Environmental Scrutiny of Traditional Mediterranean Forms for Contemporary Application (An Empirical Study)

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Abstract

Traditional architecture has successfully created a desirable indoor environment with minimal energy consumption and compatible with social and cultural contexts. The proper use of environmental passive design strategies that were widely employed in regional, traditional and vernacular architecture is crucial. However, employing traditional architecture vocabularies within contemporary buildings requires a proper understanding of their forms' environmental-behaviors. Consequently, modifying forms, geometries, and design-concepts may enhance their environmental performance. On the same time such traditional forms will stand for architectural identity that appropriately serves environmental, cultural and social contexts.

A building that respects cultural and social beliefs of the people is believed to address more practically the issue of sustainability. The undertaken review and investigation in this paper seeks a better understanding and application of traditional architecture forms and geometries in Egypt's northern-coast contemporary architecture. The investigations highlight the methodological approach carried out, to seeking a better understanding of the thermal and solar performance of these traditional passive systems regardless of their construction materials and colors. This is done, as a contribution towards improving their physical qualifications and energy efficiency performances.

Furthermore, the paper is a low-energy architecture approach for more energy efficient and passive buildings (particularly low-rise buildings) in the new communities that are being developed recently in Alexandria, Egypt and other hot-arid parts. Therefore, it establishes an architectural approach to resist the rapid growth of international styles and produce an environmentally, culturally, and socially appropriate architecture. In order to verify whether these forms are environmentally and climatic sound quantitative analysis needs to be carried out. The paper is part of continuing research work carried out on certain traditional roof forms. This is discussed through empirical and experimental tests for number of traditional forms (domes, vaults and cones) in the contemporary built environment of Alexandria city and Egypt's northern-coast. The paper focuses on the methodology and approach used in the analysis of the chosen forms.

Introduction

In most of hot-arid regions, where outdoor-overheated conditions are the main problem that building has to deal with, the general goal of all passive cooling strategies in traditional architecture is to avoid overheating, which is primarily generated by sun [1]. Traditional architecture depended on defensive strategies that mainly avoid solar heat gain, heat transfer, and evacuate heat from buildings to provide a desirable indoor thermal comfort. Technically, it depended on heat flow by natural means; convection, conduction, radiation, and evaporation. In this context, the paper reviews and investigates a number of traditional passive techniques to understand their technical configurations and particularities, also to find out the possibilities of improving their thermal and solar potentialities within the modern architecture.

Some successful applications of such techniques in both ancient and recent architecture have been investigated as preliminary steps, which positively helped the research towards building-up the experimental roof-geometry investigations. In the past, people (the natural architects) have had some reasons for what they built and erected. Their buildings were more than natural or organic materials, shapes, forms, and traditions. They were derived from a real understanding of their local environmental and climatic conditions, and materials.

Nowadays, traditional techniques are missed in most of hot-arid regions modern architecture. The accumulated misunderstanding of these architectural techniques means and strategies broke the real knowledge that is supposed to be passed down from generation to other. The new importance of such traditional architecture is that by proper experimenting, modifying, and developing their architectural principles and climatic control performances will not only make it more applicable as energy efficient means but also adaptable within modern architecture, new building materials and technologies [2]. Most of Egyptian settlements are rightly concerned about the loss of urban and architectural identity. The concept of passive indoor thermal comfort and energy efficient buildings in Egypt has yet to be more properly addressed.

1. Energy Requirements in Buildings

The energy required for heating and cooling of buildings is approximately 6.7% of the world's total consumption [3]. By proper environmental design, at least 2.35% of the world energy output can be saved. In hot climate countries, energy needs for cooling can be two or three times those for heating, on annual basis, which effects their economic and political situation specially the limited natural resources countries [3]. Consequently, in developing countries, traditional passive cooling technologies must be considered as a crucial strategy for a sustainable environmentally friendly future [4].

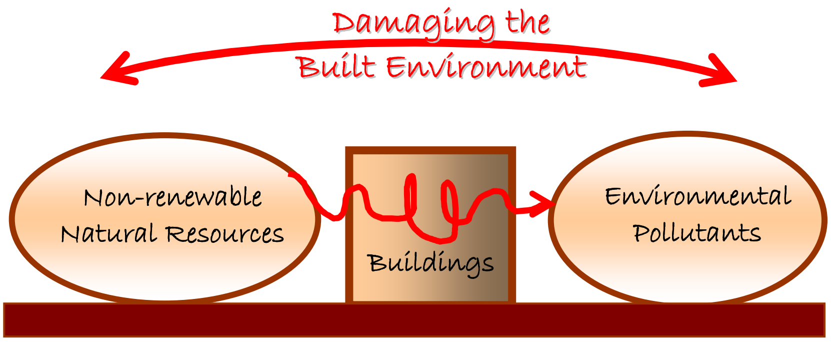

Figure 1: Analytical Sketch on Architectural Products (Building in Use)

2. Traditional Passive Cooling Technologies; Preliminary Investigations

According to this context, this research aims to consider making use of traditional vocabularies and solutions as an effort to regain and revive the missed architectural identity. It aims at abating the rapid growth of the western-international style seeking an environmentally, culturally, and socially adapted architecture. For natural passive cooling in buildings, the roof has a major influence on thermal indoor conditions. Approximately 50% of the heat load in buildings comes from the roof, because it is the most exposed element to the sky [5]. Roof form and geometry can reduce the solar radiation gain; their thermal properties can be increased according to their form and geometry. This research undertakes a quantitative analysis in order to put forward an understanding of the scientific facts behind the potential for micro-climatic control of such traditional forms. A number of empirical studies are carried out for air flow and solar analysis using mathematical models such as SRSM (Solar Radiation Simulation Model) [6,7], and wind tunnel investigations through airspeed analysis and visualization of air.

3. Environmental Performance of Traditional Geometries and Forms

(Domes, Vaults, and Conical-Tents)

In most Mediterranean cities, curved roofs are noticeable forms of traditional roofs, some as domes, vaults and tented structures shown in Fig. 2. Mathematically, a curved roof has less than the twice surface area of a flat one Fig. 3 (a) [5]; it will receive between one-third and half of the sun radiation per unit area [8]. On the other hand, the larger surface area of curved roof radiates the stored heat to the sky faster than the flat, which make indoor spaces cooler at night, Fig. 2. According to this context, the curved roofs were not only, traditional and shapely attractive but also thermally practical and energy efficient. A number of curved roof forms shown in Fig. 2 (b and C) were defined to investigate the solar performance and airflow behaviour of their curvature and find out its direct impact on building solar load and indoor comfort level in hot-arid climates.

Figure 2: Photos Showing Domes, Vaults and Cones in Mediterranean Cities

3.1 Geometrical Analysis of Arbitrary Forms

Most of curved and conical forms have been geometrically resembled by a group of planar segments, pixels, or stripes. This technique is employed in most CAD tools and software for two and three-dimensional drawings, Fig. (2). Sensibly, and regardless of the nature of the tested parameters, increasing the number of planar segments will produce more accurate simulation of the arbitrary forms. Fig. (3) shows a curved roof cross section CCS, which has been geometrically resembled by two types of planar segments in order to simplify the calculations of solar radiation intensity on the roof surface.

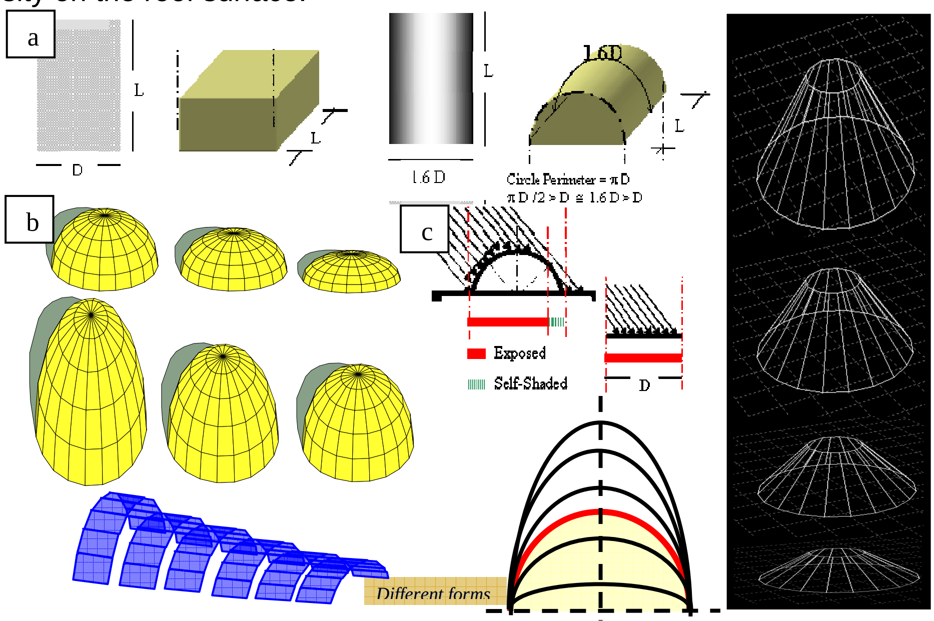

Figure 3: (A) Comparison between Surface Areas in Flat & Curved Roofs; **(B)** Diagrams of Different Forms Used; Domes, Vaults and Conical-Tents with Different Geometrical Configurations; **(C)** The Exposed Area in Flat & Curved Roofs

3.2 Environmental Performance of Curved and Conical-Tent Geometries in Respond to the Received Solar Radiation Intensity and Airflow Patterns

This research work investigates the environmental performance of traditional forms in order to provide indoor thermal comfort, enhancing natural ventilation and lighting, minimizing solar and heat gain, and creating more shaded surfaces on exposed building envelope elements (roof and walls). Computer simulation and experimental rigs, which have been used in this research project, have proved that building envelope geometries can be positively employed as passive cooling techniques for convection heat loss, minimize received solar radiation, and enhanced indoor and surrounding air flow.

In addition to geometry (form, and cross-section ratio), solar and thermal behaviour of roofs is affected by their thermo-physical properties. This experimental and computational study aims to highlight the solar performance of the curved and conical roofs and to investigate the impact of geometry on the amount of solar radiation intensity received by roof surface in terms of cross-section and orientation characteristics (height-to-width ratios (H/W) “surface curvature”.

There are a number of methods to evaluate the solar and thermal behaviour of a curved roof. Despite their accurate results, site measurements are time consuming and difficult to handle. Also they are expensive to run and require adequate equipment. The other alternative is to simulate the real environment either by computer simulation software or experimental scaled models. Experimentally and computationally roof geometry and its solar performance is discussed in terms of calculating and comparing the solar radiation intensity at different points or segments of the domes, cones and vaults, that are placed above the surface of a curved roof model and along its middle cross-section, Fig. 4.

As stated earlier, the chosen forms to be tested both mathematically and in the wind tunnel are the domes, vaults and cones. These being some of the simplest and most frequently roof forms used in the built environment, thus it was decided to use these forms for the empirical study carried out for the purpose of this research. The structures tested in the wind tunnel were adjustable in case of the 3 forms chosen. For example, in the case of the conical structure it was with an adjustable cone height shown in Fig. 4. The cone’s apex could be either opened or closed in order to investigate the effect it might have on the airflow pattern and rate. The height of the supporting mast is adjustable. The cone could be inverted to represent an inverted cone, and its base could be either opened or closed as well. The height of the straight or inverted cone from the ground was kept constant in all the wind tunnel experiments, and the mathematical investigation of SRSM presented in this paper. The domed structure tested was such that to fix the diameter of the dome and increase and decrease its height Fig. (4 & 5). Like both cones and domes, vaults were tested such that to fix its width and change the height regularly.

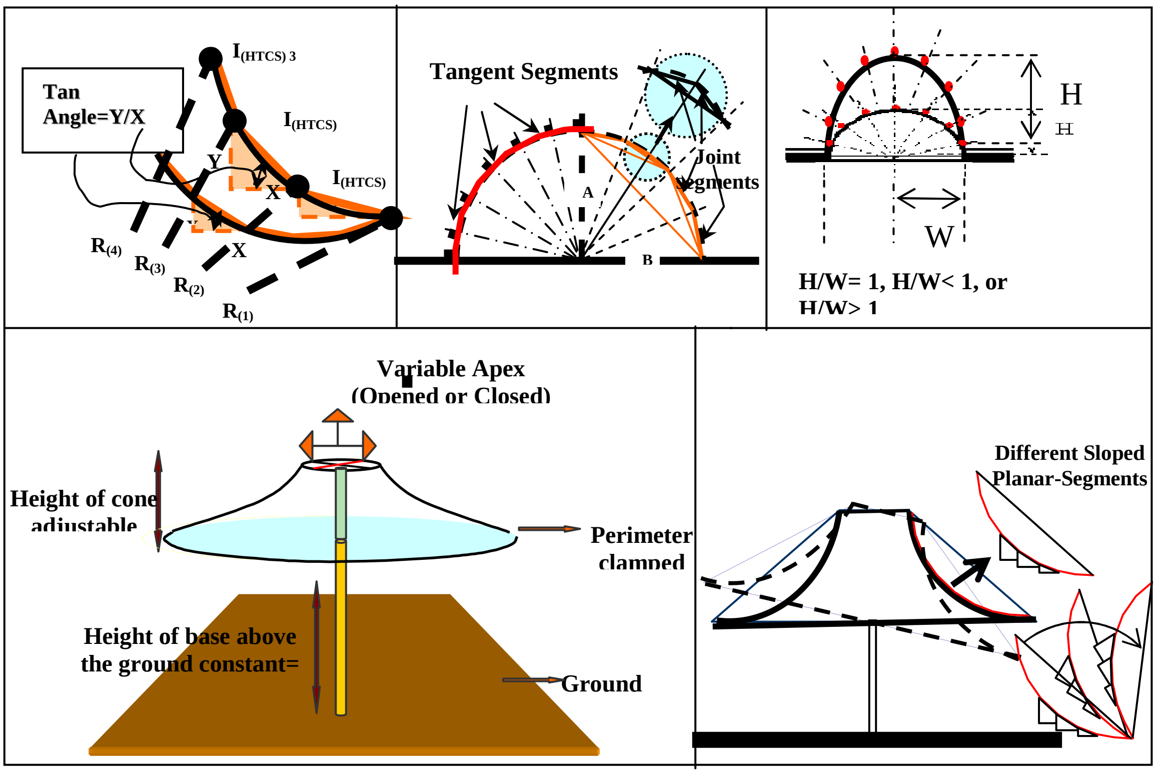

Figure 4: Diagram Showing How Arbitrary Forms are Divided into Sloped Planar Cells for Solar Calculations and the Adjustable Dome and Conical Structures

The research work presented in this paper presents three forms which are the most commonly used roof forms in traditional architecture and have been successfully used for a large number of buildings. The models tested in case of cones have a large apex, in order to verify the effect of this on the airflow behaviour underneath and in the vicinity of the structure. Therefore, airflow speed was set at a low speed of 1.4 m/s that was thought to be adequate enough to the purpose of this research.

As described earlier these three forms were selected as they represent some of the simplest and most frequently used traditional roof forms. A series of wind tunnel tests were undertaken to visualize the airflow pattern, and to determine the wind speed under and around the structure. The tests were designed to understand the effect the form of the roof itself has on the airflow, in order to assist in the design process and to identify and explore strategies to enhance natural ventilation and passive cooling techniques within such structures. A schematic diagram of the conical model used in the wind tunnel experiments is presented in Fig.5 showing the cone used and direction of inclination and height change.

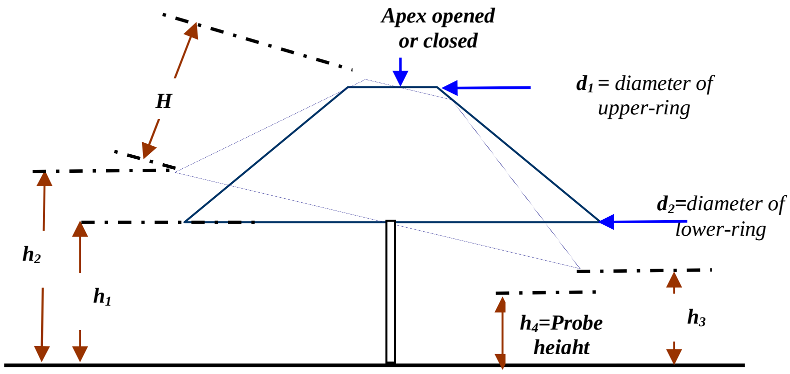

Figure 5: Schematic Conical-Tent Model Used in the Wind Tunnel Experiments

3.3 Airflow Visualization Under and Around a Conical Tent-Structure

In warm weather, even if the air temperature is high, directing higher air velocity over the body helps in cooling down the occupants by the use of evaporative cooling, thus providing some level of human comfort, within the enclosed or semi enclosed space [9,10]. Air flow patterns under and around the models were visualized using a smoke generator. From the observations, flow patterns and flow circulation were identified for different cone (apex opened and closed), vault and dome heights and configurations. The model of the 3 forms was set at 3 different heights (H in Fig. 6 (a & b)).

It is worth noting that, before making the final choice of heights h1, h2 and h3, several tests were carried out with alternative heights. Consequently, and relative to the tools available for the experimental work and the wind tunnel used, the most suitable heights for the models were specified and chosen. Also at the beginning of the experiments the air speed was tested at 2 different air speeds. In wind tunnel tests it was decided that for the purpose of these experiments to fix the airspeed at 1.4 m/s for all the investigation carried out. Also as a control, the same conditions were used to test a flat roof (disc-3mm height) and a flat surface with the same diameter as the cones shown in Fig. 6. Tests were finally made with the absence of models as a zero reference.

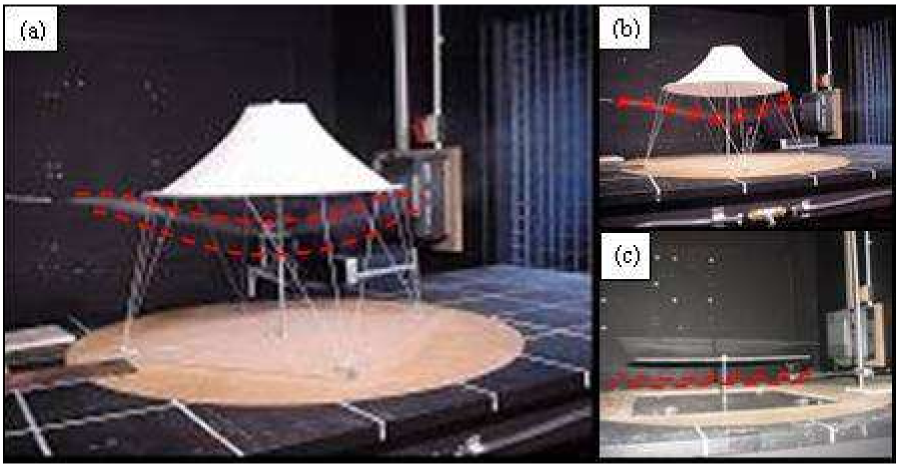

Figure 6: Wind tunnel experiments showing the effect on airflow of a 17cm conical-tent with closed apex and a circular flat disc 3mm high

4. Conclusions

Modern buildings are becoming increasingly complex; involving technologically advanced building materials, and mechanical systems for controlling interior air quality, thermal comfort, lighting and acoustics. These systems, which rely exclusively on utilisation of non-renewable energy are often expensive and environment pollutants. Increasingly in Egypt and other developing hot-arid regions, the concern is to establish systems, which make use of Natural Passive Cooling more efficiently than in the past, and to ensure sustainability of resources. For natural passive cooling in buildings, roof has a major influence on thermal indoor conditions. There would be more to learn if the modern knowledge has been applied in traditional experience. Perhaps traditional people did not know technically what it was when they built or why, but the result was effective and comfortable solutions. Better understanding of their thermal and solar performance helps towards improving the physical qualifications and energy efficiency performances of traditional passive techniques, to be well integrated within modern architecture in hot-arid climates. The paper represented the methodology undertaken to test various traditional roof forms, such as vaults, domes and cones.

Reference List

1. A.A. Konya, Design Primer for Hot Climates, the Architecture Press, London (1980).

2. Amira ElNokaly, J. CHilton and Robin Wilson, Environmental Behaviour of Tensile Membrane Structures, Proceedings of the world conference on technology advances for sustainable development (Energy, Water, and Environment), Cairo, Egypt. ; 11-14 March, 2002 ; Cairo, Egypt.

3. S. M. and A. D., Passive Cooling of Buildings,1996.

4. B. Givoni, Man, Climate and Architecture (New York, Applied Science Publishing Company, 1976).

5. S.A. Al-Sanea, Thermal Performance of Building Roof Elements, Building and Environment, Vol. 37, pp: 665-675.

6. R.H.B. Excell, SRSM Solar Radiation Simulation Model For Quick Basic, Regional Energy Resources Information Centre, Asian Institute of Technology, Bangkok .

7. R.H.B. Excell, A Program In Basic for Calculating Solar Radiation in Tropical Climates on Small Computers, Renewable Energy Review Journal, Vol. 8, no. 2. (1986).

8. A.B. El-Seragy and M. Gadi, Energy Efficient Potential of Traditional Curved Roof Forms in Hot Arid Regions, SET 3- 3rd International Conference on Sustainable Energy Technologies.

9. Francis Allard, Natural Ventilation in Buildings "A Design Handbook" (James and James (Science Publishers), 35-37 William road, London, 1998).

10. N. B. Hutcheon, Canadian Building Digest (CBD) - 102. Thermal Environment and Human Comfort [Web Page], (2003). Available at http://www.nrc.ca/irc/cbd/cbd102e.html, accessed November 1921.