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Traditional Ways of Dealing with Climate in Egypt

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Abstract

Egypt is occupied in the hot dry/arid climatic zone of the world and part of the great desert (Sahara) of North Africa except for the narrow valley extending linearly around the Nile River across the country (Mostafa, 2001). This climatic zone is characterized by arid climatic conditions with extremely high temperatures and almost no rain and a very high diurnal difference throughout the year (Givoni, 1998). Egyptian people have tried from ancient times to reduce heat impacts and provide shade by several ways (traditional passive cooling devices) in order to have the feel of thermal comfort.

The passive devices such as; Courtyard, Malkaf, Mushrabiya, Salsabil, Shuksheika, Taktaboosh, are marked by perfect responsiveness to the climatologically pressures they endure. During a field trip in Egypt, a number of existing traditional buildings around the country have been visited. In exploring these precedents, it became evident the use of passive cooling devices as natural environmental controls was effective. Moreover, the richness of the architecture had evolved as a result of their application. This paper demonstrates the importance of these passive cooling devices as environmental mediators, creating thermally pleasant living conditions. This is done through reviewing, classifying and analyzing their design characteristics.

Keywords: *Passive Cooling, Traditional Measures, Low Energy Architecture, Thermal Comfort, Hot Arid Zone*

1 Introduction and research problem

The architectural designer should attempt to perform the control task by passive controls (i.e. by the building itself), and resort to active controls (i.e. by energy-based heating or cooling systems), only when the passive controls cannot ensure comfort. This approach is suggested for three main reasons (Hui, 1997):

• ***Economic*** - the installation of mechanical equipment means a capital cost and also the recurrent cost of energy consumed and system maintenance;
• ***Ecological/environmental*** - passive buildings impose the least load on the ecosystem, consume less energy and should produce less waste; and
• ***Aesthetic*** - passive buildings are more likely to be in harmony with their environment.

People have tried from ancient times to adapt their buildings with the harsh climate in the hot-dry zone through reducing heat impacts and providing shade. In a previous work (Mohamed, Osman, & Gado, In review), found that traditional ways of dealing with climate such as earth Architecture began to decline in Egypt with the introduction of concrete construction. Conversely, in Europe and America there have been a number of new developments in earth Architecture technology. This in turn has lead to an increase in its popularity as a more sustainable alternative to accepted mass construction techniques. Also, during the subjective assessment of this work, the authors found that the majority of people in Egypt do not have the knowledge and the know-how of these intelligent ways. The current work tries to present these ways, their characteristics, and how they can provide occupants with comfort.

2 Research aim and objectives

The current research mainly aims to review, classify and analyse the passive cooling devices as environmental mediators. This is achieved through the following objectives;

1. Review the previous work and the literature review;
2. Find and develop an appropriate classification to the environmental mediators;
3. Analyse and set out simple guidelines on using these mediators.

3 Research context

According to Koppen's climatic classification (Encyclopaedia Britannica (UK) Ltd, 2002), Egypt is located in the hot-dry zone between 23° and 32° latitude.

Where, most of the tropical, true desert climates of the Earth occur between 15° and 30° latitude. According to Givoni (Givoni, 1998), this zone is characterised with aridity and clear sky which promote solar heating during the day and radiant loss during night (Horizontal global radiation reaches 1000 W/m^2). Temperatures are high, with monthly means in the range of 21°C –32 °C. (Encyclopaedia Britannica (UK) Ltd, 2002) where, actual surface temperatures may reach 82 °C on dry sand under intense sunshine. Also, diurnal differences in temperatures are extreme and could reach 35 °C. In most low- latitude deserts, cloud cover is uncommon (fewer than 30 days per year have clouds in some areas). Precipitation amounts are mostly in the range of 0–25 centimetres (Encyclopaedia Britannica (UK) Ltd, 2002). In addition that, dust storms are a common feature in the hot dry regions and particularly during the afternoon. All the above weather characteristics lead to a very harsh environment that needs a very cautious and professional ways of dealing with it.

4 Previous work

Many attempts have been made aiming to look into traditional ways of dealing with climate in the hot dry zone. Oliver (Oliver, 1997) (Oliver, 2003) presented and discussed the main features of traditional buildings in Egypt in terms of structure, materials and styles. He also mentioned some passive ways that have been adopted by the Egyptians in their buildings such as; the mashrabiya, hosh, durqa’ah, and the courtyard. Fathy (Fathy, 1986), discussed the principles and presented examples of natural energy and vernacular architecture in hot arid climate. He categorized the passive techniques in three main categories based on three main strategies; passive solar, natural ventilation, and evaporative cooling. The environmental performance of Government primary schools in Egypt was investigated and found very poor (Mohamed, Gado, & Unwin, 2005). In a following study (Mohamed, 2009), Mohamed confirmed that using some appropriate passive strategies and measures within the façade skin could enhance the thermal performance of the case studies by 13 %. Mohamed et al. looked into the technical and social factors that led to the decline of earth Architecture in the Sahara desert (Mohamed et al., In review). The results suggested a strong possibility of reusing earth Architecture from the environmental point of view. However, a number of limitations were identified, including; durability, buildability and the attractiveness of the mud architecture to the locals. Filippi, F. (Filippi, 2006) analysed the main characteristics of the urban pattern and buildings' typologies of the traditional earth architecture in two settlements of El Dakhla oasis. Iscandar (Iscandar, 2006) presented some neo-vernacular case studies of Michael Graves, Hassan Fathy and Ramses Wissa Wassef. Iscandar suggested that those examples show respect to the site, the natural environment, the climate and was successful in mixing traditional techniques with contemporary requirements.

5 Research methodology

Two types of studies were employed in the current research. The analytical study based on literature review and previous work, and the field study based on two scientific trips. These trips covered wide areas of the country such as the capital city of Egypt “Cairo”, representing the semi desert region”, and four oasis of the western desert “Al-Baharia, Al-Farafra, Al-Dakhla, and Al-Kharga, representing the desert climatic region”. It was not possible to monitor all the cooling devices in this work. However, some measurements in traditional and contemporary buildings were conducted to investigate the performance of the mud material against concrete, and the performance of traditional design of houses.

Figure 1: The author during measuring the air temperature inside AL-Souhimi house

Figure 2: The 4 in 1 instrument

In order to assess the cases studies objectively - in terms of air temperature, Humidity, sound and lighting -, the 4 in 1 digital instrument was used (Figure 2). In this paper, only the air temperature measurements are employed and analyzed for the comparison purpose. Three case studies are located in the same area of Al-Farafra oasis – western desert of Egypt- and one case study is located in Cairo City were under investigation.

6 Achieving thermal comfort in hot arid zone

There are several factors that control human comfort and make up what is known as the ‘human thermal environment’. Mohamed (Mohamed, 2009) conducted a wide review on these factors and found that they can be divided into two main categories; factors related to the individual and other factors related to the environment. The human factors include; clothing level and activity level. While Environmental factors “which could be lie partially under the architect control” include; air temperature, Mean Radiant Temperature (MRT), relative humidity, and air velocity (McMullan & Seeley, 2007). According to Givoni (Givoni, 1998), there are several design details that affect the thermal performance of buildings in hot-dry zone which in turn affect the human thermal comfort. These are; i) Internal and attached open spaces, ii) Orientation of main spaces and windows, iii) Window size, location, and details, iv) The layout of the building's plan, v) Shading devices, vi) The colour of the building's envelope, vii) Building's materials, viii) Vegetation around and inside the buildings. Also, Ventilation devices, roof construction, and humidification strategies can be added to the above list (Mohamed, 2009). The passive cooling devices that can enhance the state of thermal comfort inside buildings are (Fathy, 1986; Givoni, 1998; Oliver, 1997, 2003):

1. Sahn /hosh: The Courtyard
2. Malkaf: A wind catcher.
3. Nafora: The Fountain
4. Shesh: The Venetian blinds
5. Taktaboosh: A covered outdoor sitting area at ground level.
6. Mushrabiya: open wooded lattice screens.
7. Rasha/taka: A small opening at an upper level of a wall
8. Salsabil: A water-fed cooling plate
9. Shuksheika: The vented or fenestrated lantern over the main hall.

The current work classifies the traditional passive techniques based on Fathy's classification and Givoni's affecting factors on thermal performance of buildings. This helps to devise an integrated classification system for the traditional passive ways of dealing with climate in Egypt. Although some of these measures have an impact on more than one factor that affect the thermal performance of buildings, this study classifies each one of them with regard to one factor which has the greatest impact on it. Figure 3 illustrates this classification.

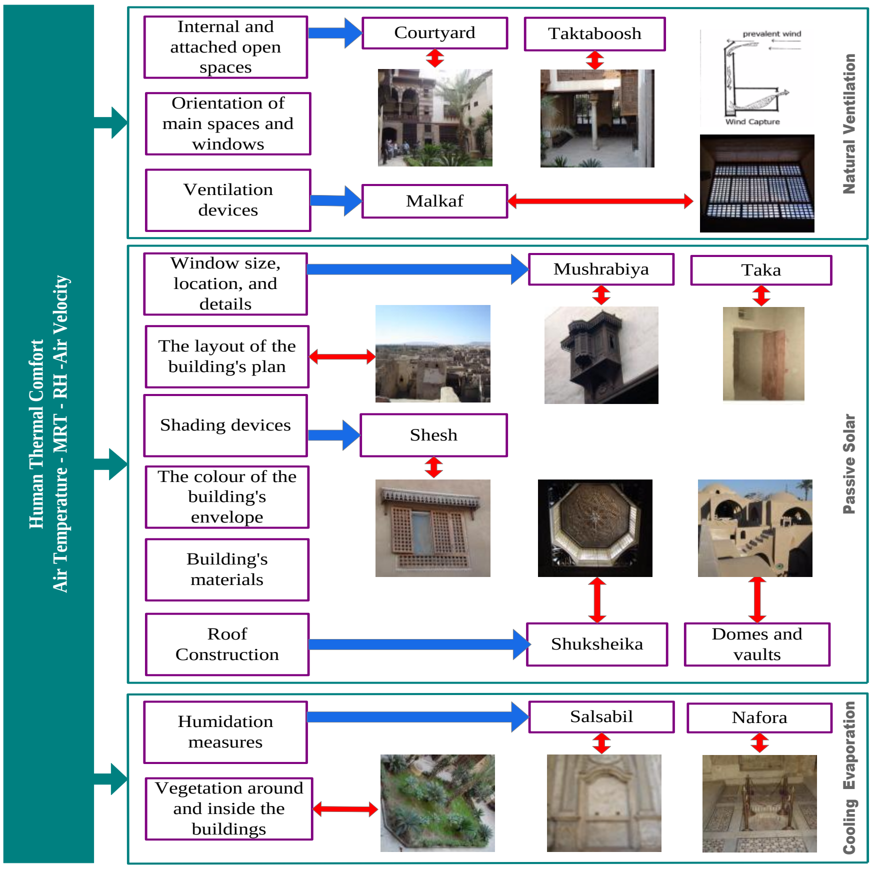


Figure 3: The integration between the traditional passive measures/factors affecting thermal performance of buildings/factors affecting Human thermal comfort, by the author

7 Passive cooling devices

7.1. Internal and attached open spaces

Shaded open spaces are very preferable in the hot dry zones. They can reduce the daytime air and radiant temperatures at the occupied space.

7.1.1. The Courtyard

People used to open their houses onto a private internal open space that visually and acoustically separated from the outside called Sahn "The courtyard" (Figure 4) (Afify, 2002). The courtyard helps in maintaining cooled indoor temperatures. With some modifications to the courtyard such as using water and vegetation in its landscape, the benefits can be maximized and particularly the benefits of the thermal performance.

The phenomenon of the stack effect is employed in the courtyard to enhance thermal comfort by producing cool breezes (Wazeri, 2002). In the evening, the warm air of the courtyard, that was heated directly by the sun and indirectly by the warm buildings, rises and is gradually replaced by the cooled night air from above. This cooled air accumulates in the courtyard in layers and leaks into the surrounding rooms cooling them (Oliver, 1997). In the morning, the air of the courtyard, which is shaded by its four walls, is heated slowly and remain cool until late in the day when the solar radiations penetrate the courtyard (Fathy, 1986). There are three factors affect the capability of the courtyard (Figure 5) (Wazeri, 2002).

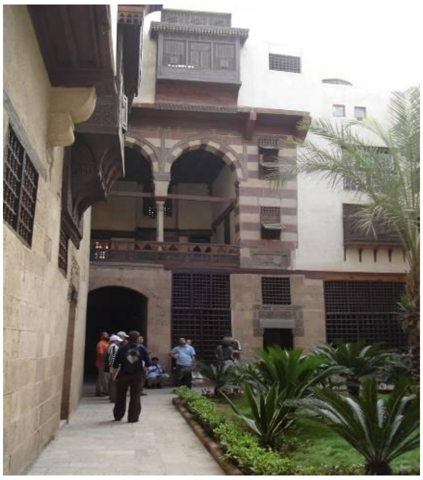


Figure 4: Courtyard of al-Souhimi house, Cairo

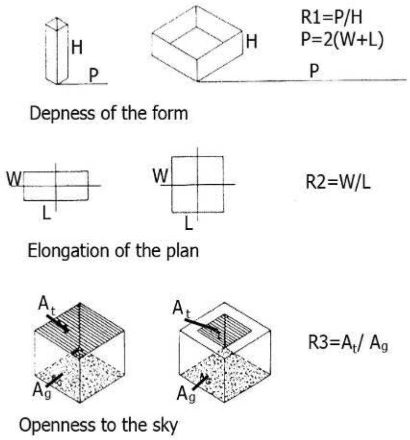


Figure 5: The geometric dimensions of the courtyard (Wazeri, 2002)

- The deepness of the form (R1), which is the ratio between the courtyard's perimeters to the height. (R1 should not be less than 3)
- The elongation of the plan, which is the ratio between the length to the width of the courtyard. The rectangular shape of the courtyard's plane is better than the square one. He also recommended that the ratio between the length, width and the height must be not less than 1:2:1.4.
- The openness to the sky, which is the ratio between the area of the top to the area of the bottom of the courtyard.

He added that the best orientation to the courtyard is by orienting the long side to the east west. A recent study (BMT Fluid Mechanics, 2007), concerned by the effects of surface openings on the air flow caused by wind in courtyard buildings, suggested that openings should be in the upwind and downwind surfaces to achieve the max air velocity. It added that the larger the upwind surface openings, the more the velocity increases significantly.

7.1.2. The Takhtabush

To ensure the air flow, a covered area at the ground level (The takhtabush) was introduced to the traditional house (Figure 6). It is located between the courtyard and the back garden, opening completely onto the courtyard and through a mashrabiya onto the back garden which ensure a steady flow of air by convection (Fathy, 1986). Since the back garden is larger and thus less shaded than the courtyard, air heats up more than in the courtyard. The heated air rising in the back garden draws cool air from the courtyard through the takhtabush, creating a steady cool breeze. (Fathy, 1986)

Figure 6: The Takhtabush in al-Souhimi house, Cairo

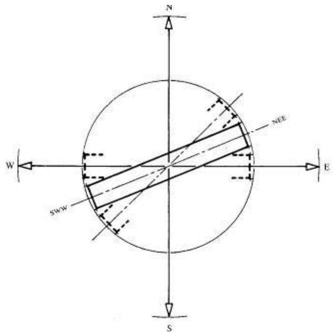


Figure 7: The optimal orientation with regard to the sun and the prevailing winds (Fathy, 1986)

7.2. Orientation of main spaces and windows

In such climate, the sun is the major source of heat and hence the position of the sun regarding any site is very important. The main criterion of choosing the appropriate orientation is to minimize the penetration of the sun radiation in the summer and maximize it in the winter. However, the prevailing winds can not be denied, especially in the hot season, but it could come as a second criterion (Givoni, 1998). Previous studies (Fathy, 1986), (Givoni, 1998) found that, in Egypt, the best orientation with regard to the sun factor is the east west, While, it is the north to south with regard to the prevailing winds. Fathy (Fathy, 1986) solved this problem by bisecting the angle between the two optimal orientations (Figure 7). He added that by using other ways to ventilate the building e.g. the malqaf or wind catcher, the designer can concentrate on orienting the building with respect to the sun factor.

7.3. Ventilation devices

The Malqaf is one of passive ways to catch the desirable wind, which means wind catcher. According to Fathy (Fathy, 1986), it is rising higher than the building with an opening facing the prevailing wind. It captures the cooler and stronger wind from upper boundary layers. Under the pressure difference effect, it blows the air down inside the building. The malqaf is also useful in reducing the sand and dust because the captured wind from above the building contains less solid material than the wind at lower heights. Moreover, much of these solid materials, if any, are dumped at the bottom of the malqaf. It is also very useful in the dense cities, where the wind velocity at the level of the windows is very slow. It can also work as a wind escape; if its opening faced the opposite direction of the prevalent wind (Figure 8) (El-Wakeel, 1989).

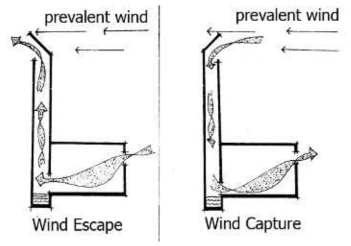


Figure 8: The Malqaf can work as a wind escape or wind capture according to its direction (El-Wakeel, 1989)

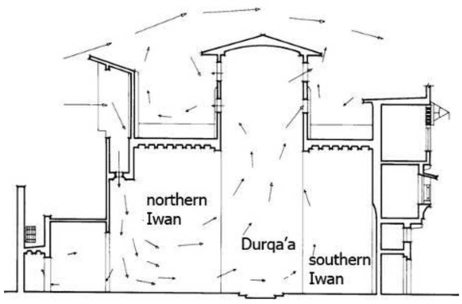


Figure 9: Section through the Qa'a of Muhib AlDin (Fathy, 1986)

The excellent example of the Qa'a of Muhib AdDin in Cairo "*the main hall of a house or building, comprising a dorqa'a "central hall" and two iwans "side halls"*", (Figure 9) demonstrates the operation of the malqaf as a part of a complete ventilation system. According to Fathy (Fathy, 1986), the malqaf is placed in the northern iwan to catch the desirable air and channels it down. The system of acclimatization was developed depends primarily on air movement by pressure differential and convection. The ceiling of the dur-qa'a rises above the ceilings of the iwan and includes windows in its upper structure. In addition, to provide the space with diffused and agreeable lighting, these openings provide the required air escape. By increasing the size of the malqaf and suspending wetted matting in its interior, the airflow rate can be increased while providing effective cooling. Air can be directed over a Salsabil, a fountain or a basin of still water, to increase air humidity.

7.4. Window size, location, and details

Reviewing vernacular architecture in hot dry climate suggested small windows with total area of about five to ten percent of the floor area (Givoni, 1998). However, large windows can be provided with special design details. Insulated controllable shutters and screens to prevent insects in certain periods could be added to the windows. Figure 10 shows two types of modifications on windows. The first is a wooden lattice screen as an external layer of the windows and the second is an aluminium mesh screen fitted on the glazing "the internal layer".

Figure 10: Modifications for windows, Ramsis Wesa Nassef Centre, Giza, Egypt

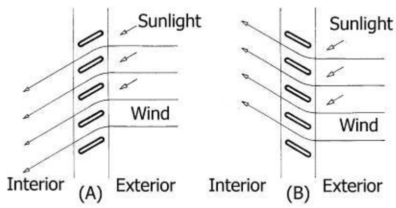


Figure 11: The movable Venetian Blind (Fathy, 1986)

7.4.1. Shesh

The shesh can be added directly to the window. The blind is made of small slats, about 4-5 cm wide, closely set in a wooden frame. The slats are often movable so its angle can be changed. This feature of adjustability is very useful in regulating solar radiation and wind flow into spaces. The sun's rays can be blocked out without obstructing the breeze. When the blinds are drawn, they completely obstruct the view to the outside as well as considerably dim the light reaching the interior (

Figure **11**) (Fathy, 1986).

7.4.2. Mashrabia

The name of mashrabiya is derived from the Arabic word "drink" and originally meant "a drink place" (Figure 12). According to Fathy (Fathy, 1986), this is a cantilevered space with a lattice opening, where small water were placed to be cooled by the evaporation effect as air moved through the opening. The mashrabiya can do five functions according to its design. These functions are to control the passage of the light, to control the air follow, to reduce the temperature of the air current, to increase the humidity of the air current and to ensure privacy (Wazeri, 2002).

Figure 12: Exterior view of a mashrabiya, Hassan Rashed house, Egypt (Steele, 1988)

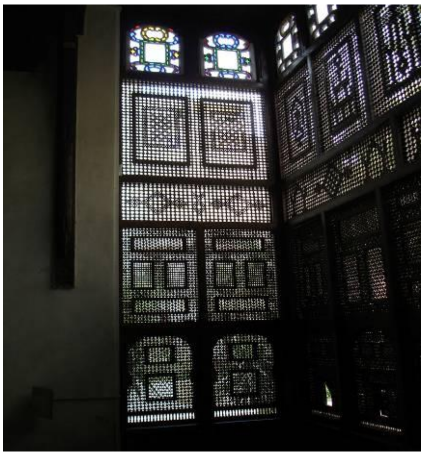


Figure 13: Internal view of a mashrabiya in al-Souhimi house, Cairo

The sizes of the interstices and the balusters of the mashrabiya are adjusted to intercept direct solar radiation using a lattice with small interstices and to allow air flow using a lattice with large interstices (Fathy, 1986). Therefore, large-interstice pattern is used in the upper part of the mashrabiya to allow the air flow while small interstices is used in the lower part of the mashrabiya to prevent the direct sunrays (Wazeri, 2002) (Figure 13). Also, the dimensions of the mashrabiya can be increased to cover any size of opening, even to the point of filling up the entire facade of a room (Steele, 1988).

7.4.3. The Taka

Old houses in Egypt included "*Rusha" or "Taka"* which is higher than the window and facing it. This causes different speed in the air movement and in turn causes the cross ventilation. Thus, the air will be sucked down across the occupants (Figure 14).

Figure 14: The taka under the roof level, in Al-Qasr house, Al-Dakhla Oasis

Figure 15: The compact urban design in the old areas, Al-Dakhla Oasis

7.5. The layout of the building’s plan

The surface area of the external envelope of the buildings should be small as much as possible to minimize the heat flow into the building during the daytime. This could be achieved in a compact urban design (Figure 15). According to Givoni (Givoni, 1998), the ventilation rate, during the day, must be kept to the minimum required for health (about 0.5 air change per hour) in order to minimize heating up the internal spaces by the hotter outdoor air. He added that, during the night times when the outside cool air becomes desirable, higher ventilation rate will be required. This could be achieved through employing some techniques such as using terraces with shutters and openable glazing along the lines of the external walls.

7.6. Shading devices

Internal devices such as Venetian blinds, roller blinds, and curtains, are not preferable in such climate since they intercept the solar radiation after transmission through the glazing and heat up the space (Fathy, 1986). Therefore, the outer shading devices become essential. The size and the position of the shading devices are placed to block the solar radiation in the summer session and to allow the solar radiation in the winter session (Figure 16).

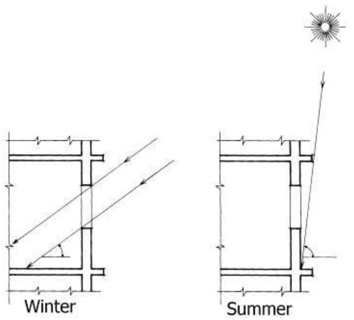


Figure 16: Small overhang shading device on the southern façade (Fathy, 1986)


Figure 17: Frame shading device, Hassan Fathy palace of art “paris”, Egypt

Shading devices could be in the form of; fixed and movable devices. Fixed shading devices could be in the form of horizontal overhang, vertical fins, and a combination of the overhang and the fins “frame”. Horizontal overhang could be used on the southern windows extending on both sides of the windows. Vertical fins are more effective than horizontal overhangs on the eastern and western windows (Fathy, 1986). Figure 17 shows an example of a frame shading device. Movable external shading devices are more effective than the fixed ones, since it can be employed to prevent or admit solar rays according to the weather conditions but it is too much expensive in comparison with the fixed devices.

7.7. The colour of the building's envelop

Light colours of envelop can reduce the heat gain significantly in comparison with the dark colours. However, in desert regions of the hot dry climate with the light colour and the lack of vegetation, the problem of the glare becomes very common (Givoni, 1998). To solve this dilemma, a required careful design of some building projections and a selective choice of colours with adding landscape vegetation as mush as possible is essential. Figure 18 shows different types of projections with darker colours on the eastern façade of an old house in Cairo. By this ways, these projection elements can reduce the glare as they are the most exposed elements to the outside. The building surfaces behind them can be kept in light colours as they in direct contact with interiors.

Figure 18: Different types of projection elements, Cairo

7.8. The choice of building's materials

In the hot dry climate, high resistance and high heat capacity of the envelope elements is necessary. High resistance minimize the conductive heat flow into the building mass during the daytime (Givoni, 1998). Actually, this can also reduce the rate of cooling the building mass during night time, but it could be overcome by admit night-purge ventilation strategy. High thermal mass has been achieved traditionally by thick walls that made of heavy materials such as stone, bricks, adobe, and mud. Today the availability of modern insulating materials make it possible to achieved indoor thermal comfort with thinner walls than in the past.

7.9. Roof Construction

The roof surface is always exposed to the sun. Therefore, the outer surface of the roof is heated up by absorbing solar radiation (Givoni, 1998). The roof then transmits this heat to the inner surface, where it raises the temperature of the air in contact with it by conduction. Consequently, the shape of the outer surface of the roof and the thermal resistivity of its materials are very important.

7.9.1. The Shuksheika

People used to shade the roof more naturally by arranged the roof into open galleries and lightweight roof covers (Fathy, 1986). These open areas and roof have the double function of shading the roof and providing cool air. Hot air can escape from the lower floors during the day and cool air descends during the night. This method was developed to be the Lantern (Figure 19) (Wazeri, 2003), which is an opening in the roof covered by a combined of wood and glasses.

Figure 19: The lantern of a house in Rasheed City, Egypt (Wazeri, 2003)

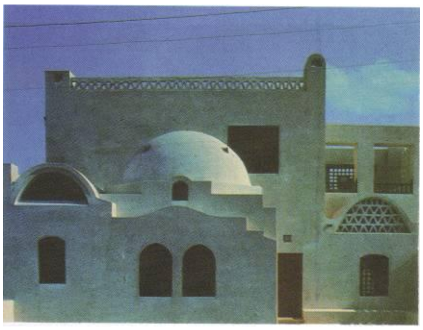


Figure 20: Dome and vault in Halawa House, Elagami, Egypt (Wazeri, 2003)

7.9.2. Domes and Vaults

One of the most useful ways to adapt with the hot climate is pitching or arching the roof. This is well known in the traditional architecture by domes (the form of a hemisphere) and vaults (the form of a half-cylinder) (Figure 20) (Fathy, 1986). These roof shapes have many advantages. Firstly, the height of the space is increased, and thus sending the warm air that rises or is transmitted through the roof far above the heads of the inhabitants. Secondly, for most of the day, part of the roof is shaded from the sun (El-Wakeel, 1989). At which time it can act as a radiator, absorbing heat from the sunlit part of the roof and the internal air, and transmitting it to the cooler outside air in the roof's shade.

7.10. Humidification measures

In the hot arid zones, providing buildings with water is very important strategy that increases the humidity to promote the thermal comfort. Therefore, the people in Egypt tried to remain in contact with it as long as possible during the hot season.

7.10.1. The Fountain

The fountain plays a role equivalent to the fireplace in the temperate zones, although one is used for cooling and the other for heating. It is an architectural feature occupying a privileged place in the house plan (Fathy, 1986). It is placed in the middle of the courtyard with the living spaces opened onto it. It always has a symbolic form, square in shape, with the inner basin in the form of an octagon or a decagon (Figure 21) (Abdel Karem, 2002). The fountain display its water and mixing it with air to increase the humidity.

Figure 21: The fountain in Shahera house, Egypt (Abdel Karem, 2002)

Figure 22: The Salsabil in Al-Souhimi house, Cairo

7.10.2. The Salsabil

In places, where there was not enough pressure to permit the water to spout out of the fountainhead, architects replaced the fountain with the salsabil (Fathy, 1986). The salsabil is a marble plate placed at an angle to allow the water to drop over the surface, thus facilitating evaporation and increasing the humidity of the surrounding air. The water then flows into a marble channel until it reaches the fountain in the middle of the courtyard. (Figure 22).

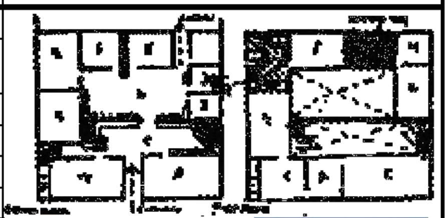
7.11. Vegetation around the buildings

Maximizing the amount of vegetation inside and outside buildings affects positively the thermal performance of buildings. Since vegetation can do the followings; shading of the external surfaces of the building, shading the opened spaces, reducing and filtering the dust in the air, and elevating the humidity level (Givoni, 1998). Specific types of trees and locations should be selected to suit the climatic context. Suitable trees that can be planted around the buildings in order to decrease wind speed from the south that always comes with dust and sand such as *Casuarina, Eucalyptus, Abizia, Acacia Fanesiana, and acacia Arabica* (Institute of Environmental Researches and Studies (IERS), 1992).

8 Field measurements

Two field studies were conducted. The one was conducted for three buildings represent the three different trends of construction in the western oases; a concrete house “concrete skeleton and blocks wall”, an old mud house in the old area of Farafra and a new mud house built in the new area of Farafra. The concrete house is a normal skeleton concrete with white lime bricks/burned clay bricks. The two mud houses are constructed from the local materials. The bearing walls are the structure system of the buildings with clay bricks. The roofs were constructed from the palm trunks as the main bearing elements and then they were covered by rows of palm leaves followed by a layer of mud bricks then finished it by paste of clay. One of them (the new mud house) Badr's art & sculpture museum is one of the few contemporary vernacular architectural buildings in Egypt. His owner is a sculpture artist called Badr Abdel Moghny. The building consists of two stories including mainly exhibition large spaces, two central courtyards, services spaces, and open terraces in the first floor. The height of the building is relatively high. The four sides of the museum are free with small openings in the facades. The other one (the old mud house) consists of one floor plan with a relatively low height and small spaces. Only one side is free with one small courtyard. All the measurements were conducted between 12.0 pm to 1.0 pm on the 18th of October. Table 1 presents the measurements of the air temperature and their location inside the three buildings in addition to some pictures of them.

Table 1: Field measurements inside the first three cases in Farfra oasis

Building/ Place	Monitored space	Temperature °c	Plans/pictures	
Badr's Art & Sculpture Museum	GA - Exhibition	30.7		
	GB - Exhibition	30.1		
	GC - Courtyard	31.2		
	GD - Courtyard	29.6		
	GH - Shop	29.6		
	GI - Exhibition	29.1		
	GJ - Exhibition	28.8		
	FD - Exhibition	31.3		
	FE - Exhibition	30.5		
	Average	30.10	The courtyard	Main Elevation
House 1 - Concrete construction	Family Space	31.7		
	Bedroom/Living	31.6		
	Courtyard	30.7		
	Toilet	32.4		
	Kitchen	33.2		
	Average	31.92	Corner Elvation	Family Space
House 2 - Old Adobe construction	Kitchen	33.1		 
	Bedroom	32.7		
	Living	30.8		
	Hall	31.7		
	Average	32.075	Elevation	courtyard / bedroom

On analysing the temperature measurements of the three houses, it is obvious that the performance of the new mud house is the best while the old mud one is the worst. Unexpectedly, the concrete house is better than the old mud house.

This is could be because the new mud house employs efficiently the passive strategies and measures (natural ventilation, night purge ventilation, thermal mass, …etc) while the old mud house does not apply them effectively. This is confirmed that the mud as a building material is not performed as well as we may think.

The second field study was conducted inside Al-Souhimi house in Cairo. It is considered one of the few witnesses on the intelligence of the traditional architecture in the east in general and in Egypt in particular. The real ingenuity of their designs lies in the structural modifications that were introduced into traditional spaces (like the qa'a, maq'ad, takhtabush, etc.) to produce independent spatial units adapted to climatic conditions [24] (Table 2). This house contains many of traditional passive measures, if not all known ones, such as the thermal mass, malqaf, the mashrabiya, the courtyard, the takhtabush, the fountains, and the lantern. The bearing stone walls are the structure system for this house. The roofs were constructed from the temper beams followed by temper sheets with additional layers of floor finishing with few spaces covered by lantern.

Table 2: Field measurements inside Al-Souhimi house

Building/ Place name	Monitored space	Temperature °c	
Al-Souhimi House	A - Qa'a	29.1	 Ground floor of Al-Souhimi house
	B - Guest Space	30	
	C-Intermediate	30.3	
	D - Maqiad	29.7	
	E - courtyard	25.7	
	F -	27	
	G -	27.4	
	H - Courtyard	28	
	 A view from the Takhtaboush to the Courtyard	 The courtyard	

On analysing the temperature measurements of the different spaces inside Al-Souhimi house, it is obvious that the performances of the surrounded spaces to the courtyard are better than the outer spaces. Also, it could be asserted that the Takhtaboush (D and E) is playing an important and essential role in cooling the building since the temperatures inside it are the lowest. This confirms the importance of accompanying the two passive measures (The courtyard and the Takhtaboush) when be employed in the passive design of buildings.

9 Conclusions

This paper was concerned with traditional ways that modern building should adopt to respond to the hot dray climate. The paper presented the main characteristics of the hot dry zone and climatic considerations to achieve thermal comfort inside buildings. Traditional ways of dealing with climate in Egypt were presented. The main outputs of this work could be summarized in the following points:

1. The main thermal consideration for such climate should achieve; slow rate of indoor heating during summer daytime, fast rate of indoor cooling in summer evenings, minimizing dust penetration, good ventilation in the summer evenings, and higher indoor temperature relative to the outdoors in winter;
2. Important design details that architect should consider are; building’s materials, orientation, shading devices, building's external envelope, and openings, the internal and attached open spaces, water and vegetation around and inside the buildings;
3. Traditional ways of dealing with climate in Egypt can be categorized into eleven different factors that affect thermal performance of buildings under three main strategies (natural ventilation, passive solar, and evaporative cooling)
4. The mud as a traditional material is not performed as well as we may think all the time. While it is more important to use the local materials in combination with the appropriate passive design strategies and measures;
5. The courtyard is an efficient device in cooling the buildings. However, it could work more efficient if accompanied with the Takhtaboush.

10 Further Work

The outputs of this paper will inform the choosing of the appropriate measures to be investigated and modified in the future work. This will be done through conducting detailed physical environmental measurements and in deep computational analysis. These processes will aid the research to design/develop contemporary, environmentally responsive measures to be employed afterwards to enhance the thermal performance of specific case studies.

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