THE APPLICATION OF TRADITIONAL ARCHITECTURE AS PASSIVE DESIGN STRATEGIES FOR MODERN ARCHITECTURE IN HOT DRY CLIMATE

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Abstract. Traditional Architecture in Cairo is noticeable to give a great respond to climatic conditions in hot dry climates. This paper aims to analyse the application of traditional architecture elements as passive design strategies in modern architecture of Cairo. The methodology of this research is based on a computer simulation. As a case study of one building mass was design and simulated in this study. Building design was based on the application of traditional residential building in Cairo. Then, the performance of building design was simulated in terms of solar simulation, wind direction, and also heating and cooling loads. From the result, the application of traditional element was relatively effective as passive design strategies to reduce solar heat gains and applying natural ventilation because it has less opening in the south, catch the breeze air from south-west and north-east axis, while consumed less heating load. However, the cooling load was relatively the same with the conventional building, this might be lowered by using another passive design strategies. Keywords-traditional; modern; architecture; cairo; hot dry climate; climatic; design.

1. Introduction

1.1. Climatic Condition

Egypt is a hot-arid climate country that is located in 30°2’N 31°13’E. The main characteristic of hot-dry climate is the extreme temperature, where during the day the temperature is extremely high while during the night the temperature is relatively low. According to World Meteorological Organization (UN) from 1971 to 2000, the highest temperature was 47.8°C, and the lowest temperature was 1.2°C. The number of rainfall per year in Cairo is extremely low. The precipitation reached 0 mm during summer (July, August, Sept) [1]. The average relative humidity is 56%, with minimum 46% and maximum 61% [2]. In terms of amount of sunshine hours, Cairo received an excessive number during summer, with maximum 363 hours in July [1].
1.2. Traditional Architecture in Cairo

Traditional architecture in Cairo or identified as Islamic Cairo are basically classified as four different periods, Fatimid (from 969), Ayyubids (1171-1250), Mamluks (1250-1517), and Ottoman period (1517-1805) [3]. Architecture in Fatimid period recognized by the development of Mosque (Mosque of Ibn Tulun, Mosque of El-Hakim, and Mosque of Al-Aqmar) which is characterized by square plan, large inner courtyard in the centre, arcades, fountain, minaret, and also decorative crave pattern. Ayyubids period known as the development of Islamic school (madrasah) building (Al-Salih Nagm Al-Din Ayyub) where the square plan and Minaret was the remaining element in this period. This era was the transition between the late Fatimid and the early Mamluk. Mamluk’s period combined mosque and madrasah as one unit block. This period was recognized as the development of giant buildings where mosques become monumental. Building also characterized by geometric decorative pattern. Cairene homes were developed from late Mamluks and throughout Ottoman period. Some element in Cairene homes are a great application of passive design strategies. Sahn (inner courtyard), malkaf (wind catcher), and takhtaboosh (courtyard arcade) utilize as natural ventilation. Mashrabiyya (wooden lattice screens), maq’ad (overhand), shuksheika (skylight) are applied as passive solar design. While, nafora (fountain), and salsabil (water cooling plate) are implemented as evaporative cooling strategy.

Hot dry climate is characterized by its excessive sunlight, dry, and low precipitation conditions. The extreme climatic conditions force traditional residential in Cairo to be adaptable to achieve comfort. Passive design strategies were applied as a respond to climatic conditions.

Mohamed (2014) said that traditional houses in Cairo were built close each other to confront climatic conditions [4]. According to Olgyay [10], the arrangement of buildings shelter design in hot-arid climate can be managed by house types, general arrangement, plan, form and volume, orientation, interior, and colour.

Fathy (1986) stated that increasing the height of the building provide shading to indoor house spaces and use as shelter from direct sunlight [8]. Indirect entrance in the Cairene house has two turning, where the first turning protect inside house from wind, dust, noise, and the harshness from outside [7] and the second turning deliver to the inner court.

Inner courtyard in Cairene houses were utilized as ventilation, daylight, and interaction among building masses [5]. Gianni (1988) stated that walls and floors of the courtyard stored solar energy during the day while releasing hot air and storing cold air during the night [9]. Hakim (1988) argued that thick walls and inner courtyards of residential buildings serve as noise barrier and shading element [6].

Fathy (1986) said qa’a between two North-South axis iwans use as passive solar energy in the summer and winter [8]. Mashrabiyya provides lighting and airflow [8] while preventing dazzle [4]. Mohamed (2014) commented that shokhsheskhas utilize to enhance daylight and reservoir to release the hot air and replace it with the cool air [4]. He also added that malqafs serve as ventilation traps to capture the cool air from outside [4].

This paper aims to analyse the implementation the traditional elements as passive design strategies in modern building in hot dry climates. This study also investigate the performance of the building by simulate the solar radiation, shading pattern, wind direction, ventilation, and also heating and cooling loads.

2. Methodology

Hot and dry climate is an extreme condition where people feel uncomfortable both during day and night. People can be suffered from the hot radiation and sunlight during the day, while endure the cool breeze during the night. Therefore, this type of climate is challenging to be exercised.

Cairo was selected as a case study for this research because it represents the era of traditional architecture in hot dry climate. The building site was selected close to the Nile River to minimize hot and dry while optimizing the wind and moisture for cooling strategy. The building mass and orientation was assumed to be given from the client.

This research used no data collection where the data is purely based on the climatic data (sun path, wind speed, and wind direction) from Revit. The analysis data based on the Revit simulation result.
There were three phases of simulation, solar simulation, wind simulation, and energy performance simulation. Solar simulation was conducted based on summer (20th June) and winter (21th December) time which was simulated every 4 hours, from 06.00 am, 10.00 am, 14.00 am, and 18.00 am. Wind and energy performance simulation was simulated annually.

The analysis started with the solar simulation which illustrated the annual sun path diagram and shading pattern of the building mass, then the wind simulation which produced the annual wind rose and wind flow inside the building, and lastly the energy simulation which described the heating and cooling load of the building.

3. Results and Discussions

3.1. Design Solution

The design concept of the building was creating an adaptable building which has less energy consumption by the application of passive design through traditional elements. This strategy used to confront extreme climate condition, which is hot and arid.

The building was designed with some strategies that can accommodate the occupant comfort. This building utilizes some strategies, such as natural ventilation, passive solar heating, and cooling evaporation which are adaptable whether in maximum or minimum temperature. In the case of facade, the role of large opening windows and sun shading are essential for achieving thermal comfort. Regarding with passive solar heating, walls are thicker in purpose to store the heat and reject sun radiation going through the building. Cooling strategy is applied in form of green roof design. The roof resembles the role of inner courtyard (see Figure 1).

The concept building plan is open space. The absence of room divider contributes to circulate the fresh air in all over indoor area. Each floor is linked by the usage of voids. Voids are located in some spot in second floor. The purpose of this arrangement is to create the high-quality of air flow (see Figure 2 and Figure 3).

![Figure 1. Site plan of one block building design](image1.png)

![Figure 2. 1st Floor plan of the building](image2.png)

![Figure 3. 2nd Floor plan of the building](image3.png)

The arrangement of building facades aims not only as aesthetics but also as tool for passive solar strategy. The thick of the walls is 30cm in purpose to collect the heat energy during winter. Meanwhile during summer, the walls reduce the solar radiation which can raise the air temperature inside the building. Large shading devices (mashrabiyya) are attached in west façades to reduce summer heat and dazzle. This is because the west side is the most sun-exposed part during summer. Mashrabiyya is also applied to affirm the characteristic of Cairene house. The Islamic pattern of mashrabiyya is applied in some facade elements, such as windows, doors, and railing.
As depicted in Figure 5, the position of windows was sink in the building surface, meanwhile mashrabiyya is located far in front of the windows to protect the excessive direct sunlight entering the indoor space. Double frame windows (qamariyyah) are installed in building facades (see Figure 6). Overhang in the upper place serve to shade the windows. The function of the first frame with tight latticework is to reduce direct sunlight during the day, and as an inlet for wind circulation.

3.2. Solar Simulation (Summer & Winter)
Cairo is located in north hemisphere thus the sun position dominantly comes from the south. This can be used as passive solar design to applied shading device in the south area to reduce solar heat gains during summer and optimize the solar heat gains in the south area during winter.

It can be seen from Table 1 the daylight and shading pattern of the building. Daylight hours during spring and summer time is 13 hours (from 06.00 to 19.00), while during fall and winter is 10 hours (from 07.00 to 17.00). It is also noticeable that the most exposing-sun area is in the north-south axis, while the west-east axis is fully shaded during summer. During winter, south area is unshaded because shading area is only located in west, north, and east area. This strategy can be useful for passive solar strategy during summer and winter.

![Figure 4. Elevation of the building](image)

![Figure 5. Detail Section of Mashrabiyya](image)

![Figure 6. Detail Section of Opening Windows (qamariyyah)](image)
Table 1 The roof thermal properties of the house

|       | 06.00 | 10.00 | 14.00 | 18.00 |
|-------|-------|-------|-------|-------|
| **S** | ![Image](image1) | ![Image](image2) | ![Image](image3) | ![Image](image4) |
| **W** | ![Image](image5) | ![Image](image6) | ![Image](image7) | ![Image](image8) |
| **U** | ![Image](image9) | ![Image](image10) | ![Image](image11) | ![Image](image12) |
| **M** | ![Image](image13) | ![Image](image14) | ![Image](image15) | ![Image](image16) |
| **M** | ![Image](image17) | ![Image](image18) | ![Image](image19) | ![Image](image20) |
| **E** | ![Image](image21) | ![Image](image22) | ![Image](image23) | ![Image](image24) |
| **R** | ![Image](image25) | ![Image](image26) | ![Image](image27) | ![Image](image28) |
| **I** | ![Image](image29) | ![Image](image30) | ![Image](image31) | ![Image](image32) |
| **N** | ![Image](image33) | ![Image](image34) | ![Image](image35) | ![Image](image36) |
| **T** | ![Image](image37) | ![Image](image38) | ![Image](image39) | ![Image](image40) |
| **E** | ![Image](image41) | ![Image](image42) | ![Image](image43) | ![Image](image44) |

3.3. Wind Direction

From the energy analysis data in Revit simulation (see Figure 7) the prevailing wind comes mostly from the north east part with 35 km/ hours. This is because the site selected is alongside with Nile River in the east (see Figure 8), so it gives impact to the prevailing wind. Located near the Nile River would increase the humidity through evaporation. It also provides the advantage not only offer attractive scenery but also for natural ventilation in the building.

![Figure 7. The annual wind rose, frequency direction (Revit simulation)](image52)

![Figure 8. the site selected is alongside with Nile River](image53)

3.4. Natural Ventilation

The natural ventilation in the building was designed by means of stack effect and cross ventilation. Stack effect came from the application solar chimney. This solar chimney serves as reservoir, to release the warm air during the day and replace it with fresh air during the night. Large opening windows the first and second floor provide the cool air and shove the stale air to escape through opening in the tower (see Figure 9). Cross air circulation also occurred inside the building through the addition of void. The function of void in the center allows the air circulation coming from the lower opening to the upper opening (see Figure 10).

![Figure 9. Wind analysis for section 1](image54)

![Figure 10. Wind analysis for section 2](image55)
3.5. Energy Performance

| Location and Weather |                |
|-----------------------|----------------|
| Latitude              | 30.09°         |
| Longitude             | 31.23°         |
| Summer Dry Bulb       | 40°C           |
| Summer Wet Bulb       | 19°C           |
| Winter Dry Bulb       | 8°C            |
| Mean Daily Range      | 16°C           |

| Building Summary     |                |
|----------------------|----------------|
| Cooling Load Density | 43.01 W/m²     |
| Heating Load Density | 105.29 W/m²    |

From the building design, it can be predicted that the cooling and heating load per m² of the building was 43.01 W/m² and 105.29 W/m². According to Passive House Standard, heating and cooling load of a building should not exceed 15kWh annually or 10W/m² [12]. This was 10% of energy consumed from conventional building, that means conventional building consume 100W/m² for heating or cooling.

It can be concluded that the cooling load in the building was lower than conventional building. However, the heating load was relatively the same with the conventional building. The design was still inefficient to reduce heating load, thus another passive cooling strategies should be applied to reduce more energy consumption.

4. Conclusion

In summary, the main factor that should be considered when designing building in hot dry climates is orientation. Orientation determine the design of building elements, such as the length and the width of building shape, the position of opening windows, air ventilation, sun shading, and the slope of roof. Great design of building elements will produce high performance of a building where it has less energy consumption. The best building orientation was determined by sun path and wind direction.

The position of opening window is determined by the sun orientation. Sun shading in the building surface is important. It also determines the heating and cooling load of the building. The more opening windows are applied, the larger heating and cooling is produced. South area was the only unshaded area during summer and winter. Therefore, less opening should be applied in the south façade of the building to reduce the solar heat gains.

Air ventilation should be decided by the direction of the wind. The larger the air ventilation, the more wind comes to the building. Prevailing wind comes from south-west and north-east axis. Thus, the natural ventilation could be applied in this axis to catch more cool air into the building.

The most suitable building shape for hot-dry climate is compact building with U-shape and inner court yard in the middle. This building type create more shading, thus reduce the solar heat gains.

From the result, the application of traditional element was relatively effective as passive design strategies to reduce solar heat gains and applying natural ventilation because it has less opening in the south, catch the breeze air from south-west and north-east axis, while consumed less heating load. However, the cooling load was relatively the same with the conventional building, this might be lower by using another passive design strategies.

5. Acknowledgement

Authors would like to dedicate gratitude to Mohamed Gadi, Department Architecture and Build Environment, The University of Nottingham for assisting during the research process. We gratefully acknowledge the funding from USAID through the SHERA program - Centre for Development of Sustainable Region (CDSR).
6. References

[1] NOAA, "National Oceanic and Atmospheric Administration," NOAA, 2018. [Online]. Available: ftp://ftp.atd.noaa.gov/pub/GCOS/WMO-Normals/TABLES/REG__I/UB/62366.TXT. [Accessed 19 January 2018].

[2] W. M. Organization, "World Weather Information Service," Organization, World Meteorological, 2018. [Online]. Available: http://worldweather.wmo.int/en/city.html?cityId=248. [Accessed 19 January 2018].

[3] C. H. C. A. Group, "Cultural Property Training Resource Egypt," CENTCOM Historical/Cultural Advisory Group, 2018. [Online]. Available: https://www.cemml.colostate.edu/cultural/09476/egypt02-08en.html. [Accessed 20 January 2018].

[4] N. A. G. Mohamed and W. H. Ali, "Traditional Residential Architecture in Cairo from a Green Architecture Perspective," IISTE, vol. 16, pp. 6-26, 2014.

[5] V. Olgyay and A. Olgyay, Design with climate, 1963.

[6] H. Fathy, Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates, 1986.

[7] A. Salama, "A Typological Perspective: The Impact of Cultural Paradigmatic Shifts on the Evolution of Courtyard House in Cairo," METU-JFA, vol. 23, pp. 41-58, 2006.

[8] B. Abouseif, "Note sur la Fonction de la Cour dans la Maison Moyenne du Caire Ottoman; in (eds)," I'Habitat Traditionnel dans les Pays Musulmans autour de la Mediterrance Cairo, Institut Francais d'Archeologie Orientale, 1990.

[9] S. Gianni, "Climatic Design in the Arab Courtyard House," Environmental Design: Journal of the Islamic Environmental Design Research Centre, vol. 1, pp. 82-91, 1988.

[10] B. S. Hakim, Arabic-Islamic Cities: Building and Planning Principles, London dan New York: Kegan Paul International, 1988.