Wall Construction System for Natural Cooling

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Abstract

Every tradition has developed a building system that is regarded as a sustainable or eco-friendly product. In the Middle Eastern hot and dry climate, besides local construction materials, we find the emphasis is demonstrated by the use of common elements such as inner courtyards, lattice windows, and wind captures all of these play a foremost role in the creation of spaces that have the advantage of providing sustainable microclimate changes, enjoyment, and local identity. The elements of the traditional house were successful in cooling the building for longer hours during the day and providing human comfort in the hot summer; modern architecture lacks these characteristics. This study searches for a way to create a wall cooling system that can be applied to future building designs. A wall cooling system embodies natural applications for sustainable architecture; it stretches toward nature to learn a further new lesson of support interior space with a cool environment in regions that are confronted with a hot and hostile climate. Additionally, it searches for traditional elements that help in supporting the proposed method so that it incorporates nature and traditional house cooling systems. This study has five components: 1. The cactus plant's properties. 2. Aerodynamic behavior toward a fixed object with an example from windcatcher towers and.Nigerian traditional houses. 3. Self-shading walls 4. Water cooling systems as a lesson from the Middle East. (The concept of cool walls designed by Mey Kahn and Boaz Kahn as an inspiration from *Mashrabiea* and *Jara* is well considered in this study.) 5. Walls combining all previous ideas.

KEYWORDS*:* Self-cooling wall, self-shading wall, wind capture, aerodynamic behavior, decorative wall

Introduction

In his book “Design with Nature”, McHarg (1992) has directed our attention to the place of nature in our world. Nature is an inspiration for thought. Rushing for sustainable living world, countries haveinevitably become morecomprehendingof the need for the balanceof man-nature relationship. Similarly, design in nature is another good angle that highlight how the constructional law governs evolution in biology, physics, technology, and social organization (Bejan and Zane 2012). “Man is that uniquely conscious creature who can perceive and express. He must become the steward of the biosphere. To do this he must design with nature” (McHarg 1992: 5). It is a convivial indication of our integration with nature. Indigenous peoples around the world sensitively developed their way of life to preserve nature. Our ancestorshad followedsimilar step while evolvingtheir traditional physical environment along withcultural aspects (Lynch1981), climate,and natural resources (Rapoport1969). The product insured aptness to geographical characters.Keeping in mind the possibility of designing with nature, a possible question would inquire how much a design has naturalelements that reflect our traditional built environment? The cover page of the proceeding of “Terra 2008: The 10th International Conference on the Study and

Conservation of Earthen Architectural Heritage" posted a picture of mud structure from Nigeria that share two main architectural elements of the Arab Gulf countries.Beside the brutal exposure of the earthen construction material, the structure has grid-like ribbed elevationswithsystematic distribution of short horizontally projected wooden posts(Rainer, et. Al 2008)(Figures 1 and 2). Looking at both Figures,one may questionhow earthen structure fits into the hostility of the arid environment?The study digs deep into the concept of traditional mud structure in Arabic Gulf Countries.

Nature and Design

The previously proposed two questions impulse the search for a plant that belongs to arid environment with basic design that resemble the traditional architecture presented in Figures 1 and 2. The cactus plant shown in Fig. 3 is best fit the criteria. Cactus is aspiny plant adapted to survive in hot, dry climates. "It depends upon taking in precious water. Water intake that begin from the available soil moisture by its fibrous roots continues with a cactus plant's storage units being located in the stem". [2]Researches go on describing the physical parts (roots, leaves, areoles, spine, flower, stems, taxonomy), photosynthesis and metabolism, and phylogeny.Regarding the function of spines and thorns researcheslimited their use only to protect the fleshy stems (which contain water) of the cactus from predators.This study goes beyond the common approach to includes the plant ability to reduce the heat impact that itself, the aim of the study, will be explored in traditional mud structures.

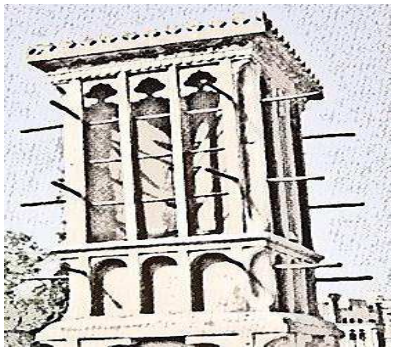


Fig. 1. Earthen structure, Nigeria and Fig. 2. Wind catcher tower in Dubai.Figures3illustrate cactus Plants. [1]

The similarity between the Nigerian and Arab Gulf traditional structure presented by the projection of both the ribs and wall beams and by horizontally projected wooden sticks that also resemble thepattern presented in the cactus plant shown inFig. 3. Ribs and wall beams strengthen the structure and at the same time workcollectively as a shading devise or self-shading wall. The percentage of the wall shading depends upon the pattern itself and on the sun angle. By looking at both Figures 1 and 2, the average shading may range from 5 to 50 percent. The application of self-shading wall is considered in modern sustainable architecture that applies adjacent screen walls or attachinga screen wall to the southern wall. Many examples are found in the case of Sultan Qaboos University, Muscat, Oman.

Mud walls act as an analogue to cactus plants' water storage in the stem, and similarly helps keep the heat away from the inner space. Usually the temperature inside the structure is 5 to 7 centigrade less than the temperature outside. That is good enough to

make space during hot days with the temperature ranging between 30 to 45 Centigrade tolerable. The typical thickness of the mud wall is 80 cm which is what makes it a good insulator. Also, such a wall works as a cooling system because it stores the moisture and maintains the lower temperature of the night. During the day, when the outer surface is exposed to heat, the moisture evaporates, causing the wall to cool I call this process the Terracotta *jara* effect. Terracotta *jara* is widely used in the Middle East to cool down water. Terracotta not only makes the *jara* surface moist, but also keeps the water contained. It is place where there is air current for better results. Fig. 4 represents a model that summarizes the similarity between the cactus plant and traditional earthen structure in the Arabic Gulf Region.

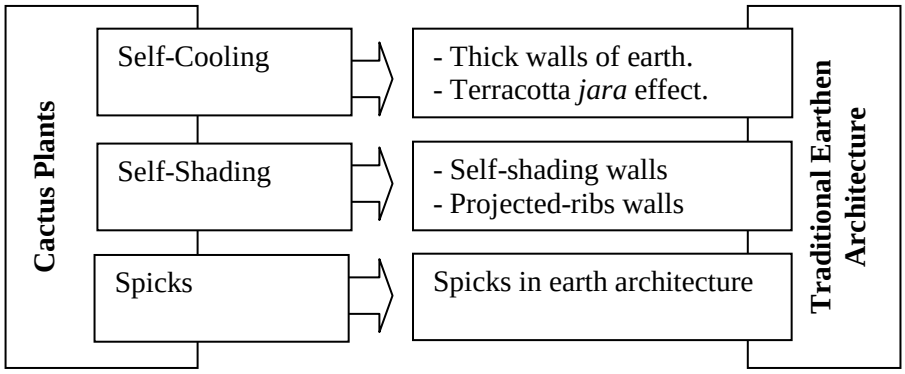


Fig. 4. Nature and Design: Schematic model for the research (Author)

The study will analyze four parameters:

I. Windcatchers
II. Aerodynamic behavior
III. Self-Shedding Walls
IV. *Jara* and water cooling
V. New proposed system for self-cooling wall in hot-arid climate Regions

I. Windcatcher[i]

Because of the compact structures, the cool air pass above the buildings without going through the lower levels(Mansour 1995). Traditional earth architecture direct windcatcher, particularly the prevailing wind, to the advantage of the inner spaces as a result of the negative and positive air pressure. The main function of this windcatcher is to channel the wind into the house and moderate the climate inside by providing airflow inside, if it is not cold, at least the airflow provides cooling effect. Al-Wakil and Siraj (1989) summarizes the advantage of windcatchers in three functions: a- Provide air circulation and replacement; b- Provide convective cooling; c- Provide evaporative cooling.

There are three main systems that are registered in that regard: wind-tower *(Baggadeer)*, windcatcher (*Malkaf)*, and geo-cooling system.

Wind-Tower (Baggadeer): It is used in architecture in the Arabic Gulf, Iran, Pakistan, and Afghanistan.

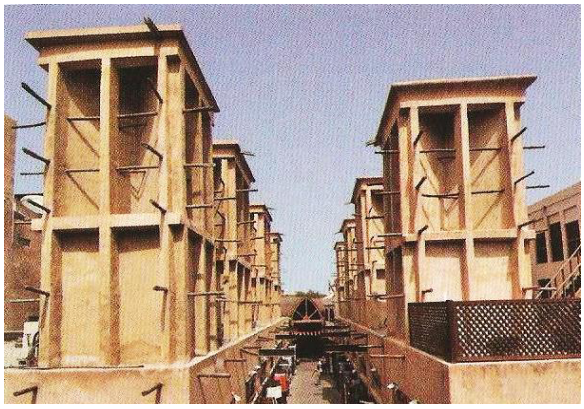


Fig. 5: Wind-Tower*(Baggadeer)* symbolizes the traditional Arab Gulf Architecture

- The square plan layout in Fig.5 shows the wind-tower as a main traditional element.The tower height is 15 m (45 ft.) for two-story building, and 8 m (24 ft.) for one-story building. The base has the height of 2 m max. while its side is around 2.33x2.33 m (7x7 ft.) (Fridoni 1995). (Fig. 6)

- The inside void is divides into four identical volumes by two diagonal crossed walls. The air penetrating the tower from the winddirection straight down into the room wherethe continually open-base of the tower is located.

- The identical opening of its four elevations with vertical dividers that vary in numbers. The height of the tower is 3-5 m and 3-2 arched openings for the four elevations.

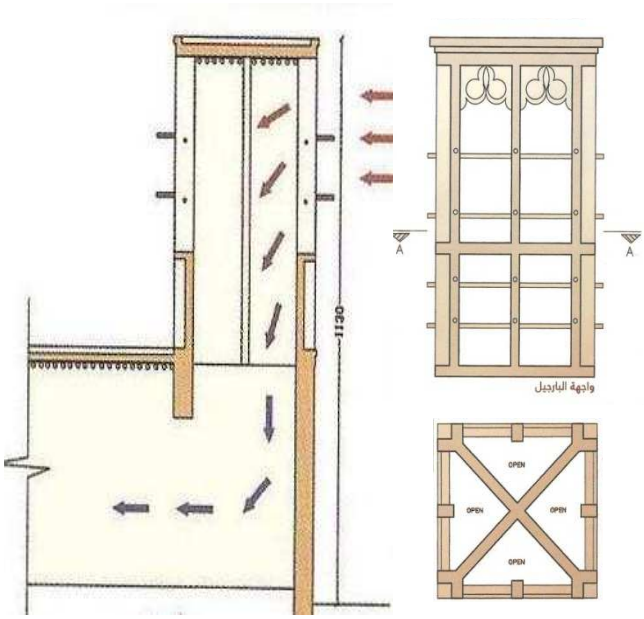


Fig. 6: Plan, section, and elevation of a wind catcher

- On the elevation of the tower vertical and horizontal wooden spikes are projected out with the length of 30-40 cm. Some people refer to the spikes projected out of walls as a functional element, holding the roof from both sides. They are long wooden beams placed next to each other, covering the whole span. They act as carriers for the roof, holding it from the top. Furthermore, if the householder wanted to extend the existing span of any room in the house, it can be done easily by adding new wooden beams to the existing projected ones and connecting them together. As a result, thee room span will increase and the roof will carry more load. This shows the importance of these wooden beams in the past as a structural roof system.

Wind catcher, *Malqaf*

It is one direction windcatcher stand above the roof level facing the prevailing wind. It is mostly located on the outer walls where a gap in the wall creates a channel allow the air to flow from the roof down into the house. According to Attia and De Herde (2009), the idea of the *malqaf*has been presented by Egyptians in the houses of Tal Al-Amarnathrough is represented in wall paintings of the tombs of Thebes (1300

B.C.). Fig.s7 and 8 illustrate the location of *malqaf* and the airflow. The *malqaf*dispenses with the need for ordinary windows to ensure ventilation and air-movement in addition to enhancing indoor environmental quality. The *malqaf*is also useful when filters are integrated within the shaft; in reducing the sand and dust which is so prevalent in the winds of hot arid regions (Fathy1986).

Geo-Cooling Channels,wind-assisted temperature gradient system.
It is a qanat in the ground which works as an earth-to-air heat exchanger. (Fig. 9 and 10) A wind-tower is also used along with the ground sub-surface channel used to provide the inner space with cool air from the earth as the airflow move upward due to temperature gradient. Cold water body may be used in the ground to magnify the geo-cooling effect by the water vapor. The level of the ground channel is between 1.5 to 3 meters. The ambient earth temperature is typically 10 to 23 °C (50-73 °F) [5]

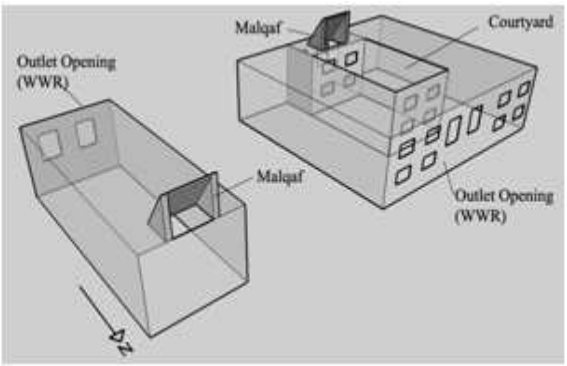


Fig. 7: A typical windcatcher or *malqaf* used in traditional Persian/Arabic architecture. (Al-Wakil, and Siraj 1989)

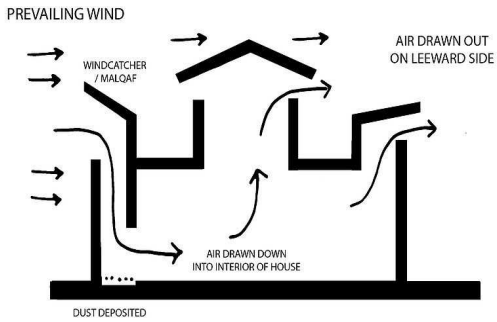


Fig. 8: Advanced wind-catcher system or *malqaf*. [3]

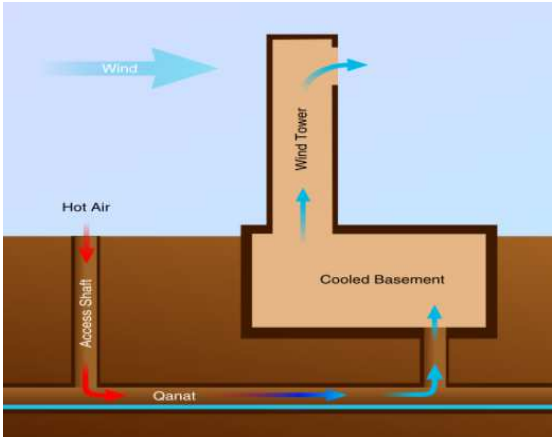


Fig. 9: Diagram of a building cooled by a qanat and wind tower natural ventilation system, by Samuel Bailey cited in Wikipedia [4]

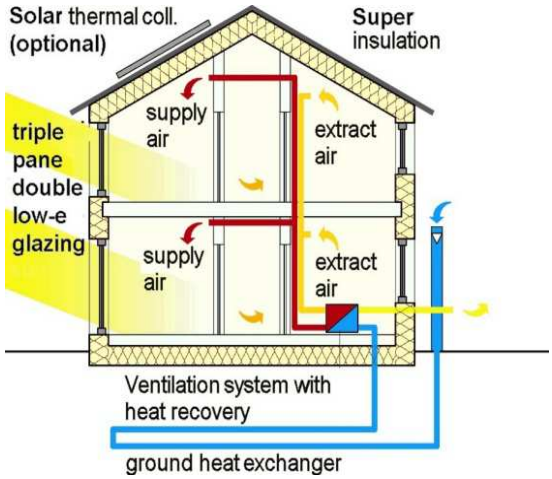


Fig. 10: An advanced ground geo-heat exchange system. [5]

II. Aerodynamic

Aerodynamics "is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a solid object". [6] The following is a literature review that introducesthree concepts that will help illustrate the airflow through natural cooling system in traditional Arab region.

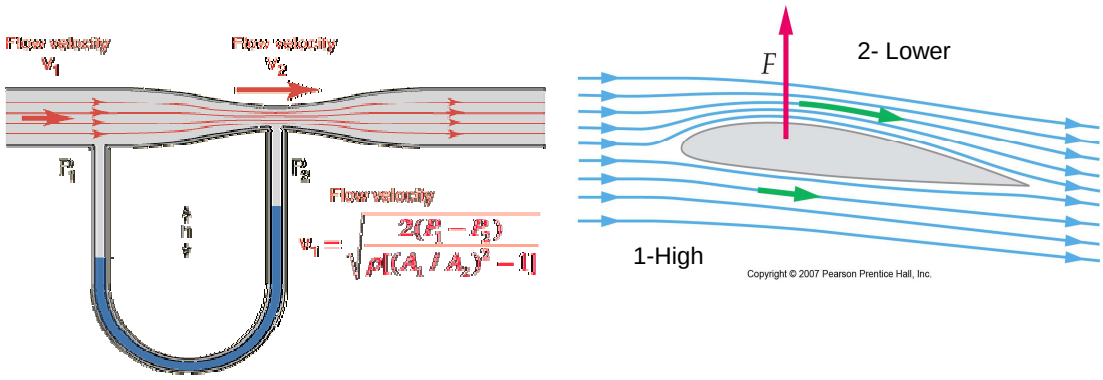
1. Venturi Effect

Venturi Effect that is defined as the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe (Fig.11). It is also called a jet effect; as with a funnel the velocity of the fluid increases and when it crosses sectional area decreases, with the static pressure correspondingly decreasing. Bernoulli's equation (1) is used in the special case of incompressible flows, such as the flow of water or other liquid, or low speed flow of gas, the theoretical pressure drop at the constriction is given by: [7]

$$p_1 - p_2 = \frac{\rho}{2}\left(v_2^2 - v_1^2\right) \tag{1}$$

where ρ is the density of the fluid, v_1 is the (slower) fluid velocity where the pipe is wider, v_2 is the (faster) fluid velocity where the pipe is narrower (as seen in the Fig 11). This assumes that the flowing fluid (or other substance) is not significantly compressible - even though pressure varies, the density is assumed to remain approximately constant. [7]

Similarly to the Venturi Effect, the case shown in Fig. 12 illustrates asymmetry of a wing shape, making air travel faster over the top rather than the bottom. That explains the wind flow channel effect, where an opening in a building or street that demonstrates airflow travels faster than the original velocity. [7]



Figures 11 and 12. The pressure at "1" is higher than at "2", and the fluidspeed at "1" is lower than at "2", because the cross-sectional area at "1" is greater than at "2". [7]

2. Vortex Airflow:

As mentioned in the introduction, the cactus plant protects itself with spines spread partially or completely around its body. Although the question ignored by studies is if these spines serve a function climatically. This research assumes that the air moves around the spine creating a local vortex. So the focus is on aerodynamics of the horizontal projected spines. The advanced study of aircrafts shows that wind behavior around an aircraft's wing creates the vortex motion by "the difference in pressure between the upper and lower surface of the wing (Fig. 13). The high pressure air below the lower surface of the wing moves around the wingtip towards the lower-pressure region on the upper surface, creating the vortex" [8]. Presumably the case is similar to a spike projected out of a solid wall and windcatcher. The difference is that the craft wing is moving while for a spike, the wind is facing a fixed object. Velocity is another parameter to consider here, requiring a lab experiment to determine the speed and angle where the vortex will take place.

Fig. 13. A vortex is created by the passage of an aircraft wing, revealed by smoke. Vortices are one of the many phenomena associated with the study of aerodynamics. [8]

3. Airflow in Traditional Arab Gulf Architecture:

The study concern has three directionality: wind face a solid wall or standing object, wall with windows, and wind face walls with projected pole (spick).

a. Solid object: Before hitting the wall surface, the air move with a certain constant *acceleration*, as shown in the following equations. The speed of the air will hit the wall surface (barrier) and will start creating anairfloweitherside of the object (equations 2 and 3, and Fig.14). The maximum lateral wind loading and deflection are usually observed along wind direction, the maximum acceleration of a building loading to possible human perception of motion or even discomfort may occur in across wind direction (Taranath, 1998).

Equations for constant acceleration:[9]

$$v = v_o + at \qquad (2)$$

$$x = x_o + v_o t + \tfrac{1}{2} a t^2 \qquad (3)$$

Where,
v: Final velocity
v_o: initial velocity
a: acceleration
x_o: initial distance
x: traveled distance
t: time taken

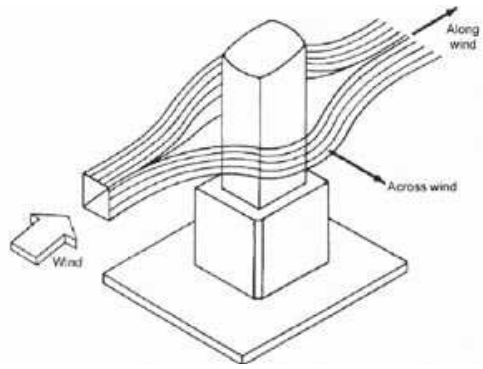


Fig. 14: Dimensional flow of wind and solid object (Taranath 1998).

Wall with windows: In respect to VenturiEffect, there are two different approaches where the air changes its velocity and move faster. First, there is a window inside the wall itself, so the air will start moving faster while entering the building in a higher velocity. For example, if the air was moving with a velocity 1-2 m/s, when it will enter in this window three to four times faster than the original velocity. It can reach 3-6 m/s. Second,If there are two rows of buildings standing opposite to each other and a narrow street in between,the air will move inside this narrow path with increased velocity. The air speed will be much less than of the airflow penetrate an opening in a building. If the air is moving with a velocity of 1-2 m/s, then it will enter this street with a speed of 2-4 m/s.The two sides of buildings create a barrier for the air. (Brown 2012)

b. Walls with projected pole (spick): In case there is a spike around an opening, the air involves in vortex motion around it. The cyclized air will increase the airflow around the opening. It is assumed that the vortex air will be sucked by the nearby opening if it face an air current, otherwise the spike will change the direction of the air current through the vortex motion and consequently will increase the possibility to have airflow entering the nearby opening.(Fig. 15)

Fig. 15: Wooden spicks create vortex flow of wind that give possibility air to flow inside the open window.

Inside the building, the cold fresh airwill replace the hot stale air, which has lighter weight causing it to move upward. In the case of windcatcher, one or two openingsfacing the wind will let the air inward while the rest will let the hot air outwards. The performance of the windcatcher depends greatly on the position, orientation and size of the inlet and outlet opening in relation to the wall ratio (Fathy 1986). In the case of *Malqaf*, another opening on the roof is usually located parallel to the first opening (Bordo 1987). In the case of Arab traditional houses, the hot air will also find its way out through windows or doorsthat are directly open into the inner courtyard. The *malqaf*and wind-tower aremost efficient and useful when filters are integrated within the shaft; thus reducing the sand and dust so prevalent winds of hot arid regions (Fathy 1986).

III. Self-shedding walls

self-shading walls are found inthree different wall systems:First, walls with recessed openings, exemplified by the work of Le Corbusier in his project le Habitat, as screens of self-shading cells that provide a considerable amount of opening and at the same time, proposed a control of sunlight penetration. Second, a solid wall with a veneer: a solid wall where the veneer is a screen wall with a thickness of about 10 cm and the size varies as the designer wishes. In some cases a veneer screen wall

provides shade up to 60% of the elevation. (Fig. 16)Third, a screen wall shadowing the elevation: The gap between the elevation and screen wall is varied depending on the screen wall design and the designer concept, with an average of 10 to 30 cm. This gap allows the air to circulate and screen to protect the elevation from direct sunlight exposure. The material can be metallic or masonry.

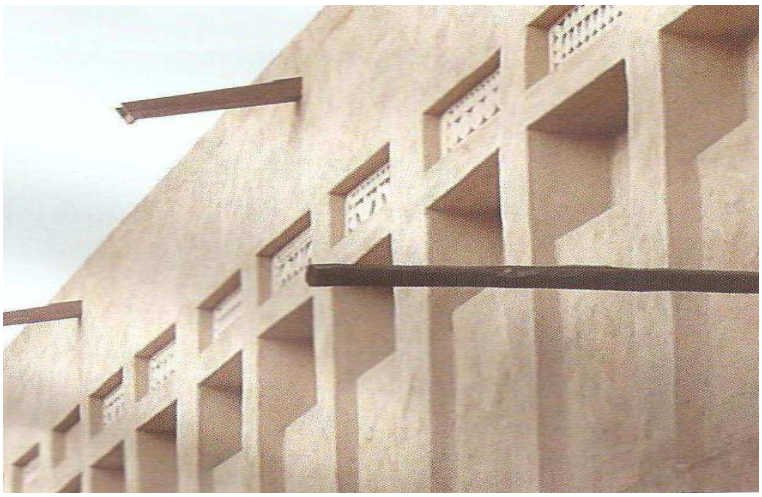


Fig. 16. The projected columns and beams create self-shading wall.

IV. *Jara* and Water Cooling

This section presents the main concept of the study. *Jaras* are terracotta containers used for water storage. When filled, it sucks up water that will evaporate once exposed to airflow. The temperature of the water will drop to cool 5 to 10 degree less than the surrounding temperature. The faster the wind speed, the colder the water will be. This is evident when truck drivers, for example, hang out their *jara*, or even metal container draped with a wet cloth. The speed of the vehicle will cause the water to cool despite the summer heat in the middle east. Both Mey Kahn and Boaz Kahn take the *jara* concept further to application inside the house. The screen is a pipe formed in a decorative way; filled with water. The airflow will go through the screen cooling the water that, in return, will work as cooling device. They called it ECOoler (Fig. 17). As stated on his internet site: “It's a very smart concept of combining to old traditional design. Just thinking about it is making me feel a lot cooler. I do believe that this is a very workable design concept and if further developed would really help promote natural and passive cooling methods in a structure.” [10]

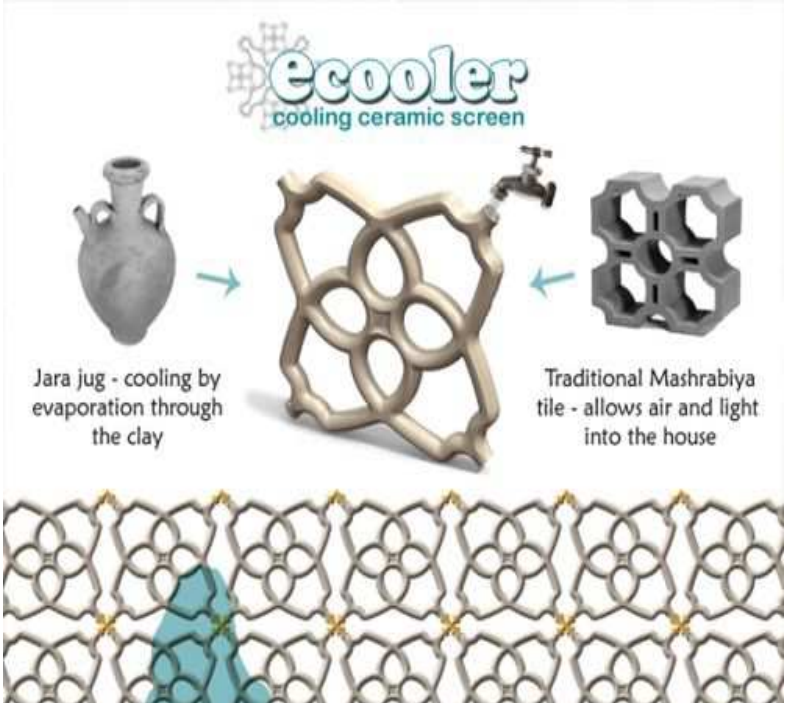


Fig. 17 illustrate the development the concepts of *jara* and Mashrabiya to ECOoler screen wall. [10]

V. New proposed system forself-cooling wall in hot-arid climate Regions.

In this final section, the concluding question is that how can all of these previous studies help develop a new self-cooling wall system? Here we have two scenarios to merge the previous studies in one coherent self-cooling wall:First, a windcatcher can be built out of terracotta with inner channels filled with water that are connected to a pipe net inherited inside an inner wall. The original function of the windcatcher is still applied with an additional advantage: the fresh air moving downwards will pass the wet terracotta and consequently will cool down. As a result, the reduction of the inner space temperature will be higher than the original method. Is it possible to apply geo-cooling channels to the advantage of the proposed self-shading wall?In reference to this method used in the mouth airbrush tool, my application is that if the exit side of the geo-cooling channels is placed at the base of the wind-catcher, its flowing air entering the inner space will suck the outer air from the wind-catcher downwards,resulting in doubling up the current circulation inside the building.

Second, the screen wall is made of terracotta and has a depth of at least 5 to 10 cm (2-4 in) with inner channels filled with water. This channel is connected with an inner wall (metallic being a good option for fast temperature exchange). The screen wall works as a self-shading wall. It is better to have at least a 10 cm (4 in) gap between the outer wall and the screen wall, this will help to increase the air circulation as well as the evaporation of the water of the screen wall surface (Fig. 18). So Figure 18 does not show spicks in the structure, it is possible to add them to the nodes of the screen walls to capture the tilt and side wind.

In both cases a natural cooling of the inner space is the result of self-cooling walls. Just like a radiator in a car, where a fan cools down the water to return back to the hot engine to keep it at an acceptable temperature. If the water movement between the outer channel and the inner channel was slow, a small pump may be applied between both walls. The surface-water evaporation in scenario one and two will cause reduction of water in the pipe system; therefore, a supplement water tank will be connected to the pipe system to keep the water level in

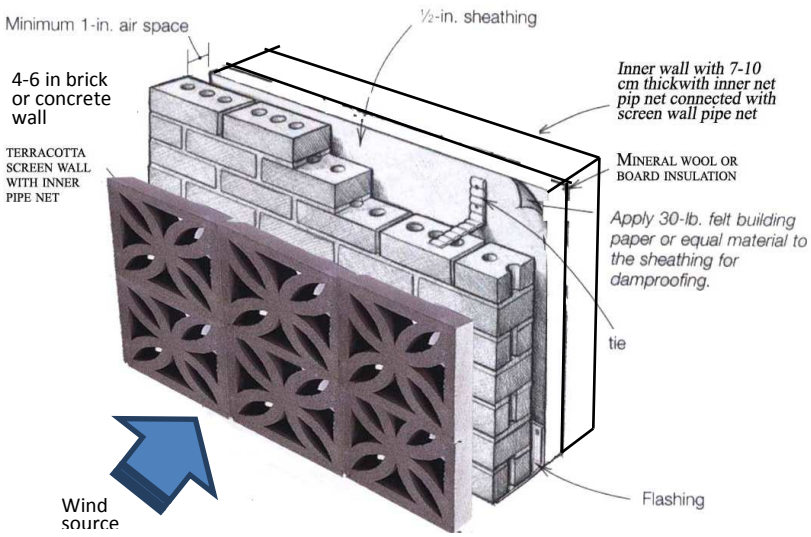


Fig. 18. The three main layer wall consists of: a screen wall that allows the wind to penetrate its opening, resulting in the evaporation of the water of the wet surface of the terracotta screen wall. A gap followed by an outer wall with cavity and insulation board, then the inner wall with an imbedded pipe net to cool the building.

the pipe constant.

Conclusion

This research went through various concepts to understand the architecture of hot, arid environments, resembling the cactus plant. As the cactus plant is adapted to hot-arid climates, its structure and form play a great role in its survival. Two prominent aspects are focused on in this research, the self-shading and the spines, both of which are addressed in the earth architecture of the hot-arid area of the middle east and nearby regions. Projected column-beam structures create a self-shading like the use of lattice windows, *Mashrabiya*, helping the reduction of the exposure to sun rays. The self-shading wall resembles the folds of the cactus plant. Additionally, there are a number of cases where good airflow is demonstrated in traditional architecture through a number of elements; two of which are wind catchers and spikes. Finally, the ECOoler helped understanding the traditional middle eastern use of *jara* to cool down water.

The proposed self-cooling wall is meant to be sustainable, energy efficient, and a pleasant architectural element. The reduction of sun exposure is one way to reduce the heat imposed on building elevations, and the screen wall will help to transfer cool-water to the inner wall surface. The study introduces an idea that has been partially tested as the discussion of different concepts, such as aerodynamics, windcatchers, screen walls, *jara*s, and spikes; all of which ensure the application of the proposed self-cooling wall. However, there are still short comings of the research which require further work to answer the following questions:

1- With the low speed of airflow around the spike with an air current of a different angle, what would bethe appropriate vortex speed?
2- In respect to various wind speeds, what would be the degrees of the heat reduction inside the structure after the application of the self-cooling wall?
3- In the wind-tower case, what would be the exact reduction of the temperature after the application of the wind pipe system in the proposed terracotta structure?

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[i]"A **windcatcher** is a traditional Persian architectural device used for many centuries to create natural ventilation in buildings. It is not known who first invented the wind catcher, but it still can be seen in many countries today. Wind catchers come in various designs: uni-directional, bi-directional, and multi-directional. Examples of wind catchers can be found in traditional Persian-influenced architecture throughout the Middle East, Pakistan and Afghanistan."

http://www.absoluteastronomy.com/topics/Windcatcher).