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Towards Sustainable Residential Buildings in Hot Arid Climates: Learning from Traditional Architecture of the Souf Region (Algeria)

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Abstract. In southern Algeria, the local traditional settlements have been generated as a response to material, spiritual and cultural needs of people, whilst, they have also succeeded to respond to one of the harshest climates on the planet. In this respect, the vernacular dwelling of the Souf region provides a very instructive example of what is now called sustainable architecture. Furthermore, the traditional architecture of the Souf embodies ingenious cooling design strategies relevant to occupant behaviour, environment adaptation, techniques and local materials that can offer great opportunities to overcome the desert climate conditions regarding the contemporary buildings. The present research addresses the issue by performing a qualitative analysis on two case studies that were selected to represent respectively typical traditional dwellings and common contemporary residential buildings. Based on in-field collected data, the selected examples were analysed in order to assess and compare their thermal performance and climatic adaptability. The sustainable passive design features used in the traditional dwelling were specified, evaluated and then the potential to use them as design alternatives at the early architectural design stage of contemporary housing projects was explored. Finally, a set of recommendations that illustrates the convenient passives strategies is provided for application in hot arid climates.

Keywords. Traditional architecture, Sustainability, Climatic responsive design, Passive cooling strategies, Hot dry climate.

1. Introduction and background

Over time, the climate has been the foremost factor that influenced the evolution of vernacular settlements and building design. The secular built environment developed by local inhabitants resulted from their history-long experiences. Their dwelling was intrinsically related to the prevailing conditions. The ingenious climate-responsive design strategies have been evolved over the course of time to mitigate the effects of climate and to provide acceptable comfort conditions only by making the best use of locally available materials and resources. Furthermore, strategies implemented in vernacular constructions are usually passive and not dependent on fossil energy, which makes them suitable for contemporary construction [1].

As global warming is presently one of the main concerns of human beings, residential building stock represents a significant potential in tackling both worldwide energy and thermal built environment challenges. Indeed, the building sector is responsible for around 40% of the world's annual energy consumption and nearly 30% of all greenhouse gas (GHG) emissions [2]. This has induced major problems in terms of environment and energy consumption, including overexploitation and depletion of energy resources, environmental pollution, and climatic changes [3]. In order to deal with these issues, architects have a greater responsibility to design buildings that are environmentally sustainable. In this regard, vernacular architectures built by local builders to meet climatic constraints and socio-cultural expectations in a given place are valuable in promoting climate-specific passive technologies to contemporary buildings.

Another aspect of vernacular architecture is that it offers sound models for sustainable design. In this regard, it is well established that vernacular architecture addresses climatic conditions by using passive design [4]. Accordingly, human thermal comfort conditions derive from adequate constructive choices, architectural components and specific design features implemented in the form, orientation and materiality of buildings. This architecture also demonstrates an economical use of local resources including available materials and known construction technologies. Moreover, due to the absence of mechanical means, traditional buildings use natural resources like sun and wind and, thus, they are tightly integrated with their physical environment and have a minimum waste of resources.

In recent years, many studies have looked at climatic-responsive building design to enhance thermal comfort conditions in living space and at the same time to reduce the energy consumption. Accordingly, several researchers investigated vernacular dwellings in hot arid regions [5-7]. In general, they focused on their design characteristics and how traditional housing developed adaptation strategies to cope with the local environment based on social and cultural factors, as well as, thermal comfort [2],[4]. In this respect, the relevant literature states that in hot and arid region the focus was to minimize heat gains during summer. With this purpose, several cooling design strategies were developed, such as, urban compactness, proper orientation facing north and south, avoiding exposure to the west, self-shading forms, clustering buildings, high thermal inertia, small windows, curved or flat roofs and light colors, sun shading devices, etc.

As assessment of thermal comfort is very important to determine the indoor environmental conditions and the satisfaction of the occupants, methodological tools in form of tables and psychrometric charts, have been developed to predict the expected indoor comfort conditions inside buildings without mechanical systems. Based on outside climate factors such as relative humidity and dry bulb temperature and by performing qualitative analysis, the tools indicate suitable passive design strategies, i.e. solar radiation, air movement and evaporative cooling, for specific climatic conditions [4].

Algeria, which is the focus of the present study, is the largest country in Africa spreading over a vast territory. 80% of which is covered by the largest desert on earth - the Sahara. Practically, all the southern part of Algeria is considered as desert land where it is very dry and hot for almost the year. Despite the harsh climatic conditions that prevail in this severe environment, the Saharan traditional architecture has succeeded to develop ingenious climate-responsive solutions that provided comfortable indoor conditions for occupants, only by making appropriate usage of the local resources including available materials and relevant construction technologies.

As a Saharan region, the Souf has its unique historic and traditional architecture characteristics that evolved over the course of time, to meet material, spiritual and cultural needs of the inhabitants. Precisely, the Souf region is known for the originality of its dwelling, and in particular, the use of domes (*gouba*) and vaults. These elements, which result in curved roofs, have shaped the image of the Souf to the point of becoming the main expression of the vernacular architecture of the region and one of the essential vectors to express architectural identity (**Error! Reference source not found.**). The vernacular architecture of the city of El-Oued (the capital of the Souf) is, also, well known by its local materials, precisely the use of "*lous*" (desert stone) and "*tefza*" (a limestone, when fired gives a plaster of excellent quality). Thus, the typical architecture of the Souf, which is not found elsewhere in the Algerian territory, combines two original elements, both relating to the construction system: the building materials and the technique of domes.

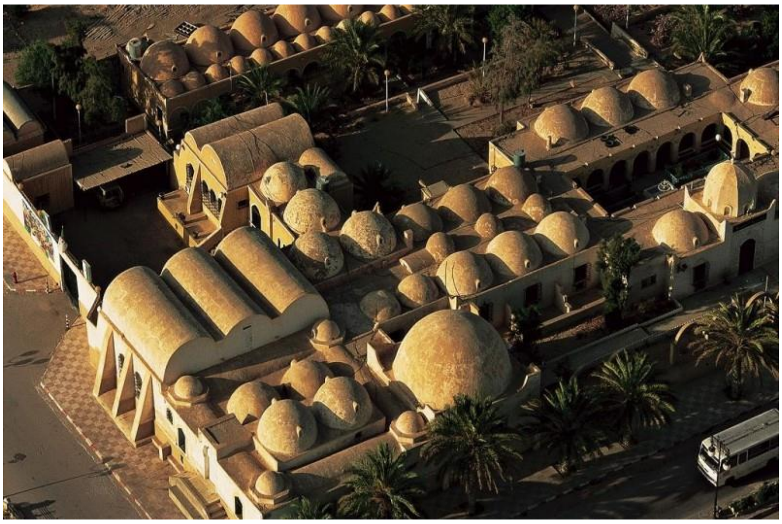

Figure 1. Domes and vaults used in El-Oued (capital of the Souf region)

In addition to its unique character, the traditional dwellings of the Souf region give a comprehensive example on how environmental constraints may be implemented to ensure survival. Considering the harsh climatic conditions that prevail in this Saharan region, the traditional architecture provides rational responses to cooling needs by focusing on protection against solar radiation and minimizing heat gains. Accordingly, various devices to attain thermal comfort were developed through the ingenuity of local builders. By using local materials and referring to specific knowledge gleaned over a long period of trial and error, the available resources were successfully exploited [7].

Within this view, the vernacular buildings of the Souf can be studied as models of environmentally responsive and sustainable architecture. Likewise, the study of ancient fabrics and traditional housing in this region can support the understanding of methods and tools for climate adaptation in harsh climates, including the Saharan regions. The current study analyses in a qualitative manner the vernacular architecture of these regions from specific location of the Souf (Algeria) regarding to climate responsiveness. In this regard, the research aims to evaluate the applicability of the vernacular cooling strategies in contemporary buildings to meet climatic requirements and achieve thermal comfort conditions with natural means.

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2. Research methodology

To assess the sustainable passive design features used in the traditional architecture of the Souf region in southern Algeria, a study was conducted based on a literature review and field research. The bioclimatic aspects of the traditional settlements were investigated through a qualitative analysis. The study was based on two main steps.

The first step focused on aspects that are most relevant for the analysis of the climatic performance of the built environment in a hot arid climate. A theoretical background has been developed. It gives an overview about the state of knowledge on the addressed topic and serves as a lever for the investigation. The city of El-Oued (capital of the Souf region) that illustrates the hot dry climate of Algeria was selected as physical context for the study. Accordingly, the climatic conditions prevailing in El-Oued were investigated based on climate data picked from the local weather station. The study identifies the suitable bioclimatic design strategies for the predominating desert climate of El-Oued using Mahoney Tables and ASHRAE's psychometric chart. The second step was analytical; it aims to identify and, then, assess the passive cooling design strategies used in the vernacular architecture of the Souf. This approach was based essentially on a fieldwork that was undertaken in the city of El-Oued. It induced site observations and field notes, used together with photo documentation and architectural surveys.

2.1. Presentation of the Souf region

The Souf is a Saharan region situated in south-east Algeria (**Error! Reference source not found.**). It is a part of the arid Grand Erg Oriental Basin at the north-eastern Sahara. According to Köppen climate classification the Souf falls in hot desert climate (BWh, in the Köppen climate classification). Typically, the climate of the Souf is extremely dry and arid; with hot, arid, and clear summers while winters are cold, dry, and mostly clear. Over the course of the year, the temperature typically varies from 5.5°C to 40.5°C and is rarely below 2°C or above 45°C. The highest temperature is in August: 49.0°C. Rainfall is light and sporadic, and summers are particularly dry. The average rainfall varies between 80 and 100 mm/year (period from October to February). The Sirocco (a hot dry wind) and sandstorms can blow throughout the year during several days and even weeks.

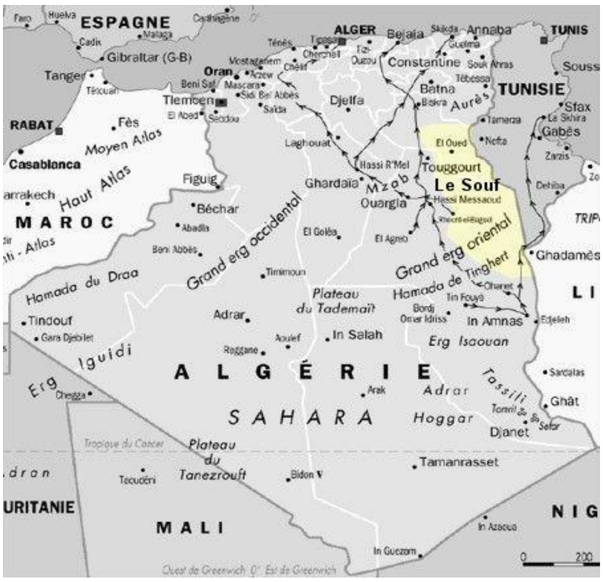

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Figure 2. Map showing the geographical location of the Souf region in Algeria.

2.2. Presentation of the case studies

2.2.1. Traditional house of the Souf. It is worth noting that the traditional plan of the vernacular residential buildings of the Souf, in both urban centres and the detached rural dwellings (*nezla*) is a faithful reproduction of the typical Arab-Islamic house. The latter has served as a reference model for the inhabitants of the Souf who interpreted it in the register of local culture [8]. From this point of view, the architectural design of the Sufi house responds to a central organisation around an open-air courtyard. Small square or rectangular single-story cells, aggregated around a courtyard, make up the traditional building type (**Error! Reference source not found.**). Each cell is covered with self-supporting domes.Furthermore, what strikes at first is the importance of the courtyard (haouch). The courtyard is the structuring space of the plan. It is also the most important space in terms of size. The surface area of the courtyard usually exceeds one third of the total area of the plot. Moreover, although it is the result of the addition of the different rooms that surround it, its configuration obeys a geometric order, which admits shapes close to the square, the rectangle or a combination of these basic shapes.

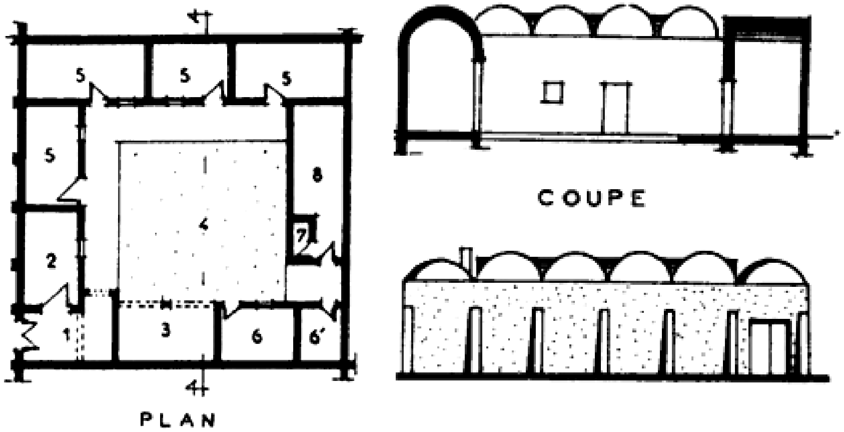
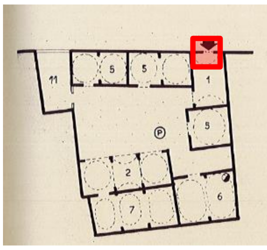
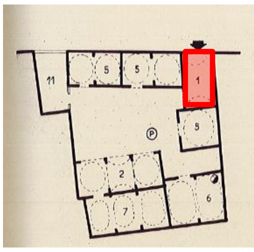
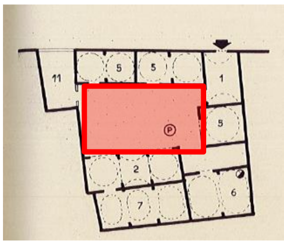
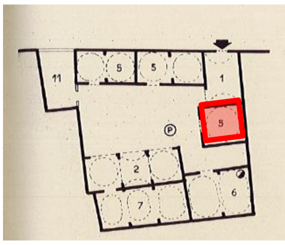
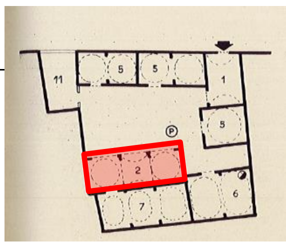


Figure 3. Architectural plans of a typical traditional house [8].

Table 1 shows the main components of a typical vernacular house in the Souf. The classification and typological analysis is based on functional characteristics, i.e., localisation in the basic residential unit, orientation and use-patterns.

Table 1. Typological analysis based on the socio-cultural patterns and spatial practices of the inhabitants in a typical traditional house of the Souf.

Space localisation in the plan	View on the space	Orientation	Usage of the space / Climate responsive design principles implemented

	1-The entrance gate 	East of the house.	• Transition between exterior and interior. • The only opening to the outside to favor intimacy.
	2- Entrance transition area “Sguifa” 	East of the house.	It plays several roles: • It is a space of stay in summer because it is a very cool corner in the hot season. • It serves to hide the courtyard from outside view. • It can be used by the householder as a reception room to meet with his friends.
	3-Courtyard “*haouch*” 	In the centre of the house.	• Main space and the core of the house. • The space that articulates all the house’s parts. • It allows access to all spaces that surround it (kitchen and bedrooms). • It is used by the inhabitants to carry out some domestic activities and to spend the summer nights. • The space where social and religious events are held. • The portico in the south of the courtyard can be used by the women as a reception room to receive their guests.
	4-Guest bedroom: “Dar dyaf “/ “Dar sguifa” 	South of the house.	• Space reserved only for the guests. • Found only in the wealthy families.
	5- Courtyard’s galerie “*sabat*”	At the south and/or north of the courtyard.	• Covered space but open to the courtyard. • Essential element to ensure thermal comfort when

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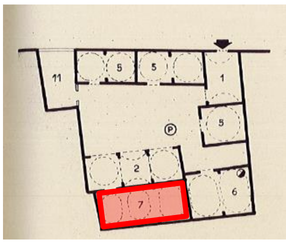
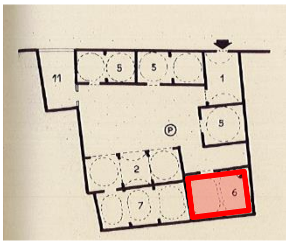
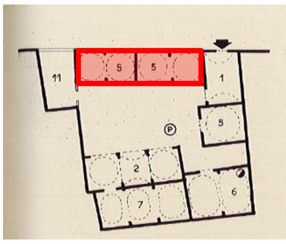
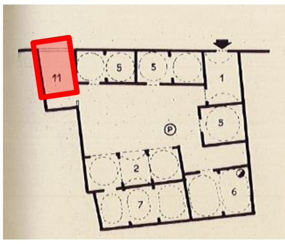
			performing domestic activities. • South sabat: cool and shaded for summer usage. • North sabat: benefit from sunshine in winter.
	6-The kitchen 		• The biggest room in the house. • Often situated in the southern corners of the house. • Generally reserved for women (cooking, household chores, etc.)
	7-Cellar /storage room “khabya”	South of the house.	• A space to stock different aliments (dates, food, etc.) where the orientation is very important to preserve the quality of the reserves.
	8-Rooms/living spaces “Byut / dar” 	North and south of the house	• Spread around the courtyard. • South *byut* are used in summer where it is cooler. • The byut are surmounted by cupolas “*gouba*” or domes “*demsa*”.
	9- Stable “ Zeryba”	West of the house	• Livestock shelter

The construction of the traditional architecture in the Souf is based on the prevailing local materials and techniques that are suited to the relevant climatic conditions. The building materials used are: desert stone (*lous*) - a very resistant building stone of gypsum crystals composed of silica and lime sulphate-, and the *tefza* gypsum used as mortar of the same material as the desert stone. *Lous* is used in the form of coarse rubbles for the construction of

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the foundations, the loadbearing walls and the domes, while *tefza* gypsum is used both for bedding mortar and plastering.

Regarding this construction techniques, the masonry is characterised by the use of the same raw material; foundations, walls and domes are all made with blocks of desert stone and gypsum mortar [5]. Hence, the walls are built with blocks of sand stones, both the external and internal walls are load-bearing, their thickness is nearly the same in many houses; about 45cm. Local materials are also used for the construction of roofs (**Error! Reference source not found.**). The rooms are covered with domes and vaults made of *lous* (local sand stone) and *tefza* (local plaster).

Figure 4. The construction process of a cell (left)**;** connection wall-dome (right) [5].

2.2.2. Contemporary dwelling in El-Oued city. What distinguishes the recently built houses is their openness to the public space. Furthermore, most of the traditional components have disappeared. Local materials were replaced by concrete; the openings are in most cases too large regarding the prevailing environmental conditions. Often, the windows are oversized, and the glazing surfaces do not seem to fit the rooms resulting in problems of glare and overheating. On the contrary, in other cases, they can be of small areas and do not ensure even the minimum requirements for daylight and ventilation. It is also worth noting that the "haouch" tends to disappear (**Error! Reference source not found.**). As a consequence, the spatial organisation in the contemporary house differs greatly from that of the traditional one. This has inevitably involved extensive transformations in terms of socio-cultural patterns and spatial practices of the inhabitants.

Technium Social Sciences Journal
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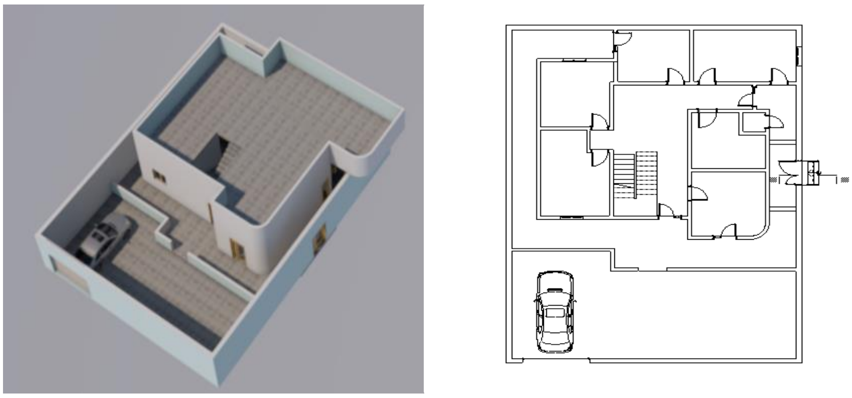

Figure 5. Example of a contemporary house.

3. Climate analysis using the bioclimatic tools

3.1. Mahoney Tables

It is a set of tables used in the pre-design phase to facilitate decision making process and identify the right orientation, compactness and openings of the building based on the climatic data of the area in order to achieve day and night comfort. Accordingly, the climatic data of the city of El-Oued has been implemented in the Mahoney Tables which provide preliminary design recommendations. They are grouped under eight headings: layout, spacing, air movement, openings, position of openings, protection of openings, walls, and roofs. The following tables give the recommendations for the Souf region (Tables 2a-f, 3).

Table 2a. Monthly mean air temperature (°C).

Month	J	F	M	A	M	J	J	A	S	O	N	D
Monthly mean max	17.8	20.8	24.8	29.4	34.4	39.9	42.8	42	37.2	30.3	23.5	18.5
Monthly mean min	4.4	6.1	9.5	13.7	18.3	23.3	25.5	25.1	21.4	15.5	9.7	9.7
Monthly mean range	13.4	14.7	15.3	15.7	16.1	16.6	17.3	16.9	15.8	14.8	13.8	8.8

Table 2b. Monthly mean relative humidity and rainfall.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Rel. Mean. Humidity	56.5	48.6	43.3	35.6	32.6	27.2	24	26	34.8	48	54.5	60
Group (.H.G)	3	2	2	2	2	1	1	1	2	2	3	3
Rainfall (mm)	4.4	2.5	5.6	6.3	1.6	0.9	1.2	0.1	0.5	6.7	8.5	6.8

Total annual rainfall: 46mm

H.G	
≤ 30%	1
30-50	2
50-70	3
≥ 70	4

Table 2c. Temperature diagnostics

Monthly mean max (C)		17.8	20.8	24.8	29.4	34.4	39.9	42.8	42	37.2	30.3	23.5	18.5
Comfort	Max	29	31	31	31	31	34	34	34	31	31	29	29
Day	Min	23	25	25	25	25	26	26	26	25	25	23	23
Monthly mean min (C)		4.4	6.1	9.5	13.7	18.3	23.3	25.5	25.1	21.4	15.5	9.7	9.7
Comfort	Max	23	24	24	24	24	25	25	25	24	24	23	23
Night	Min	17	17	17	17	17	17	171	17	17	17	17	17

Table 2d. Thermal stress

Day	C	C	C	/	/	H	H	H	H	/	C	C
Night	C	C	C	C	/	/	H	H	/	/	C	C

Table 2e. Comfort limit (from AMT)

	G.H.	AMT ≥ 20		15 ≤ AMT ≤ 20		AMT ≤ 15		G.H.
Humidity	Group	Day	Night	Day	Night	Day	Night	Group
0 30	1	26 34	17 25	23 32	14 23	21 30	21 30	12 21
30 50	2	25 31	17 24	22 30	14 22	20 27	20 27	12 20
30 70	3	23 29	17 23	21 28	14 21	19 26	19 26	12 19
> 70	4	22 27	17 21	20 25	14 20	18 24	18 24	12 18

Table 2f. Indicators

	J	F	M	A	M	J	J	A	S	O	N	D	Total
H1 essential ventilation													00
H2 Desirable ventilation													00
H3 Rainfall protection													00
A1 Thermal inertia	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		11
A2 sleep outside							✓	✓					02
A3 Cold season Prob.	✓	✓	✓								✓	✓	05

	Thermal stress	H.G.	EDT	Rain fall
H1	C. day	4		
	C. day	2 - 3	-10°	
H2	/day	4		
H3				+200
A1		1- 2- 3	+10°	
A2	C. night	1- 2		
	C. day C. night	1- 2	+10°	
A3	F. day F. night			

Table 3. Recommandations

1. Ground plane

H1	H2	H3	A1	A2	A3

			0-10			✓	Buildings oriented along an east-west longitudinal axis to reduce exposure to the sun.
			11 or 12		5-12	✓	Compact courtyard planning
					0-4		
							2. Spacing between buildings
11 or 12							Open spacing for breeze penetration
2-10							As A3, but protect from cold, hot wind
0 or 1							Compact planning
							3. Air Movement
3 -12							Single orientation buildings. Provisions allowing permanent air circulation.
1 or 2			0-5				
			6-12				Double-banked rooms with temporary provision for air movement.
	2-12						
0	0 or 1					✓	Air movement requirement.
							4. Dimensions of openings
			0 or 1		0		Large, 40 to 80% of the north and south facades.
					1-12		Medium, 25-40% of wall area
			2-5				
			6-10			✓	Intermediate, 20 to 35% of the wall surface.
			11 or 12		0-3		Small, 15 to 25% of the surface of the walls.
					4-12		Medium, 25-40% of wall surface
							5. Position of openings
3-12							In north and south walls at body height
1 or 2			0-5				
			6-12			✓	As above, but including openings in interior walls.
	2-12						
0	0 or 1						
							6. Protection of openings
					0-2		Protect from direct sunlight
		2-12				✓	Provide rain protection
10-12			0-2				Lightweight construction, covers with reflective coatings and air space
			3-12				Lightweight and well insulated

0-9	0-5	✓	
	6-12	✓	Massive construction, time difference greater than 08 hours
			7. Walls and floors
	0-2		Lightweight constructions, low thermal inertia
	3-12	✓	Massive construction, time difference greater than 08 hours
			8. Roof
	1-12	✓	Outdoor sleeping area
1-12			Proper drainage of rainwater
3-12			

3.2. ASHRAE Psychrometric Chart

Monthly data of minimum and maximum relative humidity and temperature are plotted onto the chart for each month. If the plotted line falls within the comfort zone, conditions are comfortable in the shade and in still air (**Error! Reference source not found.**). If the line falls partly or totally outside of the comfort zone, corrective measures are necessary such as the use of solar radiation, air movement or evaporative cooling [1].

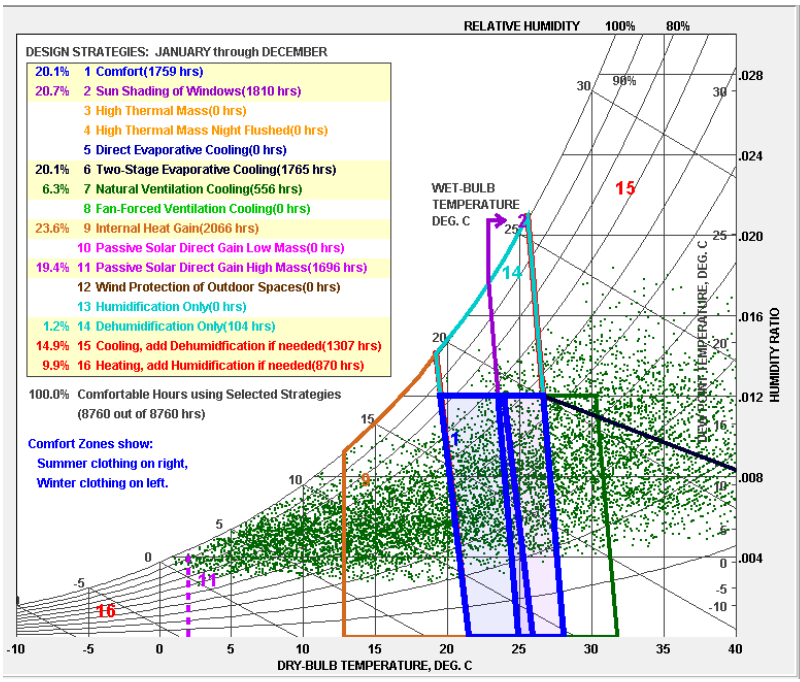

Figure 6. Psychometric chart based on the climatic conditions of El Oued

4. Results and discussion

4.1. Climate responsive design strategies according to Mahoney tables

According to the climatic analyse applied with Mahoney tables, the obtained results show that the thermal stress during the day and the night in July and August through the year is H (Hot), which means that the temperature is always above the comfort limit. At nights of September and June, the thermal stress is (/) which means comfortable, same results are found during the days of March, however the rest of the year appears to be (C) which means cold, during the day and the night, which means that the thermal stress, is always under the comfort limit.

No air movement is necessary according to the table of indicators (Table 2.f) also no need to protection against rainfall because it is very rare. The table provides the determination of the hot and arid indicators, and the result points out that the indicator for El Oued is (A1) due to high temperature in summer and low temperature in winter with a low humidity during the day and night. From January-November, and the temperature difference is more than 10 °C, which needs thermal storage for this condition. Sleeping outside is suitable as the table presents (A2) in the nights of July and August. The Indicator (A3) shows a problem of cold season form (January-March) and (November-December) (A3) [9]. The recommendation of Mahoney tables above, offer a guideline for the pre-design phase that the architect can use during the conception process to achieve thermal comfort.

Table 4. Summary of Mahoney's recommendations

Orientation	Along an east –west axis
Envelope	Compact with interior courtyard
Openings	20% to 35% of the wall surface placed in interior walls
Constructive elements	Massive walls, roofs and floors (phase shift time 8 hours)
Outdoor spaces	Sleeping outside

4.2. Climate responsive design strategies according to the psychometric chart

The chart provides the thermal comfort conditions in a range zones (21°C<T<28°C). Middle of the chart offers 1759 comfort hours, followed by the winter and summer ranges in both sides, by adding and applying different contributions of strategies, the comfort range zone can be broaden, such as sun shading devices that can offer 1810 hours of comfort, natural ventilation, passive solar gains and massive constructions.

4.3. Climate responsive design strategies implemented in the traditional architecture of the Souf

The morphology, materiality and even the use of the Sufi vernacular habitat offer an excellent lesson in adaptability to cope with the rigours environmental conditions of the desert. Thus, a qualitative appreciation of the vernacular architecture highlighted how the harsh prevailing climatic conditions were addressed to ensure indoor thermal comfort while complying with the specificities of the vernacular human settlements of the Souf.

The climate responsive design strategies employed are various and operate at several levels including: 1) the urban scale which corresponds to the human settlement (urban structure and fabric); 2) the building scale where the response to the climate was expressed through the built form, shape and envelope, the internal space arrangement, as well as, in the socio-cultural patterns and spatial practices of the inhabitants; 3) the structural and material scale as a result of the choices implemented in the design and construction of the envelope. This level embodies walls, roofing system and openings.

In this regard, it should be pointed out that it is only through the genius of the local builders, deployed in the rational use of the available materials and the innovative techniques implemented, that the inhabitants of the Souf have been able to respond effectively to an extremely hostile environment where the climatic conditions are classified among the hottest on the planet [10]. Accordingly, the main climate responsive design strategies implemented in the Souf vernacular architecture can be summarised in the following points (Table 5):

- The domes and vaults used as roofing systems minimise the roof area exposed to the sun. At the same time, the curved shapes of the domes and barrel vaults (semi-cylindrical) eliminate the risk of loading caused by the sand's deposition on the roofing, which could otherwise lead to the settlement of the foundations or the spreading of the building's walls;
- The domes are provided with small openings and mitres to evacuate the rising hot air that gathers in the upper part of the room. Ventilation by "chimney effect" is induced. An air movement is created between the air entering from outside and the air leaving through the openings in the domes, which helps to cool the interior space. The kitchen is the most targeted area for this system;
- The walls are plastered with a traditional coating, applied with fingers, which gives a rough texture with typical curved grooves to shade the outer walls. This plaster is periodically whitewashed, which increases the reflection of the surfaces exposed to the sun's rays and, at the same time, limits heat transfer by conduction through the walls;
- The counterforts across the external walls are similar to vertical screens that block out the sun's rays. The shadow cast on the walls provides additional shaded areas in the envelope;
- Sand is characterised by a low heat capacity, it is composed of silicates which retain the heat accumulated during the day particularly poorly. As soon as the sun sets, the heat of the day is quickly dissipated and the sand cools down considerably. This phenomenon is ingeniously used in the Sufi house. The surface of the courtyard is covered with sand, which allows it to cool down quickly as soon as the sun goes down. During the hot season, the inhabitants set up traditional beds (*sedda*) in the courtyard and sleep under the stars, taking advantage of the cool night air.

Table 5. Climate responsive design strategies of the traditional house in the Souf region

Climatic awareness level/ Components	**Cooling design strategies implemented**	**Description**	**Illustration**
Site and natural environment	-Providing protection against hot winds and sandstorms. -Lowering the thermal stress by providing shadowing and humidification.	Site generates a microclimate 'oasis effect' for the dwellings due to palm grove gardens and water used for irrigation.	

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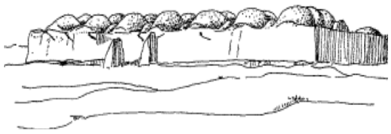
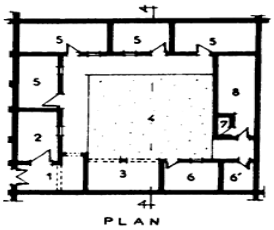
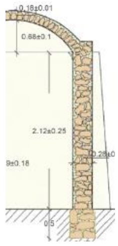
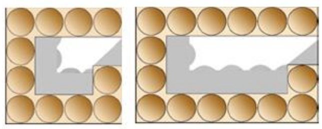
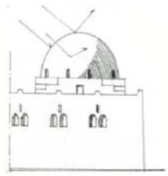
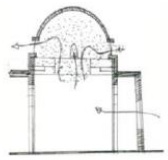
Urban morphology/ Settlement pattern	- Compact urban fabric. - Buildings connected together. - Urban-scale shading	- Urban compactness provides dwellings mutual protection against solar irradiation. -Shade between buildings is enhanced - Heat gains in summer and internal heat losses in winter are minimised. - Urban-scale shading inducing heat stress mitigating.	
Building level : built volume, shape and envelope	- Compactness at the building scale (low surface area to volume ratio).	- Reducing solar irradiation exposure.	
	- Minimizing heat gains. - Protection against solar radiation. - Creating favourable thermal indoor conditions.	- Clustering buildings contribute in minimizing direct solar radiation and heat gains. - Built volumes are of simple and mostly cubic forms. This gives protection from direct sunlight and induces favourable thermal indoor conditions.	
Spatial layout/ interior organisation	- Introverted plan; that means openings are located on the walls facing the courtyard. - Minimizing heat gains.	- This specific configuration is effective in reducing solar radiation exposure.	

	-Central spatial organisation through an open to sky courtyard called "*haouch*" and its "*sabat*" (galleries located at the north and south of the haouch). - The courtyard is covered with sand, which allows it to cool down quickly as soon as the sun goes down. Accordingly, the courtyard is considered to be a "storage area" for freshness.	- The most isolated space from the outside is the courtyard (*haouch*) and its surrounding gallery (*sabat*), so, it is generally the coolest space in the house. - Providing sun protection, daylighting, and ventilation for the surrounding rooms. - Open private space used by the inhabitants to carry out some domestic activities and to spend the summer nights.	 Courtyard's area covered with sand
Construction materials and techniques **1- Walls**	- Height thermal mass (thermal inertia). - Massive construction providing an important phase shift time that mitigate heat stress and ensure thermal comfort in summer (decreasing temperature differences between inside and outside). - Minimizing heat gains. - Protection against solar radiation.	- Load-bearing walls built with local sand stones materials (*lous*-desert stone, *tefza* gypsum, etc.) provide heat resistance and ensures a consistent time lag (> 8hours). - walls are plastered with a traditional coating, applied with fingers, which gives a rough texture with typical curved grooves to shade the outer walls.	 
Construction materials and techniques **2- Roof**	- Height thermal mass (thermal inertia). - Shadowing the envelope. - Minimizing heat gains. - Protection against solar radiation.	- Roofs built with local materials (*lous*-desert stone, *tefza* gypsum, etc.) provides heat resistance and ensures a consistent time lag (> 8hours). - Domes and vaults used as roofing systems minimise the roof area exposed to the sun. - Curved shapes of the domes and vaults eliminate the risk of loading caused by the sand's deposition on the roofing.	 
Construction materials and techniques **3- Counterforts**	- Shadowing the envelope. - Minimizing heat gains. - Protection against solar radiation.	-Counterforts shadow cast on the walls provides additional shaded areas in the exterior vertical surfaces.	

Openings	- Providing daylight and ventilation while reducing penetration of heat and solar radiations. - Ventilation by "chimney effect" Small openings located at the bottom of the dome provide ventilation by "chimney effect".	- Small size openings located at the top of the wall to maintain privacy and decrease the exposed areas to heat and Sun. - Windows located at the top of the wall to avoid incident solar radiation reflected from the ground. - Windows are located only on the walls facing the courtyard. The exterior walls are blind. -Warmer (lighter) air naturally rises inside the space and then it is removed through the openings in the domes creating a draft in open rooms.	    
Other cooling strategies	- Night ventilation - Radiative cooling - Evaporative cooling	- Thermal heat is evacuated to the outside during the night when Text<Tint; the building's mass gets cooler. -Thermal heat is evacuated through the envelope surfaces to the clear sky during the night; the building's mass gets cooler. - Air humidification by spraying water on the soil of the "haouch" to refresh the air at the afternoon.	

5. Conclusion

In the context of the worldwide concerns for global warming and a need for reducing carbon emissions and preserving natural resources while increasing energy efficiency and thermal comfort, the current study investigates the main climatic responsive passive design strategies that were used in the traditional buildings across the Souf region and assess the potential to use them as design alternatives for contemporary housing projects. The goal of the research was to assess how traditional architecture of the Souf region could be an inspiring way to achieve a sustainable built environment. Given this issue, a qualitative analysis was conducted by referring to two case studies selected to represent respectively typical traditional dwellings and common contemporary residential buildings. The study focused on thermal performance and climatic adaptability of the dwellings. Accordingly, the sustainable passive design features used in the traditional dwelling were specified.

The results reveal that the traditional architecture gives rational responses to the harsh desert climate by focusing on how to minimize heat gains during summer. Moreover, it achieves optimum passive cooling, thermal comfort, least energy consumption and finally a sustainable built environment. Finally, ancient architecture of the Souf demonstrates an economical use of local resources, and responds to climatic conditions using passive design principles that provide human comfort. In this regard, the passive design strategies used in the Souf ancient architecture are effectively adapted to local desert climatic environment and they still can be used for contemporary dwellings to meet sustainability targets. Furthermore, these design principles can provide design recommendations that could be incorporated into current architectural practices in hot arid regions.

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