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THE IMPACT OF PASSIVE ARCHITECTURAL DESIGN SOLUTIONS ON COOLING LOADS OF BUILDINGS IN HOT DRY CLIMATE: ANALYSIS OF PERFORMANCE IN SIWA OASIS

Riham Nady Faragallah*

Pharos University in Alexandria, Egypt

Abstract. In the previous few decades, climate change has been a highly essential problem to consider while dealing with buildings. Thus, passive design adjusts to the local climate to promote thermal comfort conditions for building occupants while reducing energy consumption and lowering building temperatures without the need of energy use. This paper presents the importance of passive design and its effect on thermal comfort in the built environment. It presents several passive design strategies such as designing the building form, determining the optimum orientation and selecting the most appropriate building material. Also, it highlights the need of adapting passive cooling design solutions and control principles that can optimize the building's thermal performance and can reduce cooling loads in buildings particularly in hot dry climates. In this case, a simulation analysis tool is utilized to assess and compare the usefulness of employing different passive cooling solutions that improve thermal efficiency and minimize cooling loads in Siwa Oasis, Egypt. The findings can assist architects in selecting the appropriate climatic design parameters in buildings that can be applied in hot dry environments particularly in Egypt during the design stage. According to the findings, using certain passive design features may create comfortable indoor environments regardless of exterior weather conditions.

Keywords: *cooling loads, energy use, hot climate, passive design, simulation tool, thermal comfort.*

Corresponding Author: *Faragallah, Riham, Associate Professor, Pharos University in Alexandria (PUA), Alexandria, Egypt, Tel.: 002-01007154724, e-mail: riham.nady@pua.edu.eg*

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1. Introduction

One of the most critical and challenging concerns of the 21st century is the worldwide energy crisis (Goyle & Simmons, 2014). This means that, buildings account for a large proportion of overall world energy and carbon emissions (Li *et al*., 2013). In other words, there has been a tremendous growth in the use of air-conditioning systems for cooling particularly in hot climates across the world in recent decades (Izadpanahi *et al*., 2021).

This means that, the built environment accounts for 30-40% of the total energy consumption due to heating and cooling demands as well as people spending around 90% of their lives in buildings (Hook & Tang, 2013).

On one hand, hot dry regions, such as Egypt, necessitate significant year-round air conditioning (AC). It is predicted that there will be 72% rise in cooling demand over the next century which encourage the use of passive cooling operations (Allouhi *et al.*, 2015).

On the other hand, there is an increasing concern about the environmental impact of buildings and the quality of their internal environments which has raised the debate where architects should adopt environmental solutions in the design of buildings.

Thus, the main problem of the study is there is a lack in studies that estimate the efficiency of passive design measures in buildings especially in hot arid regions under future climate conditions. This emphasizes the importance of identifying and integrating passive design solutions in buildings to develop the users' thermal comfort. Passive design strategies use free, renewable energy sources such as the sun and wind to meet cooling, ventilation and lighting requirements. Consequently, this may control energy in buildings and minimize dependency on non-renewable energy sources. Furthermore, a passive design strategy can be applicable as a cost-effective solution. It reduces energy consumption in buildings without depending solely on mechanical systems, minimizes the temperature difference between outdoor and indoor, improves indoor environmental quality and makes the building both a healthier and a more comfortable environment.

The paper assumes that using passive design strategies is a key for buildings in hot regions to minimize cooling loads in buildings and achieve a balanced thermal comfort in interior spaces in Siwa. The cooling period can be extended and the peak loads can be reduced due to the adoption of passive solutions, which in the end will reduce the energy consumption used for cooling. To support this statement, various techniques were used and evaluated by monitoring and comparing between different situations in a hot environment (Siwa Oasis as a case study) in order to determine the optimum passive design characteristics that can be taken into account during the design stage of a building.

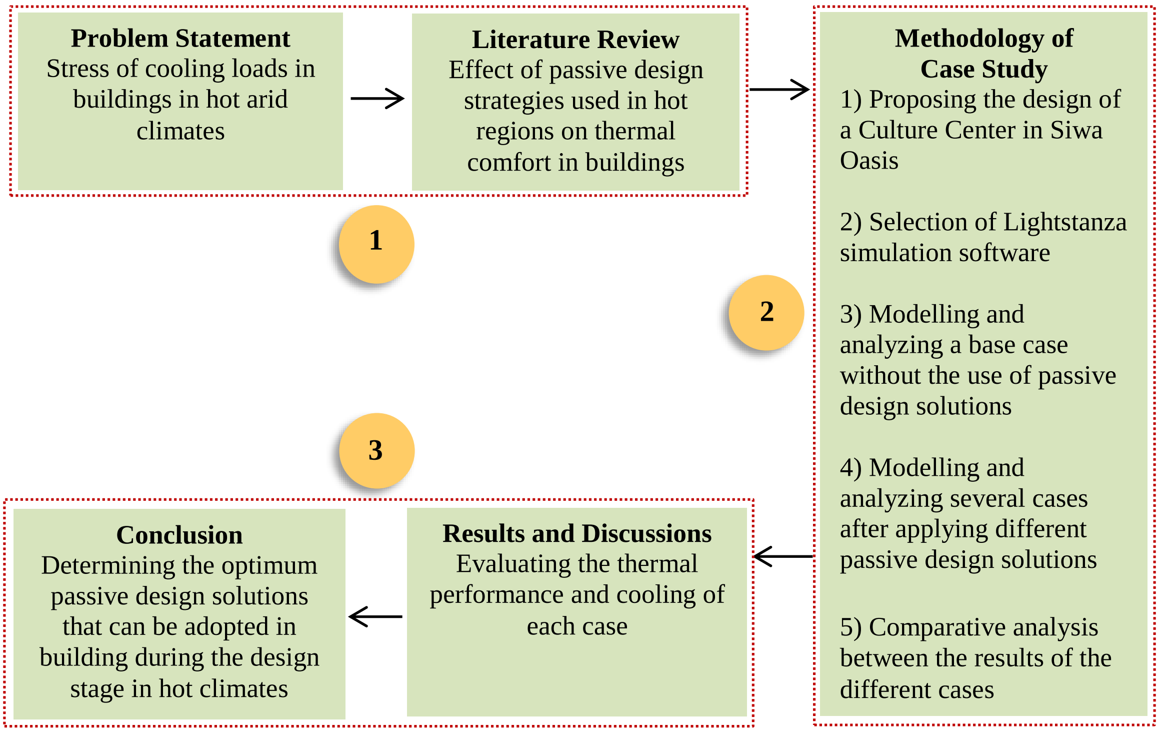


Diagram 1. The methodology of the study
(developed by the author)

The paper is divided into three main sections. First, a literature review that examines the fundamental challenges, that face passive design and its significance to achieve human comfort in buildings. It also highlights the importance of promoting passive cooling design techniques and control principles that can be suggested to be used in hot climates such as building form and orientation, proper window placement, the use of light or reflective coloured surfaces for the building envelope, locally available building materials, vegetation, … etc. The second section is the case study that proposes a design of a building (culture center) in Siwa Oasis, Egypt. Then, the paper analyses and compares the effect of using different passive design strategies applied in the building through a simulation program (Lightstanza) to compare the effect of using various passive cooling solutions that minimize energy consumption and improve cooling performance in a building in hot environments. The third section presents the findings of the simulation and climatic recommendations using passive design approaches that can be adopted in hot arid locations to promote comfort in indoor environments regardless the exterior weather conditions (Diagram 1).

The main aim of the paper is to identify and test the effectiveness and usefulness of applying passive cooling design strategies as a proposal for promoting thermal comfort conditions, reducing energy consumption and minimizing cooling loads inside buildings particularly in hot areas.

2. Passive Design and Thermal Comfort in the Built Environment

Passive design is a type of architecture that uses climate and natural elements to provide a suitable temperature within the building to maintain a comfortable environment, reducing or eliminating the need for mechanical heating, cooling and lighting systems. It compromises the use of renewable energy flows to develop thermal comfort.

Passive design, also known as “bio-climatic design” which helps maximize occupants’ comfort and health by harmonizing local climatic and site conditions with architectural design and building technologies (Yao *et al*., 2006). As highlighted in their pioneering works by Olgyay (1963) and Givoni (1969), the concept of passive design is to heat, to cool and to light buildings using indigenous design techniques and materials by reducing or even without using any energy system. The measures mainly include building form, shape, orientation, insulation, thermal mass, natural ventilation, shading and air tightness. It is hard to find an original clear definition that led to a categorization of the passive design concept. There have been many studies on this concept starting from the 1970s as an answer to the world energy crisis arisen at the same time (Sohha *et al*., 1986) and (Lechner, 1991).

The basic goal of passive design is to provide thermal comfort for people by cooperating with the outside climate and employing appropriate technology and design ideas that focuses on climate and environment (Sharma, 2016). There are two important factors that should be considered for passive design to be effective and functional: climate and comfort (Diagram 2).

Passive design responds to the climate without the need of additional devices that use energy and pollute the environment. Thus, buildings may be designed to use less energy than the current average. When designing a building, the envelope acts as a barrier between the indoor and outdoor climates in order to provide the human comfort level. Building envelopes as well as technologies used in attaining the appropriate degree of comfort play an essential role (Altan, 2016). The building’s envelope should be designed to avoid or reduce heat gain as well as shading also should be applied to reduce solar radiation (Agboola, 2011).

Therefore, in order to achieve a physical satisfaction, the human body should be in a comfort level. The demand for energy efficiency in the building industry without compromising long-term health and well-being of its occupants has motivated thermal comfort. Thermal comfort of the body is crucial since it influences an individuals' ability to function as well as their health depending on how well building design accommodated the external climate.

Accordingly, climate is one of the most significant factors influencing human comfort. As a result, due to varying climates around the world, each location has its own designs and construction techniques that can provide human comfort. However, due to technological advancements, most of the new constructions are designed to employ mechanical devices to meet any thermal loads. Extreme climatic conditions, outdated building practices and limited financial resources therefore hinder developing countries to adopt costly technologies aimed at improving interior conditions (Verma *et al*., 2017).

Built environment directly influences on human's satisfaction and well-being. Building's response to inhabitants' physical and psychological demands is important to give them a sense of self-worth, comfort and privacy. Regardless of these factors, it is necessary to create for a healthy atmosphere to improve the spirits, relax and provide contact with nature (Sassi, 2006).

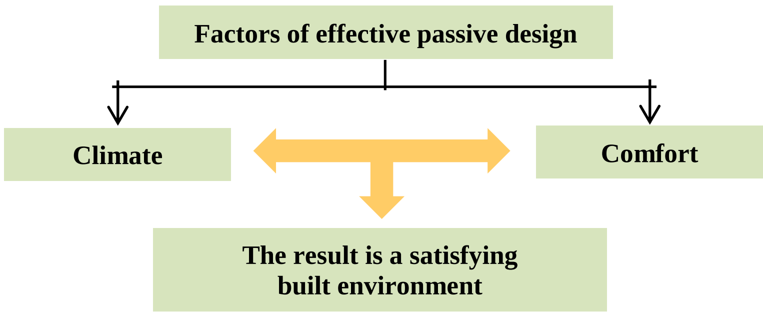


Diagram 2. The factors that affect passive design in the built environment (developed by the author)

3. Brief Literature Review on Passive Design Solutions in Hot Climate

The basic principle of any passive design strategy is to protect the building shell from unwanted heat gains in summer and from heat loss in winter. In order to achieve the required internal temperatures, the heat loss and gains should be balanced (Sadineni *et al*., 2011).

Passive design techniques are technologies that rely on natural resources to achieve comfort levels without requiring the use of artificial energy. These methods are environmentally-friendly and use abundantly available natural resources. The use of such methods enable in the transformation of building envelopes into living organic structures that can support human life (Altan, 2016). Passive design solutions operate without the need of mechanical equipments or external power sources and naturally heats and cools buildings (Tsioroli & Ioannou, 2016).

The local climate where the building is located affects passive design solutions. Most of the buildings are not comfortable for the occupants because of its inadequate design in relation to the climate. Thus, the design phase of a building should concentrate on the requirements that are important for thermal comfort without relying on too much energy consumption. For example, using passive and low-energy strategies in building construction produce environmental buildings particularly hot climate weather. There are several advantages to passive cooling design techniques such as improving comfort, lowering utility costs and adding little expense to the building. The following are some common passive design techniques that directly or indirectly affect thermal comfort conditions and hence energy usage in a building (Diagram 3).

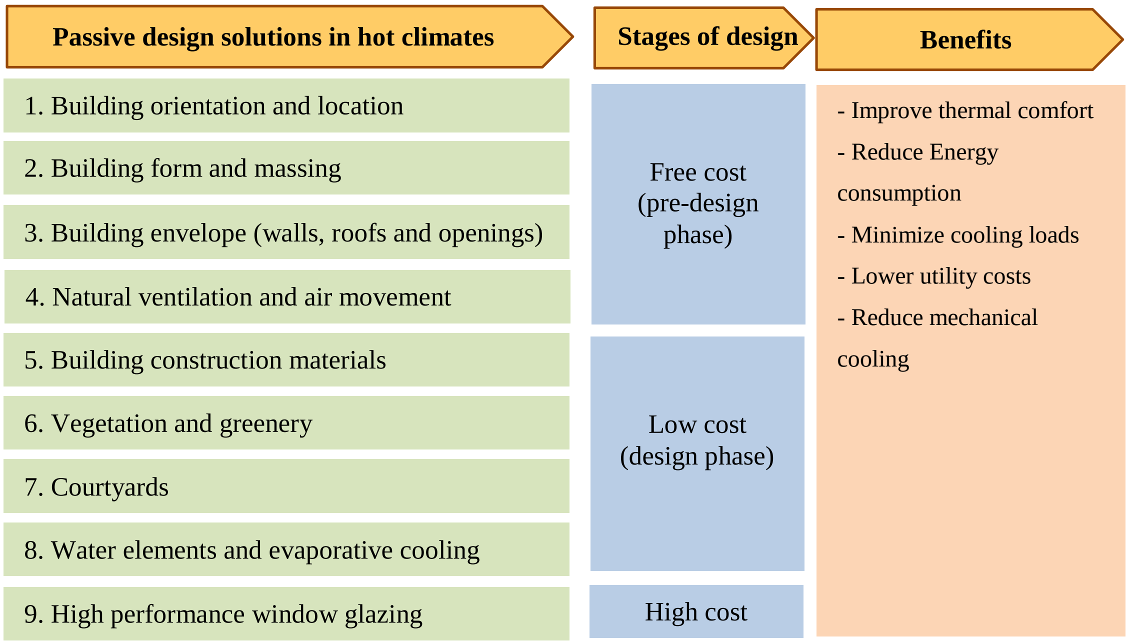


Diagram 3. Passive design solutions that can be adopted in buildings in hot climates during the different stages of design (developed by the author)

3.1. Building orientation and location in site

Building orientation is the process of selecting the direction of a building. It plays a key role in delivering passive thermal comfort to building and help designers employ the sun's free energy to reduce the cooling loads. The orientation of the building should be adjusted depending on the climate. It may be located in such a way to block undesirable solar gain and to maintain comfort inside the building. For example, in hot and dry climate zones, the best orientation for long façade buildings is north and south, in order to benefit from indirect light without glare from the north and to regulate direct solar heat gain from the south through shading. Additionally, the building should be oriented towards the prevailing cool wind direction to provide maximum cross ventilation at night.

3.2. Building form and massing

Properly massed building uses the form and size of the building to maximize its free energy from the sun and wind and to minimize cooling energy demands. Passive heating, cooling and daylighting are all crucial factors to consider in massing a building during the design phase (Bassiouny, 2021). In hot and dry environment, buildings are compact in form and minimize east and west walls to reduce heat gain. Increasing depth of a building would assist to increases thermal capacity (Kamali, 2014). The heat gain of a building is directly proportional to its perimeter-to-area ratio. Buildings with greater

P/A ratio may be applied in certain cases such as water bodies and vegetation which may modify microclimate (Afreen *et al*., 2020).

3.3. Building Envelope (walls, roofs and openings)

Envelope design is the process of investigating the overall design of building form and materials in order to obtain the highest comfort and energy efficiency. The building envelope consists of the materials used in walls, roof construction details, windows and floors through which heat enters and exists a building.

3.3.1 Walls

The colour of building envelope can affect its thermal performance and lower maximum indoor temperatures, thus reducing the demand for mechanical ventilation and cooling. White surfaces, for example, receive less solar radiation than dark surfaces, thus resulting in less heat being transferred to interior surfaces through convection. The quantity of solar radiation reflected varies from 80% on white surfaces to 20% on dark ones (Clair, 2009). Low energy materials are preferred. Heat transmission in a building is influenced by internal walls, doors and space arrangements.

In hot climates, insulation is applied on the exterior face of the wall. Thermal mass can be defined as a material that absorbs or releases heat from or to an interior space. It can assist to keep the interior cool throughout the day when the outside temperature is high by delaying heat transmission through the building envelope. Thermal mass may be used in a variety of ways. The mass can be built within the building envelope through using thick walls that provide direct cooling, or it can be located outside such as the earth under or around a building, where fresh air passes and cools before entering the occupied space (Chenvidyakarn, 2007).

3.3.2. Roofs

In hot regions, insulation on roofs can be applied using earthen pots, deciduous plants cover or creepers. Also, shutters, curtains and louvers can be provided for shading.

3.3.3. Openings (window placement)

Buildings that are naturally ventilated benefit from wide openings but they also tend to be noisy since large openings allow for more noise. Therefore, the location of naturally ventilated buildings is significant and they should be avoided in noisy areas. Assuming that the building is properly oriented with the sun's alignment, proper window placement will ensure the optimum quantity of sunlight that enters the building. As a result, to achieve the most natural ventilation, a building should be constructed with windows placed on opposite sides from each other (Khatami, 2009). In hot dry climates, the window size should also be reduced and minimum glass use is recommended to minimize the heat gain inside the structure (Majumdar, 1997).

In addition, shading is the most significant building passive design approach for comfort especially shading of openings. The window-to-wall ratio (WWR) should not exceed 60%. Thus, effective daylighting is possible with much lower WWR (Afreen, 1997). Solar gain through windows is commonly an important part of the heat gains of a building. Various methods such as shading devices near structures, vegetation and special type of glasses can provide effective shading. External shading devices are considered the most efficient, since they capture solar radiation before it enters through the building envelope into the interior space (Chenvidyakarn, 2007). For example, trees, climbers, high bushes and pergolas, can offer effective shading for the walls and windows of a structure.

3.4. Building construction materials

The selection of building materials selection is influenced by the insulation property. Good insulation is essential to limit heat transfer between the internal and external spaces (Atlan, 2016). The materials employed in the construction of a building have an important effect on heat gain inside the building. It is very important, as a designer, to understand the significance of material selection and to use locally available materials that minimizes energy usage and consequently building costs.

3.5. Vegetation and greenery surrounding/ inside the building (landscape)

Vegetation and greenery surrounding the building is a traditional time-tested and proven heat avoidance technique. Indirect evaporative cooling by vegetation has shown a promising performance in improving thermal comfort within the building and therefore, such a strategy can be applied in hot dry climates to provide shading for building, roofs and the surrounding areas (Tataresstaghi *et al*., 2018).

Plants are used to reduce the impacts of the sun, wind and pollution. Climate adopts the form and the component trees, which can help in generating the necessary weather-related adjustments (Almusaed & Almssad, 2016). Ground cover by plants also minimizes the amount of reflected solar and long-wave radiations that reach the building, thus lowering solar and long-wave heat gains. This evapotranspiration process also cools the ambient air and the nearby surfaces (Chenvidyakarn, 2007).

3.6. Courtyards (arrangement of internal spaces)

The courtyard is the most significant method using the indoor space of a building. This space has a considerable impact on the local microclimate and contributes to the improvement of environment. Courtyards are important for providing ventilation, daylighting and sometimes enhancing the cultural value. They are responsible for reducing the cooling energy needs in buildings (Afreen *et al*., 2020). The courtyard effectiveness can be improved by adding trees for shading, soft paving or a fountain (water body). The main objective of the courtyards is to provide comfort by lowering temperature through water evaporation while increasing the relative humidity. It acts as a climatic moderator by collecting cool air at night time and providing shade during the daytime. Thus, it is a vital source for natural ventilation and improves air circulation (Lu *et al*., 2016).

3.7. Water elements (evaporative cooling)

This technique is effective in hot-dry climate where the atmospheric humidity is low, evaporative cooling reduces the interior air temperature by evaporating water. Evaporative cooling uses the sensible heat of air to evaporate water, thereby cooling the air, which then cools the building's interior spaces. The rate of evaporation rises as the interaction between water and air increases. The presence of a water body near the building such as pond, lake, sea, … etc. or a fountain in a courtyard can cool the air when it combines with water and evaporates leading to a reduction in air temperature. This is called "adiabatic" which refers to a process in which no heat being gained or lost (Akande, 2010).

In order to obtain the best effect from cooling by this method, the interaction between water and air needs to be as widespread as possible. It should also be noted that water does not simply cool the air, it also cleans it. Water can remove dust or other contaminates which are found in air, these both refresh the air and create a fresher and more pleasant environment (Taleb, 2014).

3.8. Natural ventilation (cross ventilation and air movement in the building)

Natural ventilation is an efficient way to reduce energy consumption as well as providing a healthy interior environment. Ventilation in hot dry climate is useful if the air is cool (Afreen *et al*., 2020). Living in hot environment can rapidly become uncomfortable and stressful for its occupants due to the extreme heat gain inside the buildings. Therefore, adequate ventilation and internal temperature below the outdoor level will benefit the building. Natural ventilation keeps the air moving within the indoor spaces and the occupants cooler even without the use of energy. When determining the orientation of a building, it is important to lay it out such that the building shorter axis align with the prevailing winds. It will provide the most wind ventilation if is aligned this way.

Cross ventilation is a common method used in the passive design process. It uses natural wind current to cool the building (Singh & Atreya, 2011).

Cross ventilation has several advantages, it removes hot air and brings fresh air to the building while also lowering the temperature so that the loading energy will be reduced. It has the effect of providing healthier air to occupants and ensuring that the building ventilation is providing, natural, fresh air from outside to inside the building while pulling the exhaust air outside (Taleb, 2014).

3.9. High performance window glazing

While walls make up the majority of a building's façade, the glazing systems can contribute significantly more to space-cooling energy. Glazing systems cannot be insulated to the same degree as a wall due to their purpose, resulting in the windows being the most vulnerable portions of the envelope in terms of heat-flow resistance. To lower energy consumption, window design should be done depending on the specific climatic conditions of the structure using several forms of glass, such as aerogel glazing, vacuum glazing, smart glazing and prismatic glazing, can improve the energy performance of windows (Monis & Rastogi, 2022).

4. Case Study: A Proposed Design of a Culture Center in Siwa Oasis, Egypt

The case study was chosen to be in Siwa Oasis which has been considered as one of the ancient oases since Pharos' time. The oasis is called "mercy islands" because it served as resting place for travelling tribes in the desert. Also, Siwa is known in ancient Egypt as "Sekht-am" which means the "palm land" (Dumairy, 2005). It is blessed with dense landscape olive and palm trees as well as several natural springs and salt lakes.

Siwa Oasis has a distinct architectural style in construction. In summer, thermal comfort is a major concern in the oasis arid climate. Due to high temperatures in Siwa, people have relied on the usage of mechanical cooling systems to promote the indoor thermal performance of the space. According to previous studies, buildings in Siwa Oasis use 70% to 80% mechanical cooling systems (Dabaieh *et al*., 2015). Consequently, people employ mechanical cooling systems to improve thermal comfort, instead of using passive design solutions and approaches.

The paper focuses on Siwa climate which is an important element in determining the basis for the design of its buildings, distances between buildings, the form of buildings, orientation and the outer envelope of the buildings. Also, heat transfer is a key aspect in determining the building design elements such as windows, wall materials and thickness that improve thermal comfort (Ali & Tarek, 2012).

The study focuses on passive design techniques to be applied in buildings during the design stage in Siwa Oasis and the mechanisms for upgrading buildings within the hot climate conditions, by evaluating the techniques necessary to provide a satisfying life for the society in contemporary times.

Also, it is important to preserve the unique architectural and urban character of Siwa Oasis and to utilize the advantages of local and traditional martials and techniques to provide high quality of life including thermal comfort with low energy consumption (Diagram 4).

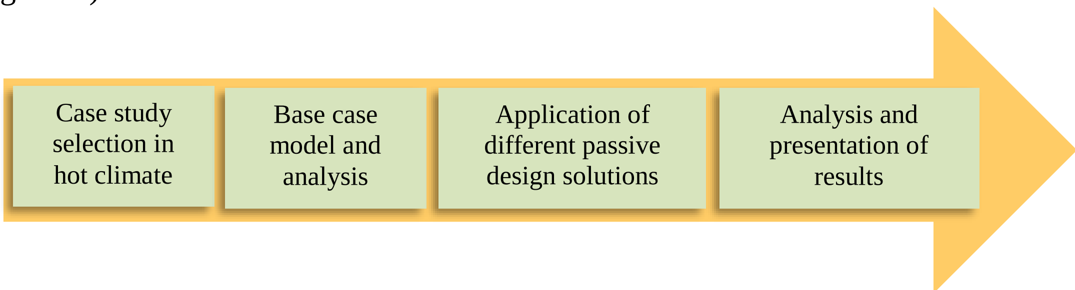


Diagram 4. Methodology adopted in the case study (developed by the author)

4.1. Site characteristics

Siwa is a small town located in Egypt’s western desert, about 17 Km below the sea level (Figure 1). It is located 12 Km east of the Libyan border and 300 Km south of the Mediterranean coast (Abdel *et al.*, 2015). The oasis extends in the east-west direction in a basin 17m below the sea level (long. 25.50 ^{0}E and Lat. 29.20 ^{0}N) (Rovero *et al.*, 2009). Siwa has a total area of 1088 square meter and populated by 11 traditional tribes totaling 20.000 people. It contains more than 300 springs, (Ahmed, 2014).

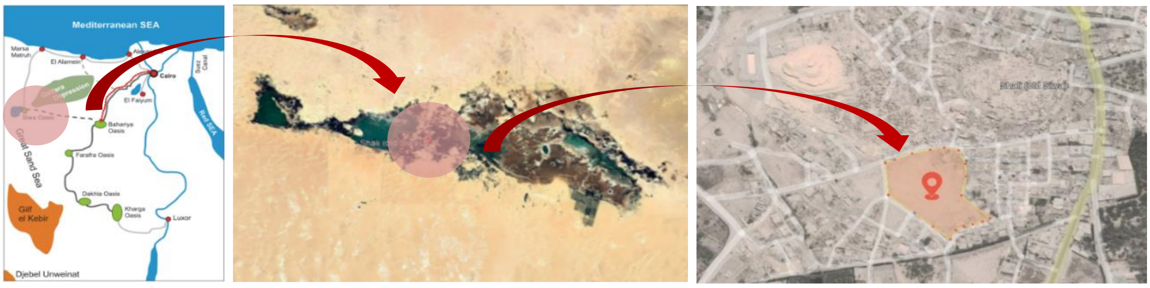


Figure 1. The proposed location of the culture center (developed by the author)

4.2. Climate

Siwa is characterized by its hot dry climate. Most of the year, the temperature is high exceeding comfort zone. During the summer months (June till August), the mean maximum temperature exceeds 40C^0 while the lowest temperature barely reaches the comfort level during summer nights. In Spring and Autumn, the daytime temperature is hot (32C^0 to 39C^0), with cold nights. The diurnal range is high (20C^0) allowing thermal storage to be used as a passive cooling approach for nine months of the year (Figure 2). Air movement is very weak in summer but high in winter, between 0.25m/s to 4m/s. In addition to that, humidity is very low due to the desert climate (Sameh *et al.*, 2019).

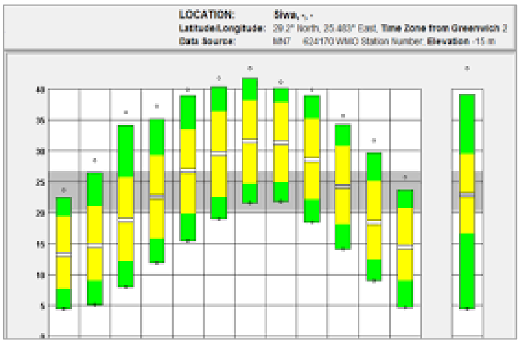


Figure 2. Temperature range in Siwa Oasis

4.3. Application of passive cooling design techniques on the proposed building

The first step was to propose a design for a public building that was influenced by the traditional architecture of Siwa Oasis. Through a modular form, the components of the project fulfil the needs of the occupants and functions in spaces.

4.3.1. Building orientation

The building is oriented towards the north-south direction to benefit from the prevailing winds.

4.3.2. Building form and massing

The building is designed as a compact structure composed of four connected wings with a central open courtyard. The first wing contains a theatre and a storage room. The second one the artisanal training rooms for various local crafts, music conservatory and mediatheque (library and AVB room). The third one contains the administration offices and the services (toilets) and the fourth and the last one is the dining area (café and restaurant). In addition, the artisanal training rooms have extended open spaces where users have the opportunity to work outside during winter days (Figure 3).

4.3.3. Building envelope (walls, roofs and openings)

- **Walls**

The walls adopt curved spontaneous forms that are built perpendicular to each other. They are thick walls of 60-80 cm and is reduced in the upper floors to 30-40 cm of local building materials. Kercheif is mixed with clay of low heat conduction materials, which act as a thermal barrier between the outside and the inside (Petruccioli and Montalbano, 2011). The outer walls are made by ordered and selected internal nucleus of kerchief blocks, joined together with mortar. The external walls are painted with white colors to reflect solar radiations.

- **Roofs**

The roof is designed to be flat and simple, from horizontal palm trees filled with fibres and covered with 10cm layer of kercheif. The roof is made from tree trunks that are appropriate with karsheif an environmentally friendly material that does not emit carbon dioxide.

- **Openings (window placement and shading devices)**

The study showed clearly that exterior windows have an important role to play in ventilation. Thus, it was proposed that the number of windows that open to the exterior sidewalks are minimized to avoid having the unfavourable climate enter the indoor area (Figure 4). The majority of windows are designed to open internally to the covered central courtyard area, which generally has less harsh conditions and more pleasant setting than the outside of the building.

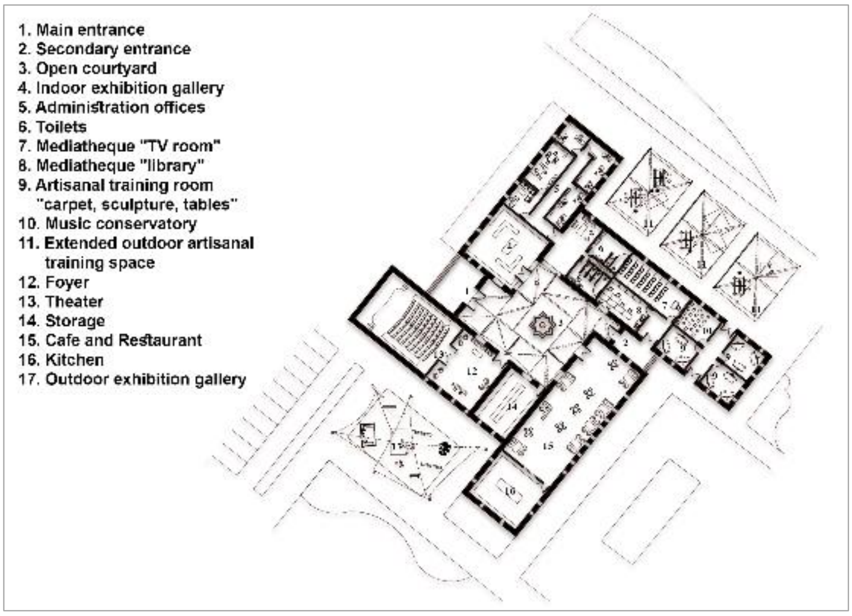


Figure 3. Plan for the proposed Culture Center in Siwa Oasis (developed by the author)

Figure 4. Small windows on the exterior sidewalks (developed by the author)

Also, windows are positioned opposite to one another to allow for cross ventilation. Another method used for cooling the air, is utilizing in-depth recessed windows with sloped sills under the window to manage daylight and shade that enters the interior of spaces.

A louvered shading device was proposed positioned on windows in the south façade of the building in order t manage the quantity of daylight and shading and block sun gain in summer and to also allow wind to pass through it and cool the area. The louvers were horizontally placed. When the sun is high, the louvers will ignore heat and still allow the light needed for the area (Taleb, 2014). (Figure 5).

Using traditional ways in building by kersheif, requires windows to be small, which formulated an important attribute in the traditional building that makes it always in good performance (Cardinale *et al*., 2013).

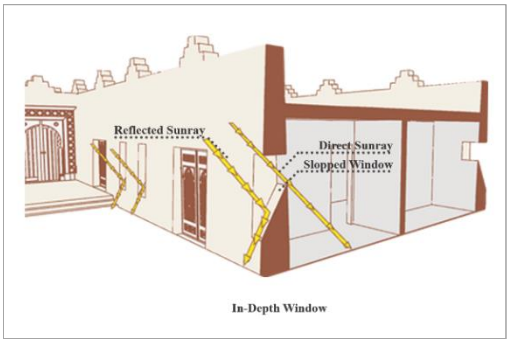


Figure 5. In-depth recessed windows (developed by the author)

4.3.4. Courtyard

The rooms and spaces were designed to open to the interior courtyard where it is sheltered against the extreme heat of summer and the cold of winter and from winds, storms and sand (Figure 6).

Figure 6. Sheltered courtyard of the building (developed by the author)

4.3.5. The use of fountains (evaporative cooling)

It was proposed to have a fountain in the courtyard that has a considerable effect of cooling in hot dry conditions where the atmospheric humidity is low. The sensible heat of air is used to evaporate water which then cools the building's different spaces (Figure 7).

4.3.6. Vegetation and greenery

Local vegetation such as palms were proposed to be placed in the courtyard and around the building to minimize high temperature and create shade on the external walls of the building.

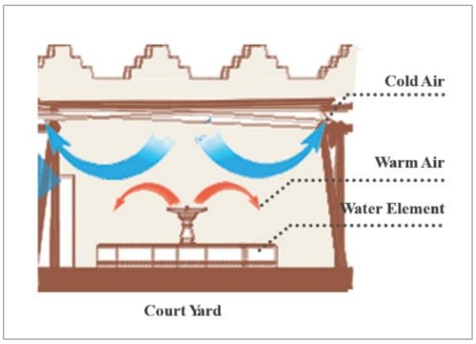


Figure 7. The effect of evaporative cooling on the building (developed by the author)

4.3.7. Building materials and construction techniques

It is claimed that the use of traditional building materials of Siwa is kersheif and lime stone and the construction system is bearing walls and palm trunk for roofs, will result in building with better thermal performance than that of the new building techniques and materials, concrete skeleton and brick walls. Kershief is a unique material made of NaCl salt crystals with impurities of clay and sand. The irregular shaped blocks are taken from the salt crust that surrounds the salty lakes and are cut in smaller blocks and used in the masonry with a mud mortar very rich in salt obtained from two different clays, tafla and tiin. Kersheif is a wall building material known to have superior thermal properties compared to common brick walls. It is proved to have better insulation than concrete.

Wood laid inside the wall thickness is to enhance joining between the external and internal sections, particularly in large walls. Clay material has a positive effect on the building thermal performance during both summer and winter. The heat energy gained and stored in the building from the sun during the day and then slowly re-released into the building at another time for thermal comfort. Passive cooling is achieved by separating the building through narrow paths to allow for wind movement as well as cross ventilation that replaces the use of air conditioning. (Mokhtar, 2016).

4.4. Building Performance and Simulation Analysis of Cooling Loads

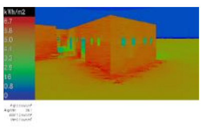
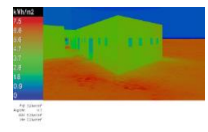
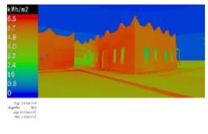
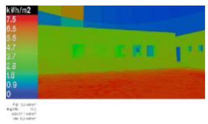
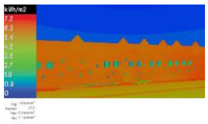
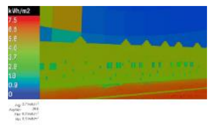
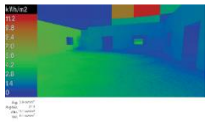
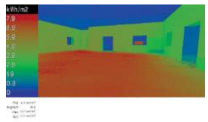
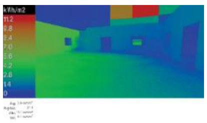
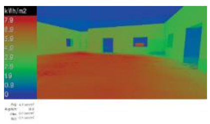
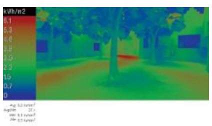
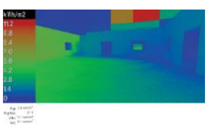
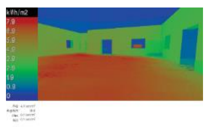
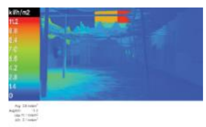
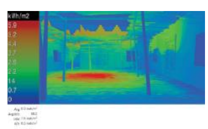
In hot and arid regions, mechanical systems are frequently used to cool the environment to make it more comfortable for users. The effect of this is that energy load is increasing and consequently the need for electricity is rising. Thus, passive design strategies can reduce the load of active systems if they are applied correctly.

Recently, building performance simulation technologies played a significant role during the early phases of design. This may help design decisions including passive techniques, hence improving the indoor thermal comfort.

In this step in the case study, it regards the development of the 3D model of the proposed Culture Center in Siwa. In this phase, Lightstanza is the energy performance simulation tool used. The study is based on a comparative analysis of the simulation outcome, aiming to evaluate the effect of using passive cooling techniques to accommodate thermal comfort inside buildings. The case study is a hypothetical building model that will be tested in two cases.

First, the base case model design was simulated and analysed without applying passive design techniques. Then, Thermal analysis was done for the proposed building utilizing passive cooling strategies. All cases were testes having the same location (Shali, Siwa Oasis), form and orientation.

Table 1. Comparison between the base case model and applying different passive cooling design techniques (developed by the author)

Comparison between different passive design strategies					
Simulation Cases	Point of comparison	**Base case model** (before adding passive cooling techniques)		**Alternatives** (after applying passive cooling techniques)	
		January	July	January	July
Case 1	Orientation and form				
Case 2	Small in-depth windows with sloped sills				
Case 3	Windows with louvers				
Case 4	Size of windows				
Case 5	Courtyard with fountain				
Case 6	Courtyard with vegetation				
Case 7	Courtyard with a shading element				

The simulation was done on the 22nd of January 2022 and 22nd of July 2022 for both cases. Comfortable indoor temperatures were achieved by the proper use of passive design methods such as building orientation, form, envelope, courtyard, shading devices and fountains.

This section presents a comparative study of a base case of the proposed project (Culture Center) and the application of different passive alternatives. Each case in the proposed design was tested with several variations. The results of each case display the effect of one or more parameters on the building's thermal performance and its indoor temperature (Table 1).

5. Results and Discussions of the Simulation Outcomes

The proposed building model is analyzed before and after applying passive cooling techniques. The reference base case simulates the worst conditions due to the absence of passive cooling strategies. It is noticed that the absence of passive design solutions resulted in high heat retention in the indoor spaces.

The following section presents an analysis and a comparison between the cooling loads and thermal comfort by using a simulation tool. The analysis represents that the building orientation, form, size of windows, louvers, vegetation, fountains, … etc. had a significant cooling effect on the proposed building.

Case (1): Building orientation and form

It is observed that the building orientation has a significant cooling effect all the year round.

Case (2): In-depth windows with sloped sills

The simulation showed that recessing and sloped windows control the entry of solar radiation into the spaces and reflected on the outside of the building.

Case (3): Windows with louvers

It is proved that the louvers and shading devices on windows are effective in the months of summer than winter as it prevents the building from direct solar radiations and enhances cross ventilation.

Case (4): Size of openings

The adoption of small size windows in the proposed building promotes natural ventilation and air movement inside the spaces and consequently reduces the cooling loads on buildings (Figure 8).

Case (5): Courtyard with fountain

The fountain enhances evaporative cooling particularly in the months of summer.

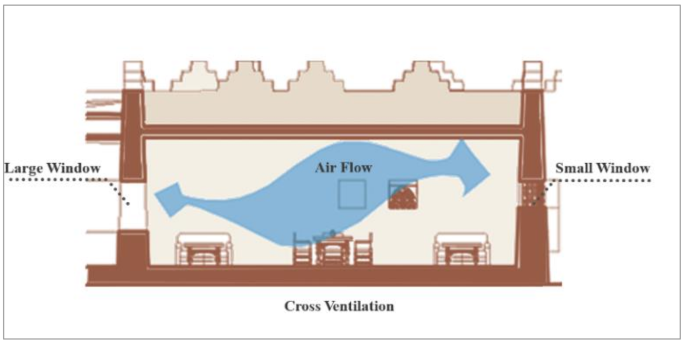


Figure 8. The effect of the small openings on the natural ventilation (developed by the author)

Case (6): Courtyard with vegetation

The green plants in the courtyard protect the building against extreme heat of the summer.

Case (7): Courtyard with shading element

In the case of using a courtyard with a fountain, a shading element and vegetation, the results showed that July has more cooling effect than January. This concludes that the use of open courtyard in the center of the building gave more cooling effects and it is considered as a good solution for air ventilation and decreasing the temperature inside the building.

6. Study Limitations

The selection of passive cooling solutions was limited to the literature review study due to the limits of Lightstanza simulation program. The program is restricted to the building model.

7. Conclusion

In hot dry climate zones, global warming leads to an increase in energy demand by the built environment. The rise in temperature enhances cooling demands in buildings. The main purpose of the study was to introduce new design approaches by passive design methods to decrease energy use and to achieve the best comfort level in interior spaces during the early stages of design.

Passive design depends on the climatic conditions of the area and should therefore be designed accordingly. A passive building is often the key foundational element of a cost-effective zero-energy building. In a passive cooling design, it is important that all main elements of the building should either block or reject solar heat gain and try to keep the building cool against the heat of the summer.

In hot and arid climate, most of the energy load is from mechanical systems, so this load could be reduced by adding or adopting some elements in the building such as louvered shading devices which can significantly reduce energy consumption.

Using passive cooling design techniques and applying it properly on the buildings will achieve better thermal comfort for interior spaces. Therefore, adapting passive design strategies in the design process and construction phase will help to achieve better energy performance in buildings.

The study found that the form and building orientation play a significant role in using passive cooling techniques. Thus, the east-west building orientation is the most efficient cooling passive measure and the low surface-to-volume ratio demonstrated better potential in energy saving. The role of building envelope, shading devices, vegetation is significant for cooling energy savings. Implementing and using most passive cooling methods is economically feasible in these areas due to their short payback period.

Through analyzing the case study, the main criteria of architectural design in hot and dry climates in terms of passive cooling was concluded. Further, the paper investigated the potential passive cooling strategies for Siwa Oasis (Egypt), proposed a design of a building and different suggested different passive cooling strategies to be applied. Lightstanza software simulation tool was used. The simulation results were analyzed and proved the potential for energy reduction and the achievement of optimal thermal comfort it passive cooling strategies were used.

The building envelope is the most influential parameter to indoor thermal comfort. The manipulation of windows, wall thickness, insulation and colour are used to reach indoor thermal comfort. According to the studies in the literature review and by analyzing the passive design techniques, it can be concluded that using the local materials is more economical than any other material used to restore the identity and the image of Siwa. Therefore, using sustainable passive design techniques will custom the natural ventilation rather than using mechanical systems, using Siwa's local material creating low-cost zero-carbon building techniques, cheaper when compared to other materials, and re-establishing the image and identity of the city that has been ignored in the present days. Also, the placement of windows in east-west direction to generate cross-ventilation in interior spaces. Furthermore, the vegetation is locally selected and planted around the proposed site to protect it from the dust storms and also in the courts to ensure shadows and to gain natural ventilation.

Finally, it is worth mentioning the lack of studies estimating the efficiency of building design measures in hot arid regions under future climate conditions. Moreover, the majority of publications mainly focused on the current weather conditions ignoring the effects of climate change on the built environment. As a result, further research is urgently needed to improve the understanding of how built environment will perform in hot dry climates.

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