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PROPOSED COOLING WALL SYSTEM: A LESSON FROM NATURE

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The study commences with a comparative analysis between desert adapted cactus plants and traditional mud houses. Primary comparative results yielded three main similarities: 1) Effective utilization of self-shading surfaces; 2) Plant spikes that resemble the wooden poles projected around wind towers and building openings in mud structures; 3) Implementation of thick walls/plant body forms with high R-values. The ribbed facade and wooden poles will go through aerodynamic experiments to illustrate their roles as essential passive energy elements in traditional houses. Experiments on traditional mud houses has been previously carried out by many researchers while assuming the wind is facing the buildings; what is significant about this proposal is that wind directions will be tested with different angles (0 to 90 degrees) to find appropriate situations where wind generates enough turbulence that help directing the wind inside the building openings. The study requires two models for experimentation, one model related to the wooden pole, and the other focused on the ribbed elevation. Tests will then be carried out using wind tunnel equipment. The QU Aspire wind tunnel has a working section of 2.5 X 2.5 X 2.5 m and can simulate wind of up to 25 m/sec at the working section. Moreover, Computational Fluid Dynamics (CFD) software will be used to minimize the wind tunnel utilization time.

Keywords: Sustainable architecture, Aerodynamic, Natural cooling, Ribbed wall, Wind catcher.

1 INTRODUCTION

Overlooking traditional building construction systems has limited the application of traditional design in modern architecture to form without function. This research raises an awareness of design elements' implication on regional architecture, even when these implications are impeded within new architecture. The significance of this research is the exploration of one dimension of traditional building that relates to climatic responsive design. McHarg's (1969) book, "Design with Nature", inspires this research to examine the similarity between traditional mud structures in the region and cactus plants that share the same climatic conditions. This study searches for better understanding of validity of traditional buildings as passive cooling systems and the direct role that their wooden poles, ribbed elevations and wind-catchers have in enhancing thermal performance. The study will go through three sections: First, literature review of related topics; second, investigation of the resemblance between traditional architecture and cactuses; third, aerodynamic experimentation with projected wooden sticks and ribbed elevations. The study highlights important traditional design principles and strategies that can be implemented to incorporate traditional passive ventilation and cooling systems in modern architecture.

2 REVIEW OF RELATED STUDIES

Concern with air motion hitting a solid wall with opening requires aerodynamic analysis. When wind hits the wind-catcher, it changes its flow pattern and speeds up inside and around the tower (KazemiEsfeh *et al.* 2012, Boloorchi *et al.* 2012) (Figure 1). The penetrating wind will submit to the Venturi Effect through an increase in wind pressure and speed inside the wind-catcher's narrow channel (Ferwati 2013). Considering the pressure generated by wind penetrating the wind-catcher, there is a study done by KazemiEsfeh *et al.* (2012) that shows "Pressure coefficients on internal surfaces of the flat roof wind-catcher's channel at a zero angle of incident" (Boloorchi *et al.* 2013, p. 92) (Figure 2). A'zami (2005) defines the Badgger (a wind tower with various inlets) and illustrated wind behavior; while Shanthi *et al.* (2012) carried out a quantitative study of El-Malqef (a single opening toward the prevailing wind). The study of Rizk *et al.* (2007) went beyond descriptive presentation to focuses on the effect of the verity entry opening's orientation with respect to wind direction and the effect on penetrated wind speed. Figure 3 indicates that with the 80 degrees of wind orientation, the speed will reach 70% of the original wind speed. It shows the weakening of wind speed as a result of the increase in wind angles. However, Rizk's study refers to the Egyptian model of wind catchers, which lacks wooden poles or ribbed facades. Most of the old traditional wind-catchers in the Arab Gulf are built with lots of protruded wooden poles. These studies are just a handful of many publications which appeared in recent decades. Some were descriptive and others experimental, but none of them referred to nature as design inspiration. Nevertheless, none of the previous related work directly examines wind sweeping the building at different angles with wooden poles or ribbed facades.

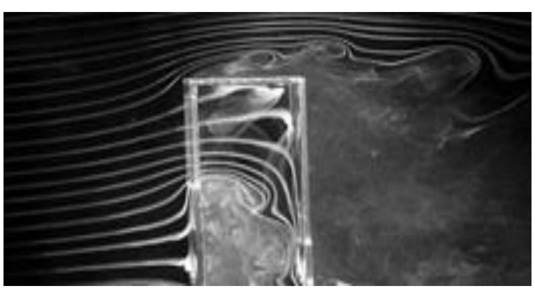

Figure 1. Visualized flow pattern inside and around the one- sided wind-catcher with flat roof (KazemiEsfeh *et al.* 2012. Cited in Boloorchi and Eghtesadi 2013, p 92).

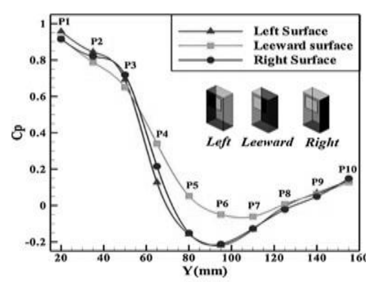

Figure 2. Pressure coefficients on internal surfaces of the flat roof wind-catcher's channel at a zero angle of incident (KazemiEsfeh *et al.* 2012).

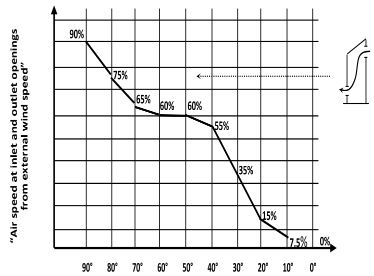

Figure 3. The effect of the verity entry opening's orientation according to wind direction (Rizk, 2007, p. 5).

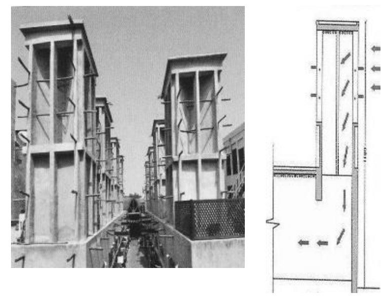

Figure 4. Wind-tower (*Baggadeer*) symbolizes the traditional Arab Gulf architecture. It has four identical elevation with openings separated by vertical dividers that vary in numbers.

3 SIGNIFICANT ANALOGUE BETWEEN TRADITIONAL MUD STRUCTURE AND CACTUS PLANT

Harsh weather demands two solutions: first, channeling the wind into inner spaces, and second, protecting the structure from the hot sun. Traditional cities are compact with narrow, curvilinear and broken streets. The average proportion of street width to building height ranges between 1 to 2. This results in self-shaded streets. In his research, Mansour (1995) finds that compact structures prevent cool air from reaching the lower level of open spaces. Wind catchers are found with different designs, two of which are *malkaf* and *baggadeer*. The wind catcher is developed to provide air circulation. It is located on the roof with vertical openings which channel wind down to different levels of the building. Several wind-catchers may be found in one building. Functionally speaking, by channeling the wind, wind-catchers help moderate interior climates by providing airflow which results in a cooling effect. Al-Wakil *et al.* (1989) see two other advantages of the wind-catcher: it provides convective cooling and provides evaporative cooling. The *malkaf* is an opening set at the roof parapet facing the desired wind direction. Since the stair case works like a *malkaf*, its door is set to face the prevailing wind. Traditional houses have inner courtyards, the advantage of which is air circulation as a result of negative and positive air pressure (Ferwati 2013). When wind is undesired, the opening is shut. *Baggadeer* is another design of a wind catcher known as a wind-tower. It has four separated openings to allow the penetration of wind from all directions. Figure 4 shows the structure in detail. Typically, its plan is square while its four identical elevations reach heights of 3 to 5 meters. Each elevation forms openings patterned with 2-3 vertical separators. From the ground level, the tower height is around 15 m for multi-story buildings and 8 m (24 ft.) for one-story buildings. It stands on a base of 2 m height and sides of around 2.33 x 2.33 m (7 x 7 ft.) (Fridoni 1995). The wind-tower is separate from the building for which it is built where an underground channel directs the wind into the building, thus taking advantage of the geo-cooling effect. As stated in the introduction, nature is a good source of environmental adaption (McHarg 1969), the attention of the study is forwarded to cactus plants, a local plant with characteristics that can be used as a case of plant adaptation to hot climate with a basic form that brings to mind traditional architecture. Cactuses are found around the world with various shapes and intensity of spines. "It depends upon taking in precious water. Water intake that begins from the available soil moisture by its fibrous roots and continues with a cactus plant's storage units being located in the stem" (Cactus 2015). Since the research concerns with the outer form of the cactus plant, it leaves out the study that related photosynthesis, metabolism, and phylogeny.

After studying prominent elements in the Arab Gulf traditional structure and cactus, three resemblances between both are found. **First**, the wall ribs and the corrugated cactus stems. In traditional architecture, rib elevation forms the first prominent element. Assuredly ribs in the elevation are used as a structural solution to decrease the overall weight resulting from the wall bearing structure. Many examples are found in the case of Souq Wakif in CBD of Doha, Qatar. Additionally, ribs cast shade on the elevation. The percentage of the shaded area to the wall ranges between 0 to 70 % depending on the time of day and the intensity of the wall-rib patterns. On the other hand, the cactus has round form which gives it an advantage over the cubic form of traditional buildings. At any time of the day, the sun hits only a smaller area of the plants surface than that of the flat elevation structure. Using the heliodome to resemble summer sun position, the plant's self-shaded surface on the southern side has a shaded area which exceeds 74 per cent while the southern elevation of the traditional building almost has 0 per cent. Fortunately, the sun moves and ribs cast their shade.

Second, thick cactus stems resemble the thickness of mud walls. Thickness of the mud wall typically ranges between 60 to 80 cm. It contributes to mitigate the impact of hot days. Searching for the difference between the outdoor and indoor temperature in Old Damascus, we find out that the inside temperature is 5 to 7 centigrade less than the outside temperature. So the reduction in the hot summer temperature to 28 Celsius makes the house atmosphere approach the range of the thermal comfort zone of 25.5 Celsius. The cactus' thick stems protect its water from drying out as a way to survey. However mud wall works differently. It works as a cooling system because it stores moisture and maintains the lower temperatures of the night (Ferwati 2013). Moisture will evaporate during the day leaving behind a cooler wall just like the mechanism of the frig system.

Third, the wooden sticks in traditional buildings resemble cactus spines: Another feature that accompanies the wind-catcher is its horizontal wooden sticks with a length between 30- 40 cm. There are several functional reasons of the sticks. It is so often referred to as a structural supportive element for the roof and for possible structural extension, for climbing up the tower, and for beautification of the elevation. None of these reasons refers to it as a climatic response design. One of this paper's objectives is to find out the role of the spike in directing or increasing the amount of wind penetrating the building. The explanation of wooden sticks in traditional architecture, the cactus spines are limited to protect the fleshy stems from predators seeking the water contained inside the plant. Additionally, "spines help prevent water loss by reducing air flow close to the cactus and providing some shade." (Cactus 2015). This study searches for the ability of the plant to reduce the heat impact.

4 EXPERIMENTS: COMPUTATIONAL FLUID DYNAMIC (CFD) ANALYSIS OF A STANDARD ROOM

This section shows part of the ongoing experiments to meet the objective of the research. A CFD model was utilized to investigate the role of the roof wooden sticks on the ventilation of a standard 4 x 4 x 4 m room.

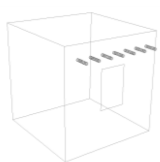

Figure 5. The room geometry.

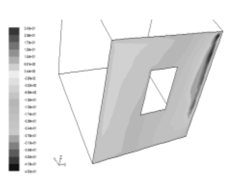

Figure 6. Pressure contours on the standard room wall.

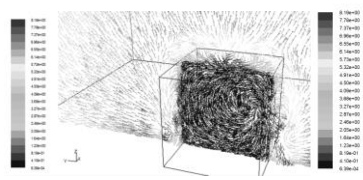

Figure 7. Velocity vectors on a longitudinal plane.

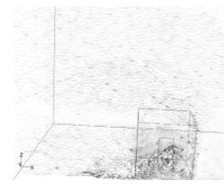

Figure 8. Transverse plane.

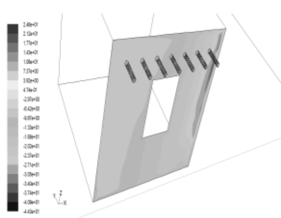

Figure 9. Pressure contours on the sticks room wall.

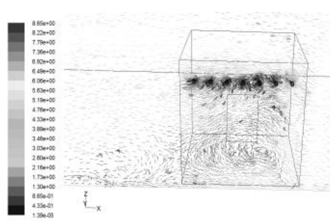

Figure 10. Velocity vectors on a longitudinal plane.

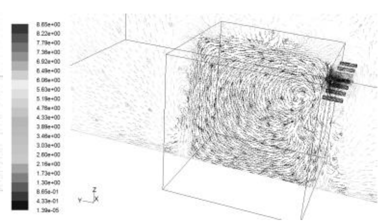

Figure 11. Transverse plane.

As depicted in Figure 5, a window of 1 x 1.5 m was located centrally on one wall. A group of 7 wooden sticks was located 1 meter below the room roof line. The wooden sticks were extending by 0.5 m out of the wall surface. Two CFD models of 310,000 cells were investigated using a standard k-E model. An inlet boundary wind velocity of 5.5 m/sec was used to initialize the flow. The first model was designated to be a benchmark case without the wooden sticks. Figure 6 shows the pressure contours in Pascal on the wall. It is evident the wall is divided into two pressure areas. The area on the right had side is mainly in negative pressure while the area on the right hand side is in positive pressure. The velocity vectors on a longitudinal plane 0.25 parallel to the wall and a plane passing through the middle of the window is given in Figures 7 and 8. Figure 9 shows the pressure contours in Pascal on the wall of the room equipped with the traditional wooden sticks. The wooden sticks affected the topology of the pressure counters on the wall. It is evident that most of the wall area now is in negative pressure.

Consequently, more air will move from higher pressure areas to the wall area leading to enhanced and sustainable ventilation rates of the room. Figures 10 and 11 are depicting the velocity vectors on a longitudinal plane and transverse plane of the room with the wooden sticks. It is clear the wooden sticks acted like a swirl generators. The generated areas of swirls created lower pressure areas leading to an overall depression zone on the wall. This depression area induced more air towards the wall and the window leading to a better ventilation rate.

5 CONCLUSIONS

Passive energy building systems require prevailing wind to mitigate the effect of hot days. This study is anticipated to highlight profound architectural solutions never studied before and is noteworthy to illustrate an example of the neglected value of traditional architectural style and poor benefits of the local style when applied in new modern designs. One of the essential benefits of the research is to promote traditional architecture on the contemporary level. Not forgetting the indirect benefit to the confirmation of place identity. The research itself is important for deeper comprehension of Qatari building heritage for architects; the major player in the proposition being sustainable development. The implementation of the study highlights the continuous need to understand traditional architecture as its elements are not only forms and fashion but also a solution to environmental issues.

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