Evaluation of the thermodynamic performance of the traditional passive systems

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ABSTRACT

The need to reduce urban consumption of energy in the buildings, one of the major energy waster resulting in emission of CO2, is pushing research in the field of building design to the appreciation of passive air-conditioning systems that can be integrated with conventional systems and determine, therefore, the so-called hybrid systems. Historically this passive systems were developed in the Mediterranean and in the Middle East area.
Actually the research activity has been focused on this problem, through an approach that involves the application of design strategies and the development of computational tools and control systems. The synergy between current scientific knowledge, advanced manufacturing and information technology allows to conceive hybrid systems.
Through the use of computer programs CFD (Computational Fluid Dynamic) have been tested different conditions iterating the process until it gets to the structure that gives the greatest contribution for the environmental comfort.
The paper shows the results of research developed to the Dipartimento di Architettura of the Università di Palermo, that develops a case study where is analyzed the effect of the natural ventilation in indoor comfort.

NATURAL VENTILATION TO THE IMPROVEMENT OF THE ENVIRONMENTAL COMFORT

The comfort of the indoor depends mainly on climatic conditions and particularly of the urban areas, where lives about 50% of the world's population.The presence of an urban area changes the temperature and humidity, and wind circulation patterns. For a medium-sized city is estimated that between centre and rural areas, there is between 0.5 ° C and 3 ° C difference with significant changes in the microclimate [1].
This can be determined by the following reasons:
1. the materials used in urban areas rather in rural areas have different thermal properties (capacity and thermal conductivity) and radiative (albedo and emissivity);
2. the lack of natural evaporative surface and vegetation;
3. the increase of the exposed surface rather a flat surface, due to the presence of buildings;
4. the heat that comes from human activities and from energy consumption;
5. The air pollution that can change the radiative properties of the atmosphere reducing the incoming solar radiation and reducing the outgoing infrared radiation.

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Natural ventilation can be an effective strategy to be adopted in regions with warm climate, improving the internal conditions of comfort, especially during the summer and during the afternoon hours when there is the greatest intensity of heat.

NATURAL VENTILATION IN THE TRADITIONAL URBAN CONSTRUCTION

The development of passive systems was caused by the large amount of population (about one third) who lives in the world in conditions of hot - dry or warm – moist climate; also most of the internal areas of the continent is characterized by summer weather conditions with temperatures that exceed the level of comfort.
Formerly, many cities of the East were originally built with passive systems of cooling conceived and developed in empirical way.
These systems utilize: natural ventilation, evaporative cooling, control of solar radiation, thermal mass of the building and the heat exchange with the ground. Today passive systems tend to become the key element of sustainable design in all weather conditions.
In the traditional building construction the ventilation was put into action by the natural forces that created the airflows in buildings that was both dynamic (wind) and thermal (temperature difference).
The wind effect produces a positive pressure on the side of the building affected by the current and a negative one on the opposite side.
These pressure differences put into action the air flow from one side to another through the openings.

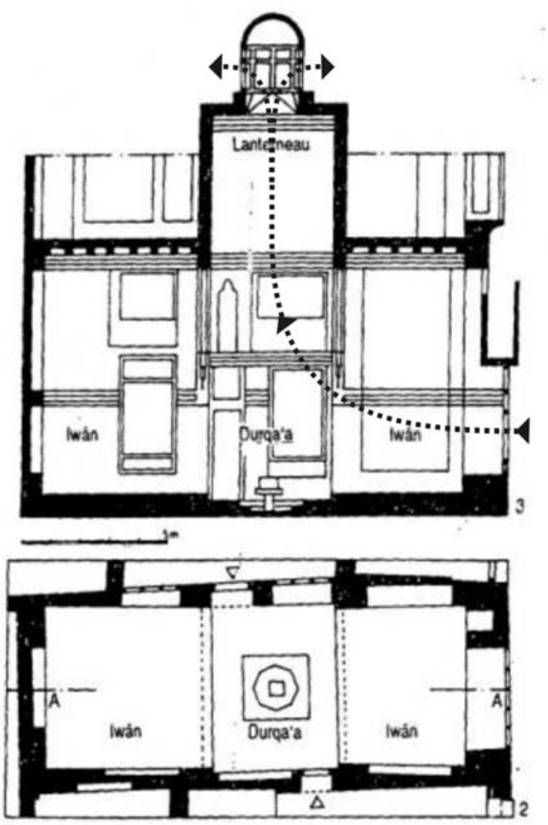


Figure 1. Qa'a, house Suhaymi, Cairo

This phenomenon can be added to the convective air flow due to the difference in temperature and therefore in air density: the less dense warm air moves upward carring cooler air from below.
Different traditional passive systems employ these physical principles, including wind towers, and the Iranian Qa'a [2].
The wind towers, used for the collection and capture of the air, are composed of architectural elements configured as vertical chimney, which rise to heights higher than the roofs and openings are equipped with properly oriented, designed to capture the flow of wind, convey it inside the building and facilitate the movement to cool off the living spaces.
The Qa'a is a natural ventilation system, probably of Turkish origin, composed by different parts.
It is widespread in cities with a dense urban fabric, where there is a slowing of the flow of air outside which makes it impossible the ventilation through the window areas.
The ventilation process is activated by the pressure difference between the different areas and between indoor and outdoor.
The air getting inside the lower levels is channeled first into the iwan, and once it arrives in durqa'a tends to go up.
This effect is due to the temperature difference that develops in the highest part of the central room corresponding to the lantern open during the summer [3].
This temperature difference is able to generate the air flow even in the absence of wind.

APPLICATION TO A CASE STUDY - THE CHOICE OF A MODULE

The physical principle behind passive natural ventilation system [4] was applied to a possible living module that existing technologies utilizes in leverage and meets the requirements now demanded, more adapted to different uses and variations of the context with which it relates[5].

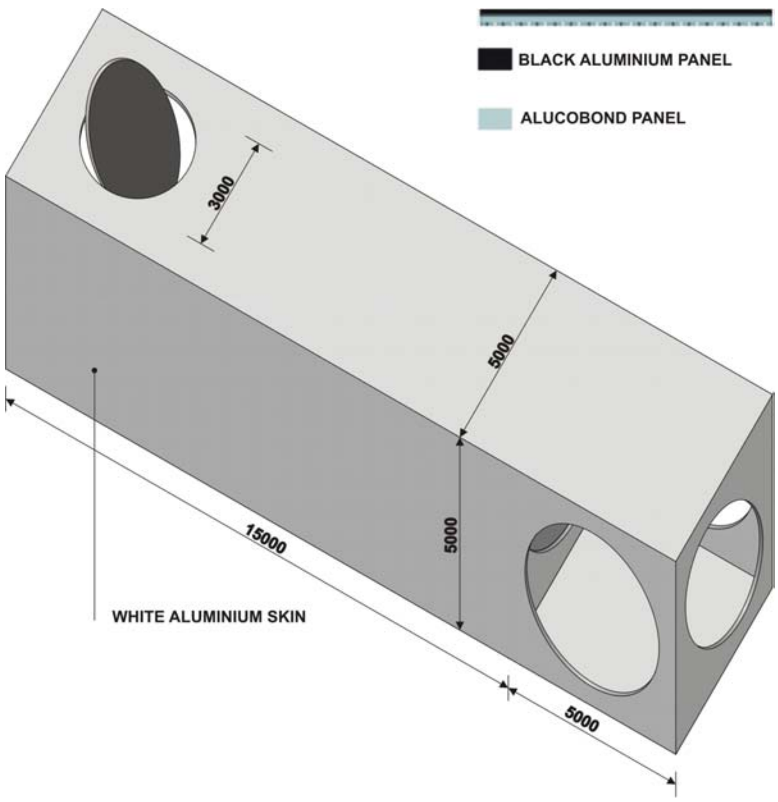


Figure 2. Revolving panel double skin

The module examined has a rectangular plan of 5m x 15m with a height of 5m with the longitudinal direction North / South.
The south-side has a large regulable opening with a front arcade, 5 meters deep. On the roof, to the north, there is an adjustable opening.
The envelope is made of sandwich panels with an outer layer of Alucobond.
The circular panel on the roof is designed with a double skin: black aluminium side absorbent, glossy white Alucobond side characterized by a high value of albedo [6].
The cooling inside the module using the principle of natural ventilation due to the effect of drawught. The panel on the roof turns the black side towards outside, being characterized by a high absorbance value of 0.96 solar warming significantly, creates a negative pressure and drawing fresh air from the opening at the bottom on the south side. The panel on the roof can take an angle of inclination referred to a horizontal plane variable by on the month and day in order to better capture the sun's rays.
In the summer, during the afternoon, the black side of the panel is facing outside and is open
In the morning hours the panel is closed with the reflective side facing out to prevent overheating. The circular openings, if supported by a building management system should accord the passive system with the change of internal and external factors.

Figure 3. Summer cooling scheme

CFD EVALUATION

The effectiveness of the passive system has been carried out through CFD (Computational Fluid Dynamics), which is a valuable aid in the design because it allows to appraise and to compare the real effectiveness of different design solution in terms of environmental comfort.
The ability to assess the effects of air flows, according to the geometric and spatial configurations positioning in the soil, latitude and prevailing climatic conditions, etc.., has now become a tool for the designing of low-power energy [7].
In particular, it allowed us:
- To evaluate indoor flows (temperature, pressure and speed parameters);
- To change the size and shape of the openings according to the comfort conditions.

To carry out the CFD simulations have been fixed boundary conditions according to a dynamic thermal simulation [8].
To check the efficiency of the system were examined the effects generated on the same model with the same outside conditions, but with different configurations:
- closed model;
- model with a revolving panel (black aluminium skin) opened on the roof and the window opened in front;

- model with a revolving panel (white alucobond skin) opened on the roof and the window opened in front;

The study was essentially developed through three phases:

- The first phase where you define the boundary conditions (material, temperature, wind speed, etc..), the flow model, the solar parameters, ecc;
- The second phase, calculation step, where you define the time steps, the number of iterations, etc.. and start up the simulation;
- The third phase where you set the plans and views and displays the characteristics of the airflow (temperature, velocity, pressure, etc.).

Boundary conditions

To obtain the boundary conditions, simulations were conducted with a thermodynamic program. The study was carried out in reference to summer in the hottest day in Rome (August 7) at 1.00 p.m. (34°C).

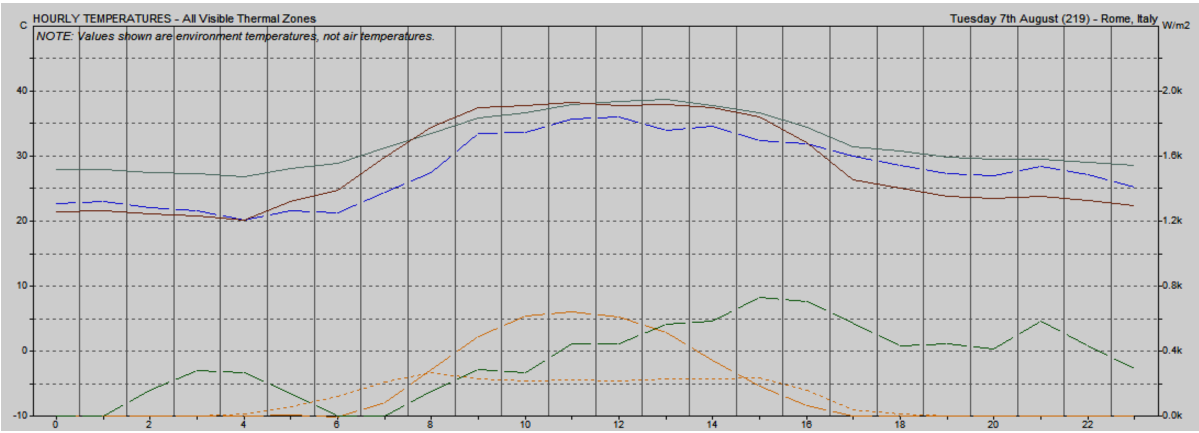


Figure 4. Climate data (7th August, Rome, Italy)

In particular, we calculated the temperature inside the module at different times of day and exposure to solar absorption values for each wall bounding the building. In the computational model has been considered the panel inclined of 45°. The temperature increase of outside surfaces, due to the proportion of absorbed solar radiation, has been calculated using the following equation [9].

$$T_S = T_0 + G \times \alpha \times R_{SO}$$

T_s [K] surface temperature

T_0 [K] outside temperature

G [W/m2] global irradiance

α absorption coefficient which mainly depends on material and surface color

R_{SO} [m^2K/W] liminare thermal resistance of surface

Table 1. Liminare thermal resistance of surface

	External horizontal surfaces (very exposed)	Roof (normal exposure)	Inclined panel (very exposed)	Vertical walls (normal exposure)
R_{SO} [m^2K/W]	0,02	0,04	0,02	0,06

The G x α has been calculated by a thermodynamic program.
From the above formula were obtained the following temperature values:

Table 2. Surface temperatures

	Roof	Closed alucobond panel	Open black panel	Open white panel	East wall	North wall	West wall	South wall
Ts [°C]	46,30	46,30	71,62	43,48	36,04	36,04	37,6	40,00

Calculation phase
The model to be analyzed by CFD was created defining the surfaces that enclose the domain of fluid to be examined. For flow analysis has been imported a model consisting of two volumes of air, the outer and inner model study.
For the outside boundary of the model have been attributed the characteristics of materials and their temperatures derived from thermal simulation.
For the volume of outside air has been considered the temperature of 34 ° with a speed of 1 m / s (maximum value for the indoor comfort).

Flow analysis
In the third phase were shown distribuitions of temperature and air velocity.

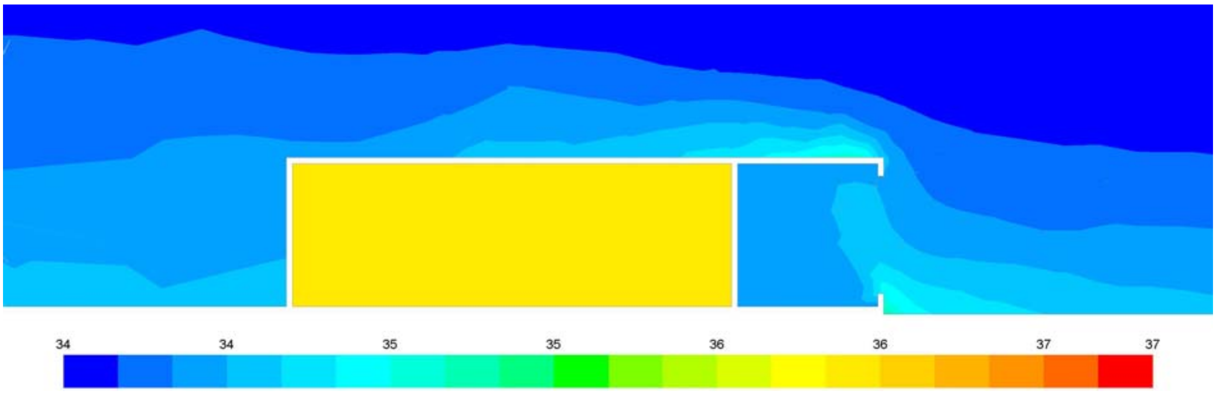


Figure 5. Air temperatures distribution (°C): closed module

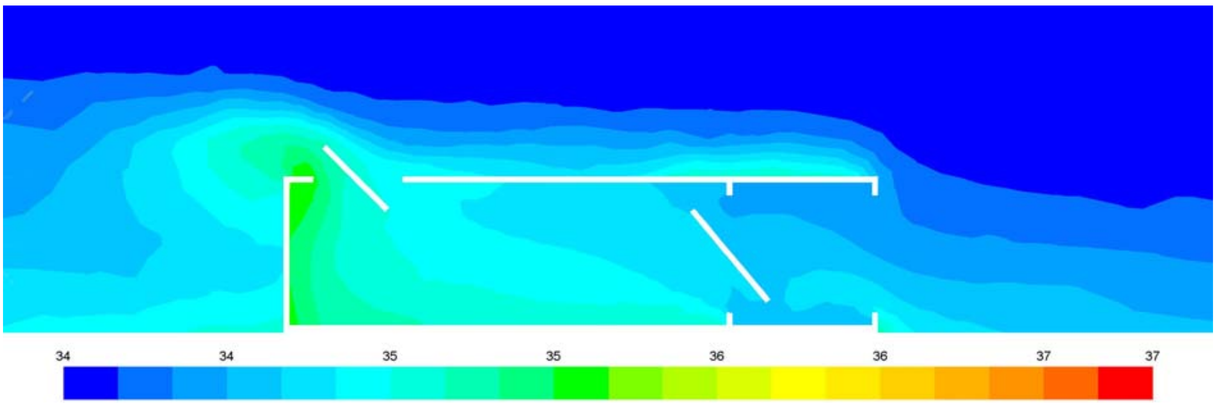


Figure 6. Air temperatures distribution (°C): open panel on the roof (white Alucobond side)

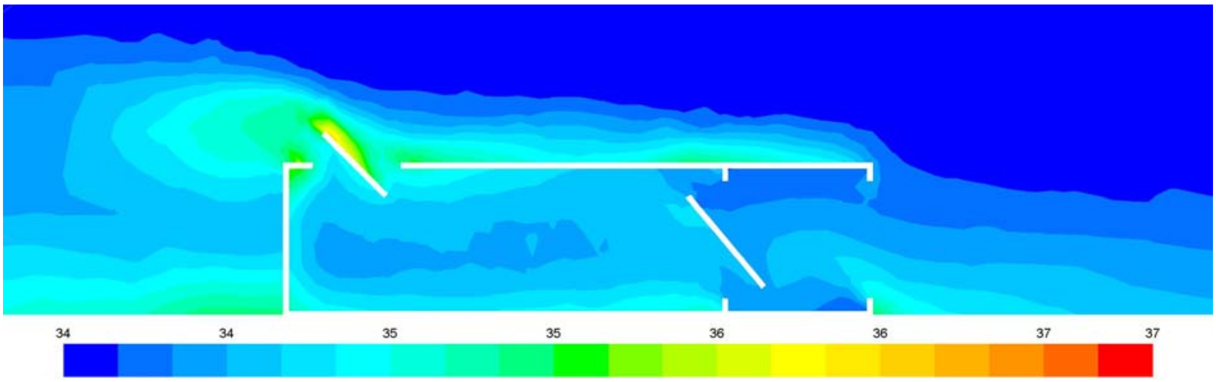
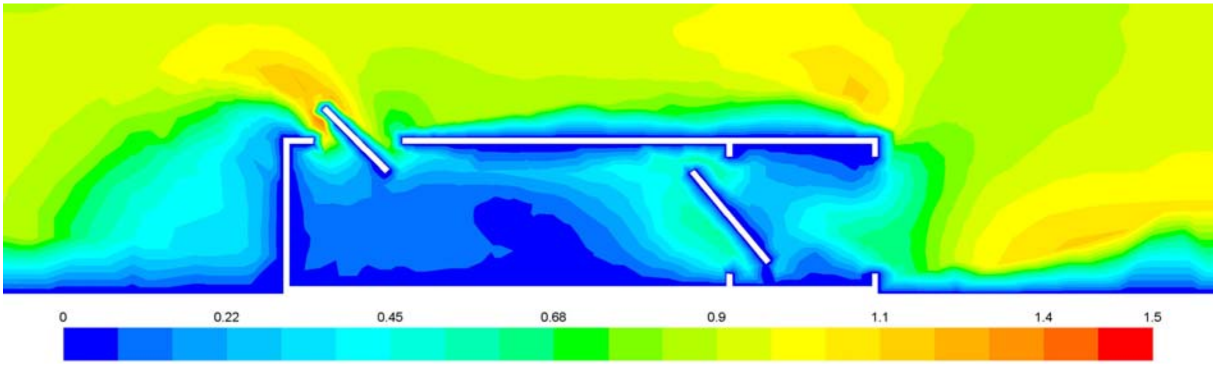


Figure 7. Air temperatures distribution (°C): open panel on the roof (black aluminium side)

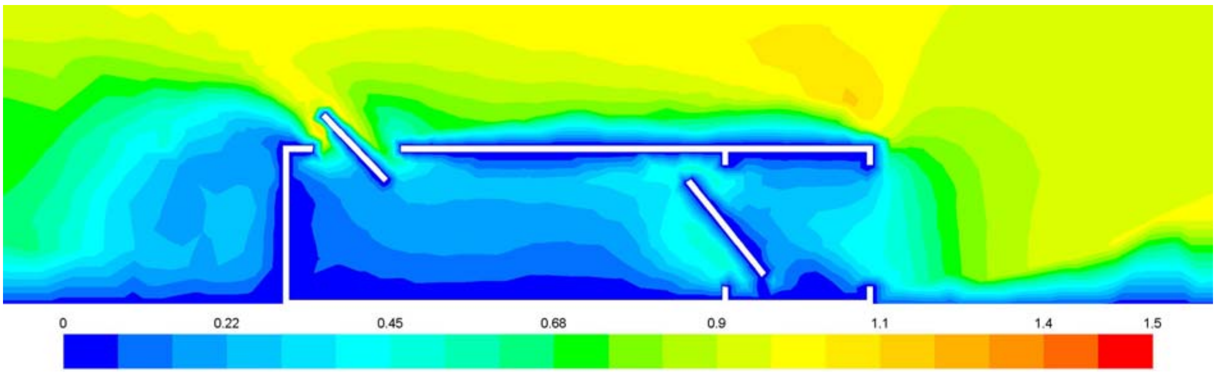
In the closed model the inside temperatures are considerably higher. The model with open panels develops the process of natural ventilation due to air circulation with a consequent drop in temperature of about 1.3 ° C (36.5 ° C to 35.2 ° C).

Placing a black panel on the roof, and tilted open, it will act as a sensor that warming decreases the density of air, drawing fresh air from the inside and allowing a greater cooling of the building. In this case it's possible to observe a lowering of the inside temperature of 1.2° C (35.2° C to 34° C).

The presence of the black panel, in the described conditions, causes an increase of the speed, a decrease in pressure, triggering more air and drawing fresh air in rooms but with air speed always less than 1 m/sec.



Figures 8. Air speeds distribution (m/s): open panel on the roof (white Alucobond side)



Figures 9. Air speeds distribution (m/s): open panel on the roof (black aluminium side)

RESULT EVALUATION AND FUTURE DEVELOPMENT

Simulations showed, in unfavourable weather conditions, time and average hottest day of the year, a decrease in temperature from 36.5 ° C (closed model) to 34.00 ° C (open model with black absorbent panel).

This substantial drop in temperature can contribute to energy savings by integrating a series of conventional air conditioning system with the adopted passive system.

The work already developed could be extended considering, for example, a residential application where the cell, with their smaller size, can be an habitation module that can be assembled side by side and in height.

In this case the two openings can be suitably controlled through thin slits slats.

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