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Breathing façades: a new concept to create dynamic thermal ambiances in buildings located in hot climates

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Abstract. *Mimicking nature is not a new approach, but has been recently reformulated under the scientific term: “biomimicry”. It aims to innovate non-biological systems inspired by nature. This article proposes a new rereading of this concept in architecture and in particular in building ventilation systems. The various methods of thermal adaptation to hot climate found in nature provide a wide source of inspiration in order to develop new concepts for achieving thermal comfort. This research introduces “breathing skins” as a bio-inspired idea, found in the skins of living organisms. It examines the changes in building thermal behavior when the overall area of façades deals with natural ventilation. This research reformulates this approach through proposing a conceptual model adapted to hot climate.*

Keywords: *biomimicry, dynamic ambiance, breathing walls, Sinai*

Architectural and biological approaches for achieving thermal comfort in hot climate

Sinai, the eastern desert region of Egypt, is undergoing major urban change being as subjected to a vast strategic plan that aims to develop it for touristic activity. Its climate is characterized by high temperature especially during daytime and summer months. More frequently, long periods with a mean maximum above 40°C are recorded (Costa, 1995). In order to overcome this hot climate, air-conditioned systems are widely used in buildings aiming at achieving thermal comfort for occupants. This behavior is widely criticized from an ecological point of view, as it consumes energy and pollutes the environment. Besides, occupants proclaim the homogeneity of thermal atmospheres produced from such mechanical cooling systems.

On the contrary, living organisms have efficient biological systems that interact with the same climatic conditions in a successful and sustainable way since billions of years. They develop numerous means of adaptation methods to create thermal comfortable conditions for their bodies (Benyus, 1998; Guillot, 2008). Our bodies keep their internal temperature about 37,2°C, but in the same time they provide each human organ with a suitable specific temperature that makes it functions correctly. This thermoregulation process creates an internal thermal variation within a general thermal limit. The same logic of thermal variation was introduced in architecture by Philippe Rahm, a swiss architect, under the term “thermal landscape” or “Gulf stream” in which he tries to create variation of climate conditions inside the same architectural space. This variation is considered as a new added value to human comfort because it enriches the human sensation during the lived experience (Rahm, 2009). Our challenge is to learn how these biological systems are functioning in such impressive way and to apply these biomimetic concepts in buildings to create thermal comfort for occupants.

Biological adaptation methods to hot climate

Biological thermal adaptive methods can be classified into three main categories: physical characteristics, behavioral reactions or cooling strategies. Certain physical characteristics help our bodies reducing solar heat gain such as fade colors of animal skins, small leaves in desert plants, high thermal insulation through waxy or hairy skins that are found in most desert plants and animals (Springuel, 2006). While behavioral reactions can be observed in some plants, such as Mangroves found in south Sinai, which avoid direct sunlight by rotating their leaves away from sunlight (Hogarth, 2007). Some animals, such as lizards, rest in burrows or move rapidly or rise up their bodies away from heated ground.

Current paper is more interested in the third category which is the biological cooling processes. Most living organisms develop natural cooling systems that help regulating their internal temperature. Some desert animals have enlarged ears which function as thermal radiators. Others open their mouths and pant rapidly to release internal heat. In case of overheating, plants, animals as well as human beings start an evaporative cooling process through transpiration or sweating. Some animals such as ants induce evaporation process by vibrating specific wet organs (Lasiewski, 1969). Natural cooling strategies depend on transporting heat from the core of the body to external skin which act as heat radiators or "active thermal surfaces" to release internal heat by direct contact with air flow or by evaporative cooling through transpiration or sweating processes (Wigginton, 2002).

Active thermal skins

The idea of adding specific properties of natural skins to building façades has been introduced by several recent researches and applications that focus mainly on self repairing, automatic responses and multi-function tasks, but less researches were done to mimic natural skins from a thermal point of view. Transforming traditional façade into active thermal surface does not only require certain physical characteristics (ex. color, volume or insulation layers), behavioral reactions (ex. reactive shading devices or rotating wind catches) or using natural cooling systems (ex. evaporative cooling or geo-cooling), but it should also be designed to be capable of using evaporative cooling, earth deepness and natural ventilation to release internal heat using the whole surface. Applying such principles means inducing the entire façades to work as active thermal skins.

Have we ever thought, what can be changed in building's thermal behavior if the overall area of the façades has the ability to control natural ventilation, reducing air temperature and using earth deepness for cooling? In other words, what can be changed if façades have the ability to "transpire" and to "breathe"?

Breathing walls

The notion of "breathing/breathable walls" is used firstly in the field of Baubiologie which was coined in Germany in 1969 to signify walls that are capable of diffusing water vapor to assure the indoor air quality (IAQ) (Straube, 1998). Hassan Fathy used the same term to describe the ability of allowing airflow to pass through walls made of natural materials, in addition to its capability to absorb the moisture from the air, thereby, reducing the air temperature by evaporative cooling (Fathy, 1986). Following the same definition of H. Fathy, we can consider that the Bedouins¹ traditional constructions as breathing buildings. The Bedouins use the same logic in achieving thermal comfort. These constructions have the ability to absorb moisture from the air and allow the passage of airflow through the entire surface, thereby reducing the temperature by evaporative cooling, with guarding its ability to prevent direct sunlight.

1. *Original inhabitants of Sinai.*

Breathing wall: new building's skin adapted to hot climate

Current paper proposes a conceptual design of “breathing wall” (fig. 1) suitable to hot climate and capable of controlling air flow through the entire surface, and cooling internal spaces by different cooling strategies. This bio-inspired concept aims at enhancing the thermal behavioral of traditional façades while creating a dynamic thermal ambiance inside architectural spaces.

This conceptual design consists of three layers that aim at minimizing direct sunlight, allowing airflow to pass and thus cooling it. Each layer has specific features and tasks:

- External layer capable of preventing or minimizing direct sun light. It can be a simple layer made of material that has the ability to absorb the moisture and allowing the air flow to pass through it such as natural textile, clay, wood or reeds.
- Middle layer resembles the “epidermis” layer in human skin, it contains controlled airflow entrances, water sprayed system and airflow ducts. This layer aims at achieving three tasks; thermal insulation, cooling airflow by evaporative cooling or geocooling.
- Internal layer contains controlled ventilation outlets managed by both building management system and occupancy desire to create the requested internal thermal ambiances.

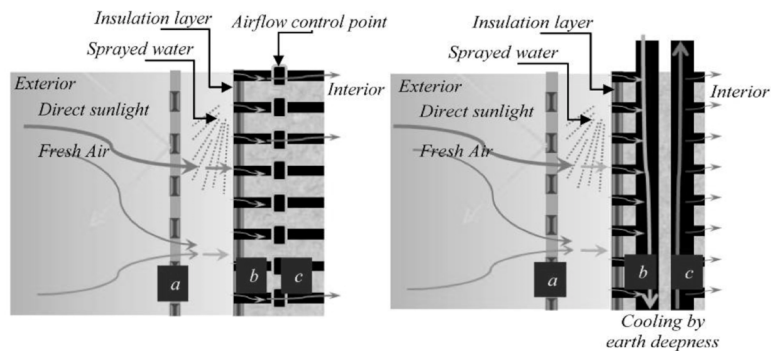


Figure 1. Conceptual design of breathing wall; (a) exterior layer (b) Middle layer (c) Internal layer (The researcher)

Field experiment to evaluate the efficiency of proposed concept

In order to prove the efficiency of “breathing wall” concept, a field experiment has been realized and lasted for 2 days during the summer of 2010 in Ismailia-East city, Sinai. Two minor models were constructed and compared with each other (fig. 2). The first model was constructed with solid traditional bricks, while the second was constructed with the proposed breathing walls concept.



Figure 2. The two models during the experiment (The researcher)

Thermal behaviour of breathing model

The results confirm an evolution of thermal behavior of breathing model in comparison with the solid one. Although the breathing model did not use evaporative cooling in this phase (fig. 3), the temperature inside this model restes lower than the solid model during the day of the experiment. The average temperature inside the breathing wall model ($T_{in-av. Breathing}$) was 29.3°C while it was 32.4°C inside the traditional model ($T_{in-av. Traditional}$). The differences between the temperatures at the same time inside the two models varied from 1,2% to 16,23% and arrived at maximum till 5.6°C lower inside the breathing model than the solid model without using the water for evaporative cooling.

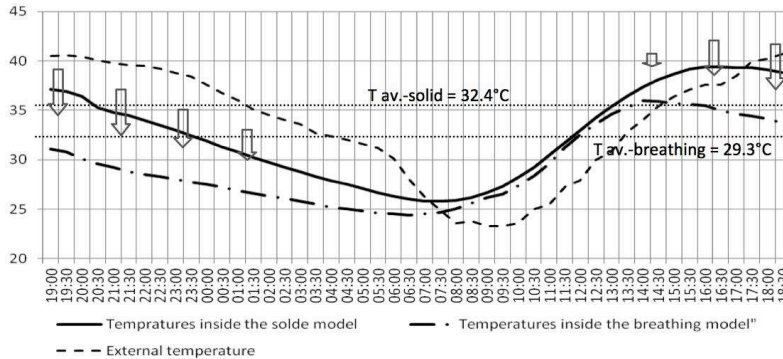


Figure 3. Temperatures measured during the experiment without the usage of the evaporative cooling (The researcher)

A further step that aims to examine the efficiency of this concept is to apply it on a villa located in Sinai. We should clarify that the villa's walls are constructed using local red bricks. The material's high inertia produces homogenous internal temperatures during the day. This remark was proved when examining the thermal behavior for two days in July 2010. While the external temperatures varied between 27,5°C and 36,6°C during the two days, the internal temperatures remained almost still between 32,2°C and 34°C.



Figure 4. Villa located in Sinai that has been measured (The researcher)

The following chart (fig. 5) shows the temperatures measured inside and outside the chosen villa with interval time of 30 minutes (thick solid and dashed curves respectively). When applying breathing wall concept on façades, we can reduce the internal temperatures through activating air movement when opening direct ventilation inlets during night time and indirect and geo-cooling system during day time. This reduction is estimated using the

same percentages that we attained from the first phase of experiment. If the internal temperatures did not achieve the requested thermal comfort, we move to the next strategy by activating the evaporative cooling system. This is done by spraying waters on the external layer to reduce the temperature of the air before entering to the building. The dashed gray curve in the chart indicates the maximum reduction of external temperatures. It has been calculated by using the psychometric chart while taking into consideration that the maximum relative humidity does not exceed 70% and the efficiency of cooling system between 70% and 80%. The estimated internal temperatures, using the two cooling methods, lie somewhere in the hatched zone located between 24,06°C and 29,3°C depending on the intensity of air flow.

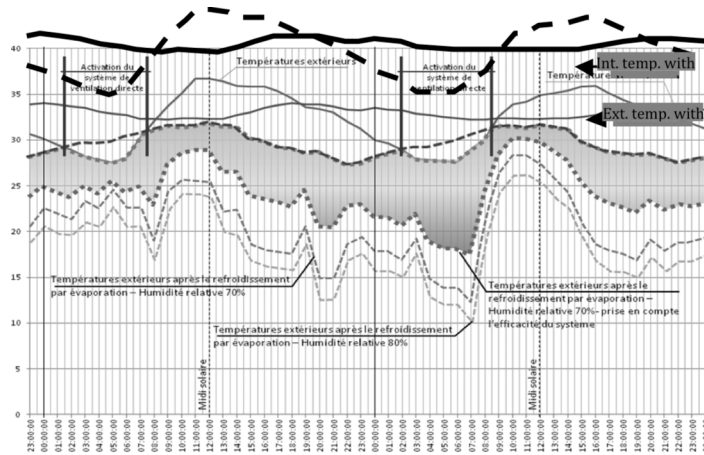


Figure 5. Thermal behavior of an existing villa with estimated internal temperatures when using breathing wall concept in façades (The researcher)

Dynamic thermal ambiance

Proposed breathing model not only provides an internal comfortable temperature such as shown in the field experiment, but also creates a dynamic ambiances. The controlled out lets dispersed over the wall diffuse the air flow with different speeds creating an internal air fountain or a dynamic thermal landscape.

In order to approve this hypothesis, the research simulate the same breathing model by an aerodynamic simulation software called “Vaseri 2.5” created by “Autodesk inc.”. A digital climate data of Sinai was used for the wind speed and direction. The following images present the simulated air flow inside and around the breathing model. These images show different types of air fountains according to wind speed and direction. These fountains could enrich the human sensation and add a new value for thermal comfort for users.

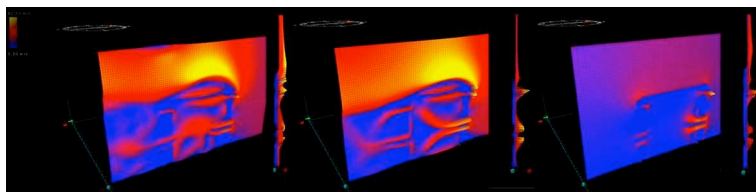


Figure 6. Aerodynamic simulation for breathing model (The researcher)

Conclusion

Biomimicry provides a wide source of inspiration for enhancing building thermal behavior. Introducing breathing wall concept changes the way that architects deal with façades as isolation layers between internal and external spaces. In this perspective, façades become a medium of connection between the two ambiances. *Porosity* of façades is therefore introduced as an architectural element (“dispositif architectural”) that can be applied in buildings located in hot climate in order to enhance their thermal behavior. These pores create tiny horizontal air *fountains* which generate a dynamic thermal ambiance that enriches human sensation. This approach fights against the rigidity of the actual definition of thermal comfort that produces homogenous internal atmospheres and creates instead thermal landscapes (“paysage thermique”) by controlling ventilation inlets and outlets that are disrupted along the façades.

The field experiment and the thermal calculations of the villa show a reduction of internal temperatures from Tmax 34°C to 29,03°C while Tmin from 32,2°C to 24,06°C i.e. about 5°C to 8°C. It is thus worth using this concept for achieving comfort particularly during thermal peak hours. However, the implementation of this concept in reality requires further studies in order to determine, on the one hand, the terms of reference or technical description of materials and cooling systems (“faire monter un cahier des charges”). On the other hand, a feasibility study should also take place to examine the economical efficiency of this proposal.

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