vegetation also has effectively used as shelters from unpleasant winds, filters sand, and dust, water and plants it is an important bioclimatic adaptation factors.

**5. Natural walls (adobe).** Sundried brick “adobe” used in the traditional building and made by clay material. During the hot day, the heat flow from exterior to interior, the consequence is a minimization of temperature change inside the building. The average thickness of adobe walls is from 30 cm to 80 cm and in some situation can be reaching to 120 cm. The traditional adobe have low heat conductivity and high energy storage capacity allows as much as 80% of the outside heat to be absorbed and only 20% transmitted inside [19]. The adobe construction has many advantages because of the inherent qualities of the material: recyclability, performance, energy, fire resistance, durability.

**6. Domes.** Domes are an architectural element and an old technical solution in hot-arid area. Oud Souf city in Algeria, called “city of a thousand cupolas” and the new Gournia project in Egypt are two cities where domes used as technical solution, the buildings in this two cities are built from the adobe and used domes, many cities use this element because the curve roof has a larger convection heat transfer surface, whereby it is more easily cooled. When air flows over a cylindrical or spherical object, the velocity of the air at the apex is increased, therefore, the pressure at the apex is lowered, the pressure difference induces the internal hot air to be discharged out through the air vent [20], and this formes are characterized by strength, stability, and dynamics [21].

**7. Mashrabiya.** The Mashrabiya is a traditional window screen used in many Saharan cities in deferent countries like Morocco and Egypt. Mashrabiya were mostly used in houses with numerous different functions among including producing an architectural envelope that can respond to sun exposure and changing incidence angles during the different days of the year, regulating air flow, reducing the temperature of the air current, increasing the humidity of the air current and guaranteeing a great amount of privacy [22]. There are different types of traditionally Mashrabiya built from wood (figure 9) or adobe, and the latticework designs different from region to region, and has offered effective protection against intense sunlight in the Sahara cities for several centuries.



**Figure 9.** Details of Mashrabiya in elevation and section view (F. Ragette)

## Conclusion and results

The passive design building is an alternative environmental technique, in comparison with mechanical systems used in the design and construction.

In the Sahara area, the compact urban form and the orientation of buildings in the sun and wind, the location of summer and winter spaces, the use of natural materials and clean energy as environmental potentials, narrow and enclosed passages, underground spaces, deep patios, thick walls, use of water and plants, as well as the morphological composition that respects the site, all this are the main characters of the traditional architecture which gives the Saharan habitation the adaptation, efficiency and durability in this extremely harsh conditions of the desert.

The proposed actions and recommendation for the passive design strategies:

- passive solar design;
- external shading for minimized infiltration of outside heat;
- using domes as solution for reducing internal temperature;
- maximizes the use of day-lighting for reducing the energy use;
- the use of patio house model;
- consideration of vegetation and fountain in the design of the house;
- the use of nature material (adobe) in construction;
- the use of Mashrabiya in the external windows.

Recently the energy demand is very high in the Saharan cities and using these techniques in the new construction can allow us to save more energy, and help in the sustainable development. Traditional construction methods achieved comfort, the using of passive design building is ultimate vision to reduce requirements for active mechanical systems.

Dwelling in the desert is like a paradox and an indispensable source for studying organizations and architectural typologies and the adaptation to climatic conditions. The designer of the new projects of habitations in the desert context can and ought to attain climatic comfort by skilfully manipulating architectural design parameters and make wise use of what nature provides us and learn from the lessons and strategies which have been used in the desert context.

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## Анализ климатических условий при проектировании жилой застройки в пустыне Сахара

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Климат — это один из основных факторов влияния в архитектуре. Исторический архитектурный опыт жителей зон пустынь является базовой информацией для исследования проблем проектирования жилой среды в экстремальных условиях. Климат также является важнейшей экологической составляющей по формированию искусственной пространственной среды для поселений в пустыне. Традиционные жилища Сахары — неисчерпаемый источник для изучения организации архитектурной типологии в экстремальных условиях жарко-сухого климата. В статье рассматриваются климатические условия, в которых строились традиционные жилища в пустыне Сахара, и методы пассивной климатизации при проектировании жилых помещений. Кроме того, представлен обзор разработанных методов адаптации, эффективности и защиты в жарко-сухих условиях пустыни, пригодных в качестве базового источника архитектурных решений для новых проектов жилых зданий массовой застройки.

**Ключевые слова:** Сахара, климат, жилые здания, окружающая среда, народная архитектура

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