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ANALYSIS OF THE TRADITIONAL PASSIVE SYSTEMS PERFORMANCE THROUGH THE APPLICATION OF CFD SOFTWARE

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Abstract

The need to reduce energy consumption is pushing the building design research to the evaluation of passive conditioning systems, since urban buildings are one of the major energy dissipater resulting in emission of CO_2.

This approach is not modern, but it is historically rooted in the architectural culture of the Mediterranean area and in the Middle East. The passive systems have ancient origins: they were developed to mitigate the summer heat and the winter cold. To understand the reasons that led to the development of passive systems, it should be remembered that about One-Fifth of the emerged planet surface and One-Third of the world's population live in conditions of warm-dry or hot-humid. In addition, most continental areas, even above high values of latitude (50°), are characterized by climatic conditions with summer temperatures over the limit levels of comfort.

Nowadays the scientific knowledge and the modern technologies allow to understand the working of passive systems in order to apply them on buildings to improve indoor comfort.

This can be obtained through a new approach that involves the elaboration of design strategies based on the development of techniques and on computational and control tools.

This work will show the results of a research that aims to verify the working of natural passive cooling systems employed in existing ancient buildings throughout CFD (Computational Fluid Dynamic) software application.

Particularly we will define, through computational tools, models and study cases to compare and to set proposals able to actualize the original passive systems conceived and developed in an empirical way.

Keywords: *passive systems, indoor comfort, CFD simulation, sustainable development.*

The Passive Systems in the Mediterranean area

In the past, passive systems were the only expedient to mitigate the adverse effects of climate and improve indoor comfort. These ancient-origin passive systems have been developed in areas where whole towns were built according to these principles. Empirically designed and developed, they have become popular in hot countries to mitigate the effect through natural expedients.

These systems utilize various principles such as natural ventilation, evaporative cooling, control of solar radiation, the building thermal mass and the heat exchange with the ground.

Many buildings belonging to the Mediterranean and Middle Eastern architecture were designed using architectural features for climate control. The architecture of Maghreb and Middle East area is particularly rich of these examples, since the very hot and dry climate requires a mitigation of its effects to improve the living conditions in indoor environments. Most of the dignified and representative buildings, such as royal palaces, have a lot of systems and techniques for passive cooling, such as solar radiation control, for example in Mashrabiya or Claustrum systems; ventilation and cooling control, as for Malqaf, clerestories, Badgir or Dur-Qa'a / Iwan systems.

In this context was very important also the diurnal control of the heat through the building mass envelope. In almost all buildings in the Middle East this was associated with a room (often barycentric and with an important symbolic meaning for social life) whit a water basin or a fountain: the *Salsabil*.

This system allowed to cool and humidify the air by means of water evaporation. Therefore beneficial effects were obtained for the interior comfort especially in a dry climate like the Middle Eastern one.

A concept of Arab building in Palermo: Zisa Complex

The integration of passive systems in Middle Eastern representative building had an excellent application also in Arabic - Norman architecture in Sicily, especially in the Zisa’s building complex, in Palermo.

It was built in 1160 by Arabian craftsmen (Fig.1). It was characterized by the presence of an evaporative cooling system and natural ventilation that guaranteed levels of comfort that could be satisfactory even nowadays.

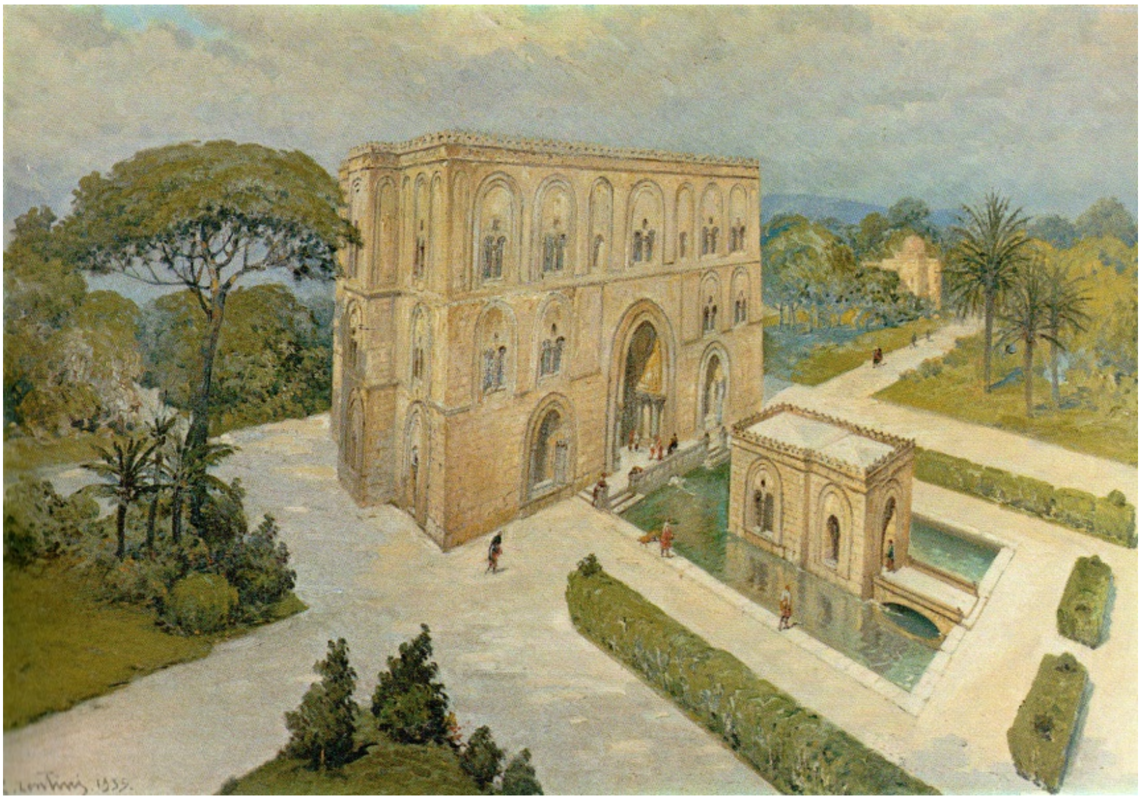

Figure 1: Ideal reconstruction of Zisa, a painting by Rocco Lentini (1935)

The current state of Zisa complex is the result of heavy tampering since Fourteenth century, when it was transformed into a fortified castle, with also some small changes, such as the creation of a crenelated crown. Later it was used as a beam agriculture and left for centuries in a state of total decay. In 1634 the building, for its poor conditions, was given to the Sandoval family, who started the renovation works that saved the building from ruin, distorting, however, its original appearance, not only in the stylistic and formal aspects, but especially in the structural ones, with some reductions of wall thickness, the destruction of the two small stairwells and the addition of a monumental staircase. Also the east elevation was transformed through the replacement of the mullion windows with larger rectangular windows, while the west elevation was changed through the creation of several openings. Superstructures were also built on the building roof, such as a central pavilion with a terrace reached by a staircase, and two little kiosks, symmetrically put on each sides, covering the three open-air courtyards of the second floor (Fig.2). There were even two pyramidal-shaped cusps over the southern and northern foreparts (Fig.2).
In 1809, with the extinction of the Sandoval family, the property passed to Francesco Notarbartolo e Pilo until 1951, when Zisa was expropriated and became a regional property. The tampering made in the Seventeenth century by Sandoval was among the main causes of the collapse of the building, but when it became a public property the situation got worse, due to the lack of timely consolidations. In 1952 renovation works started, but they were repeatedly interrupted. For this reason, on Thirteenth October 1972, most of the north wing collapsed because of the reduced wall thickness resulted from the Seventeenth-century transformation, which made the structure unstable at the thrust of vaults. The last renovation work is the reconstruction of the collapsed wing, which brought the building to a hypothetical original configuration (Fig.2). In 2002 the inauguration of the garden in front of the building has completed the renovation of the complex (Fig.3).

Figure 2: The current image of Zisa complex is the result of the renovation works, begun in 1972, after the collapse, and continued until June 1991.

Figure 3: Zisa, aerial image of the actual complex feature with its front garden

By an analysis of historical-iconographic sources you can assume that the building was an integral part of the "*Garden of Genoard*" (which means "*giardino del paradiso*", "paradise garden") which is located at an altitude of 40 meters above the sea level.
The garden was a rational way to reduce the temperature, by creating shaded areas and contributing to cooling sea breezes thanks to the evapotranspiration (Fig.4). Before reaching the palace, the sea breeze was further cooled by evaporative cooling produced by the front tank of water called "*peschiera*" (Fig.4).

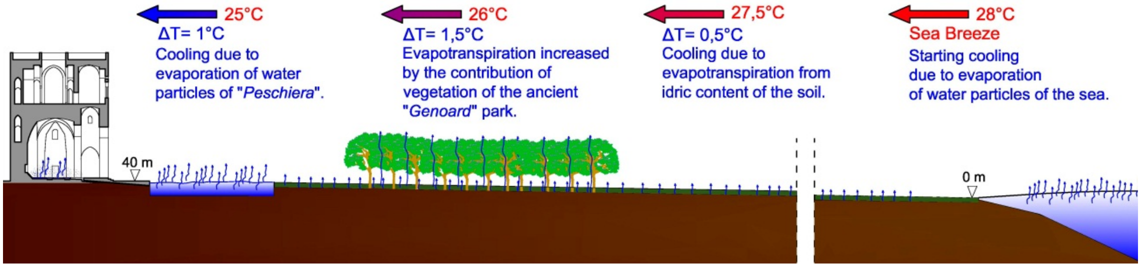

Figure 4: Schematic image of the cooling sea breeze

The complex was a place dedicated to the sovereign's rest and solace. Even today, it looks like a massive parallelepiped with two protruding volumes on the short sides. With its 36.40m of length, 19.60m of width and 25.70m of height, it spread itself over three levels with a longitudinal orientation north-south. This arrangement is not accidental because, being a summer residence, the most important rooms were oriented to the east, to expose them to the low and warm sun in the morning. The rooms arranged on the west side, receiving more solar radiations, are protected by insulating elements, such as the solid thick stone walls and the inner tube, consisting of corridors that make up a thermal mass of protection from excess summer heat. On this front elevation there are also only small windows, to prevent the heat to spread during the hottest days.
The building is built around a square room that is the heart of the complex: at the ground level it is located the room of representation, called "*Sala della Fontana*" for its stone *Salsabil*. This room, with its double height, the rich wall decorations and the presence of water, is a distinctive feature of Islamic buildings. Among the various design features, the most important role is played by the natural ventilation system inside, which, before the several changes which the building has been subjected to over the centuries, could ensure a constant flow of fresh air and the expulsion of the warm.

The passive working of the Zisa Complex: Comparing Theories

There are some assumptions about the passive systems working that have not a scientific evidence.

The hypothesis of Prof. Giuseppe Bellafiore[1] (Fig.5) considers that there is an upward movement of the air favored by the pressure gradient, the channels work as suction of fresh air and the *Salsabil* produces evaporative cooling.

The hypothesis of Prof. Armando La Pica[2] (Fig.6) gives importance to the horizontal motion of the air and to the breeze capture, but it considers improbable the channels working because of the excessive drop pressure.

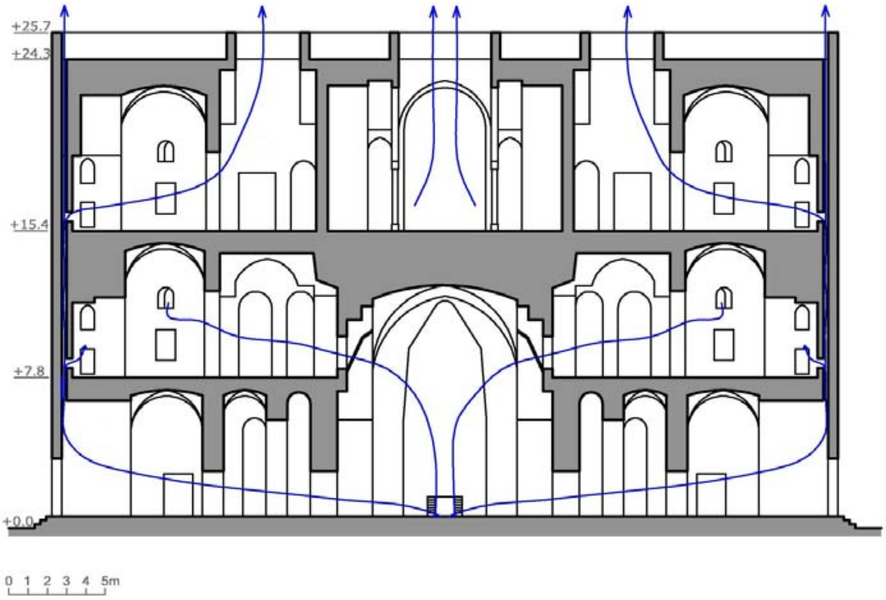

Figure 5: Longitudinal section. Original configuration and motion of the air. Hypothesis Bellafiore.

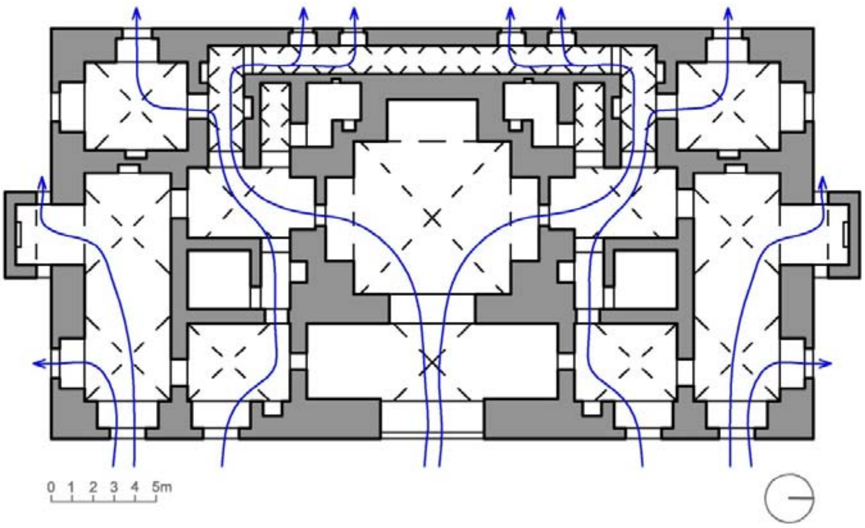

Figure 6: First floor. Original configuration and motion of the air. Hypothesis La Pica.

The hypothesis of the researcher Ursula Staacke[3] (Fig.7) considers the horizontal ventilation favored by temperature and pressure gradient; the upward flow of air on the top floor and the cooling due to the *Salsabil*.

Bellafiore and Staacke's theories on the passive systems working are developed according to their assumptions about the original architectural configuration.

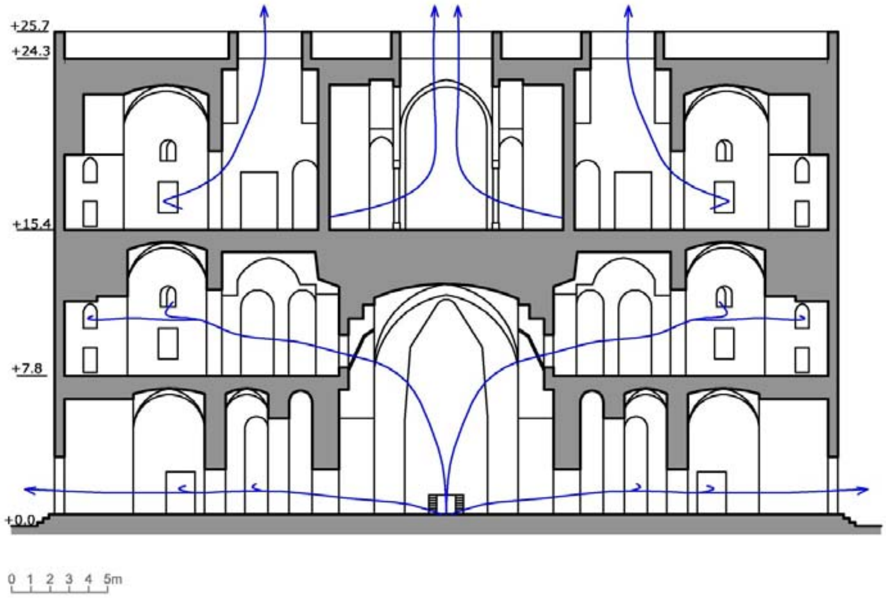

Figure 7: Longitudinal section. Original configuration and motion of the air. Hypothesis Staacke

Computational fluid dynamics (CFD)

Specific simulations were carried out using the Ansys Fluent CFD software to test the hypotheses concerning the movement of air and temperature control inside the Zisa Complex.

The model created considers the building architectural configuration, its position and its orientation (Fig.3). The adopted architectural configuration is the most shared, proposed by Prof. Bellafiore (Fig.5).

The model has been georeferenced to Palermo's latitude and longitude coordinates (Latitude 38.11°, Longitude 13.65°) and solar radiation values have been assigned in a summer day (26th August) in order to guarantee a certain amount of shaded areas and thermal gradient (Fig.8).

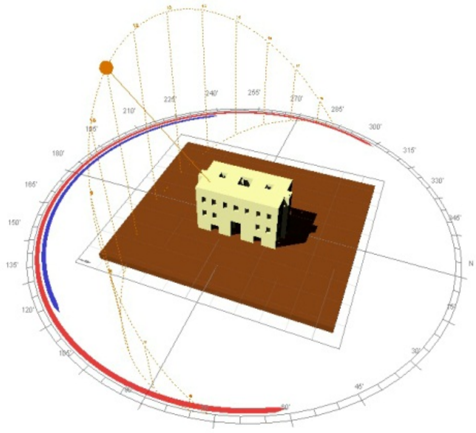

Figure 8: Sun Stereographic Diagram (August 26)

The time interval analyzed is between 6 a.m. and 12 a.m. Moreover, between 12 a.m. and 3 p.m., it has been considered the wind action, in order to simulate the effects of sea breeze, which is generated in those hours (Fig.4). It comes from East and it is considered with low intensity (0.5 m/s) and an initial temperature of 25°C, in order to analyze the model under the most unfavorable conditions.

With regard to the building, the rubble-filled stone wall has been schematized by setting a material whose thermo-physical properties are the weighted mean between real materials values.

Particularly, density (1306kg/m^3), specific heat (1362J/kgK) and thermal conductivity (0.64W/mK) have been considered. Air has been schematized according to Bousinnesq density model (1.225kg/m^3), with a thermal expansion coefficient of 0.003

Salsabil main action consists of water particles nebulization due to the roughness of surface. It has been simulated by creating a surface injecting water particles with a diameter of 10^{-4}mm, with a flow rate of 0.5kg/s and with a speed of 0.1m/s.

In the software the temporal development of the phenomenon is not-continuous, therefore the simulation considers "time steps" lasting three hours.

Looking at the results obtained at 12 a.m. and at 3 p.m., it can be observed that solar radiation heat on exposed surfaces cannot entirely conduct itself through the wall, but affects only the outer portion.

The wall dissipates heat, due to radiation, during the day and acts as an insulator, thanks to the constituent material features, but more importantly thanks to its high thick: only the thinnest walls (40cm) on the South side are completely traversed by heat, because they had already underwent solar irradiation over nine hours (Fig.9-10).

With regards to the effects of natural ventilation, in the daily hours with no wind (6-12 a.m.), it can be observed that a natural ventilation rises up in the rooms. It happens because of the thermal gradient which is established between external and internal environments. It is more evident in the rooms on the East front of the building, which undergoes only a soft radiance in the morning. It is shady during afternoon hottest hours and is cooled by the basin, the “*peschiera*” (Fig.11-12).

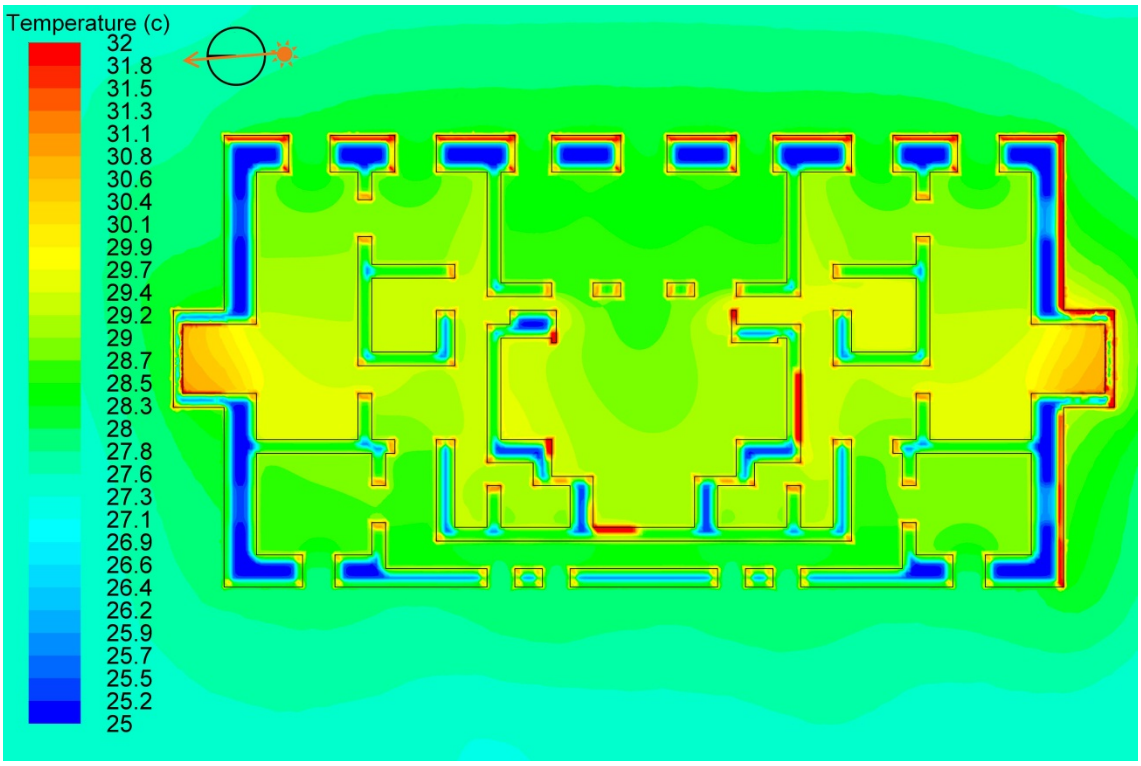

Figure 9: 12 a.m., temperature on second floor

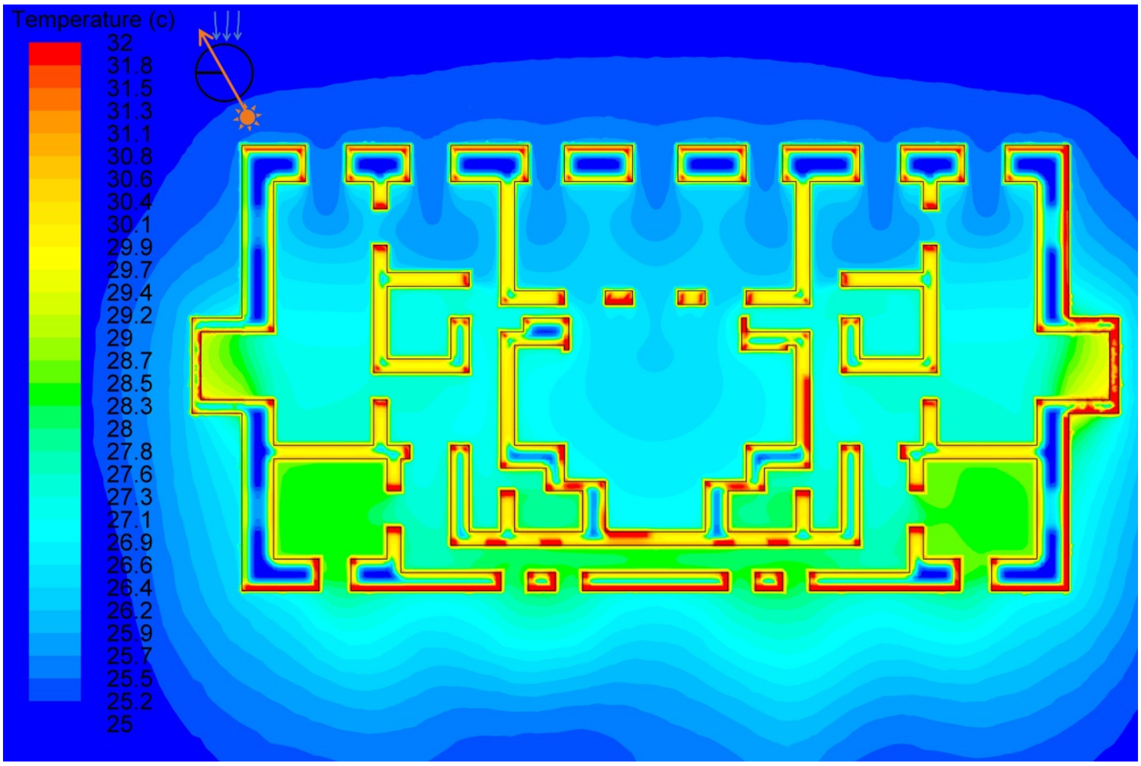

Figure 10: 3 p.m., temperature on second floor

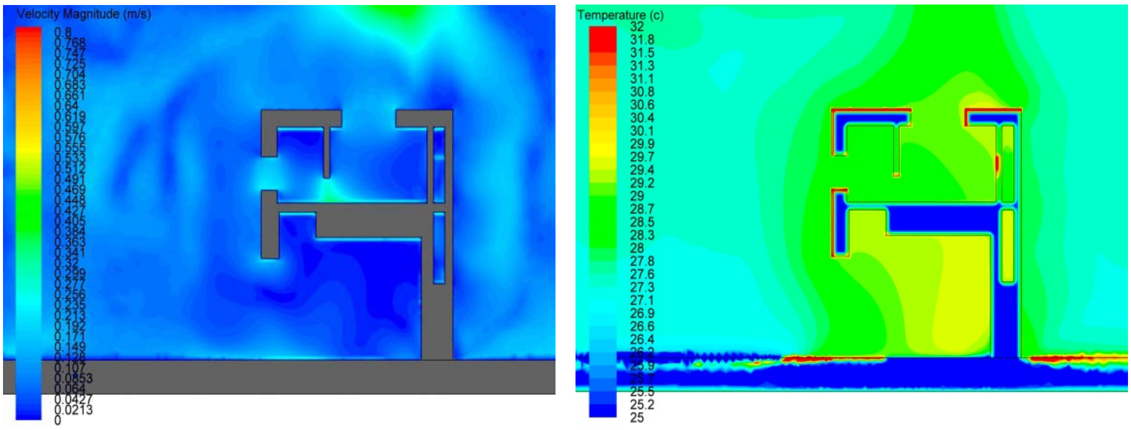

Figure 11: 12 a.m., velocity and temperature on cross section

Chimney effect starts in the Fountain Room and in the central hall (probably the real "*sollatia*" of the sovereign); this entails that hot air is expelled from the top and the fresh air is drawn from outside through the openings (Fig.12-13).

The particular shape of these rooms makes them fairly cool (28-29°C), but in the rooms placed in the two wings of the building, that are less ventilated, the hot air piles up and stratifies itself, reaching temperatures up to 30°C (Fig.13).

The building shape facilitates the use of the pressure gradient due to the breeze. Particularly, at 3 p.m., air flow rises into the building, following different paths from east to west. The air movement involves many different rooms until the maximum value of 1m/s (Fig.14).

In this case the internal temperature does not exceed 30°C, because the breeze has an initial value of 25°C (Fig.15-16).

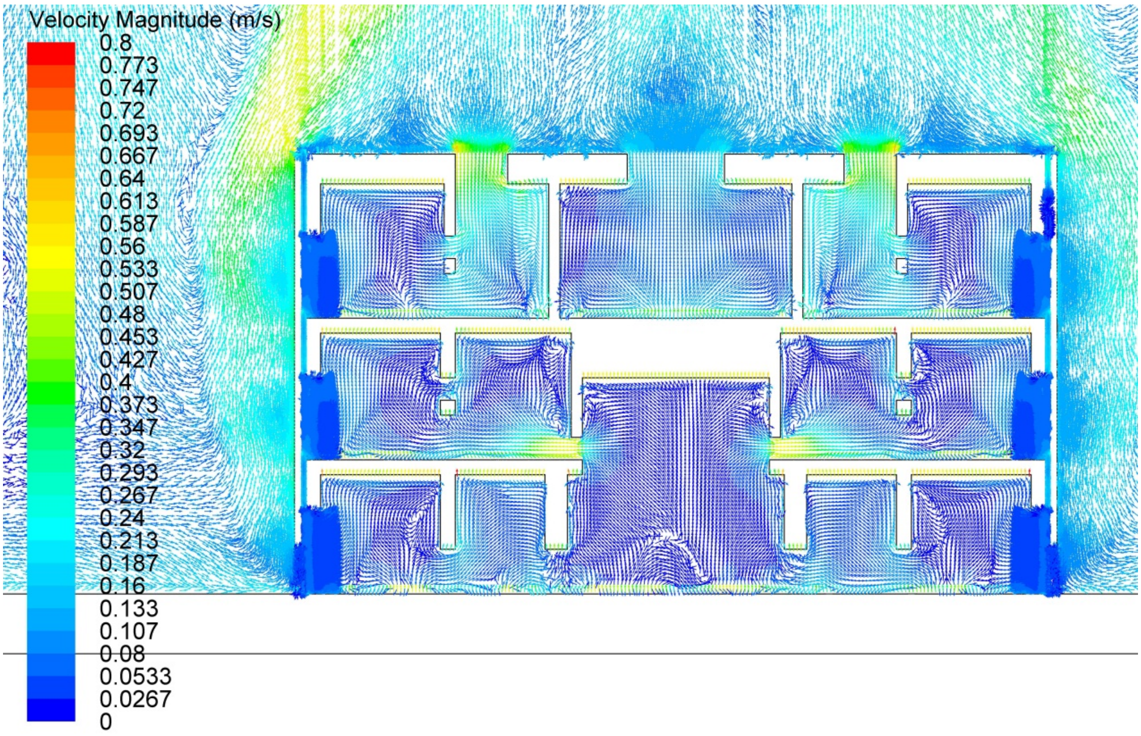

Figure 12: 12 a.m., velocity vectors on longitudinal section.

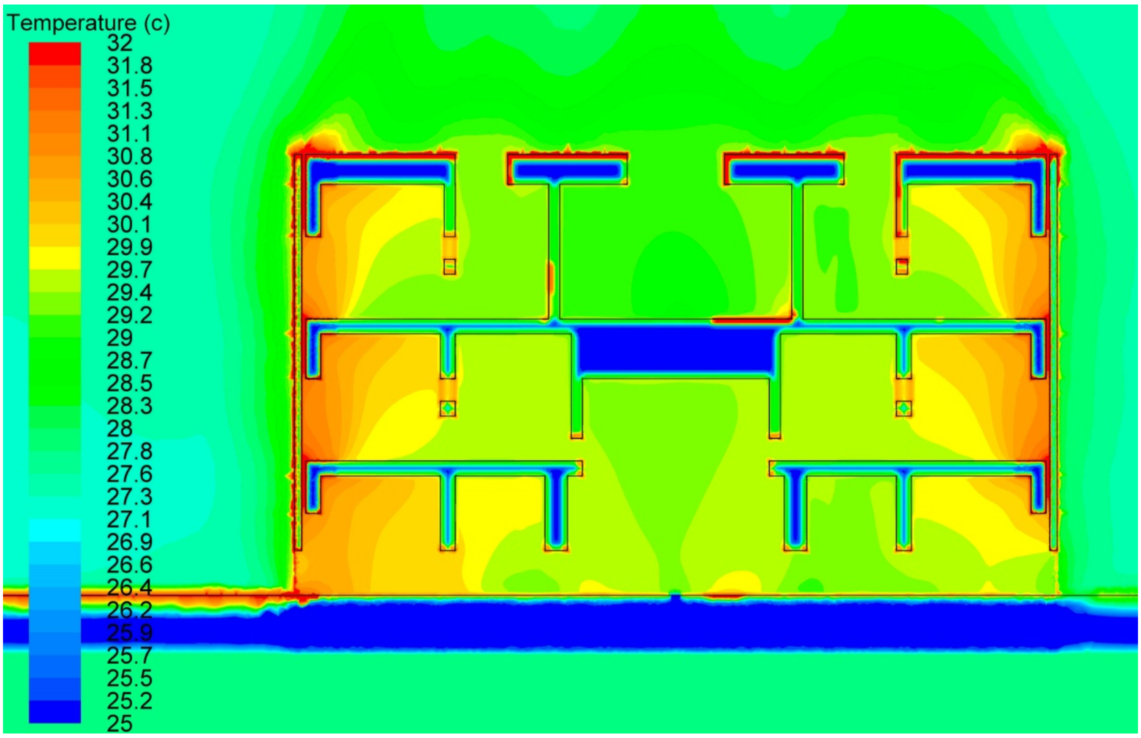

Figure 13: 12 a.m., temperature on longitudinal section.

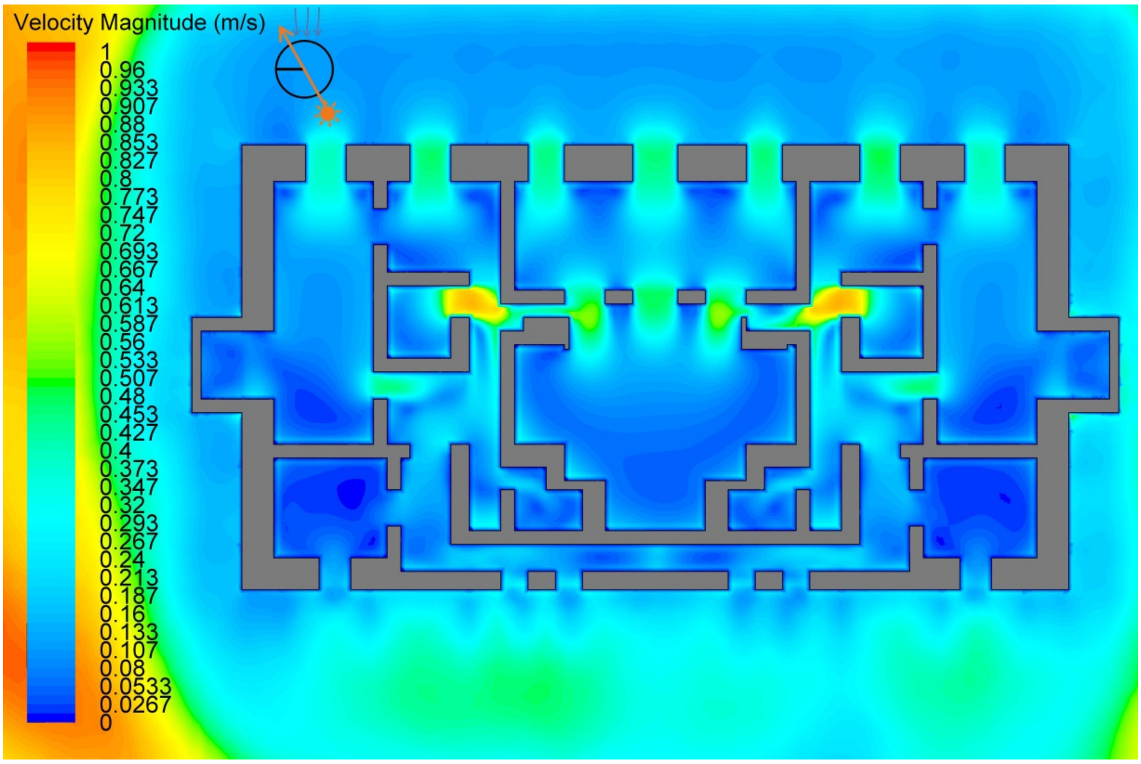

Figure 14: 3 p.m., velocity on second floor.

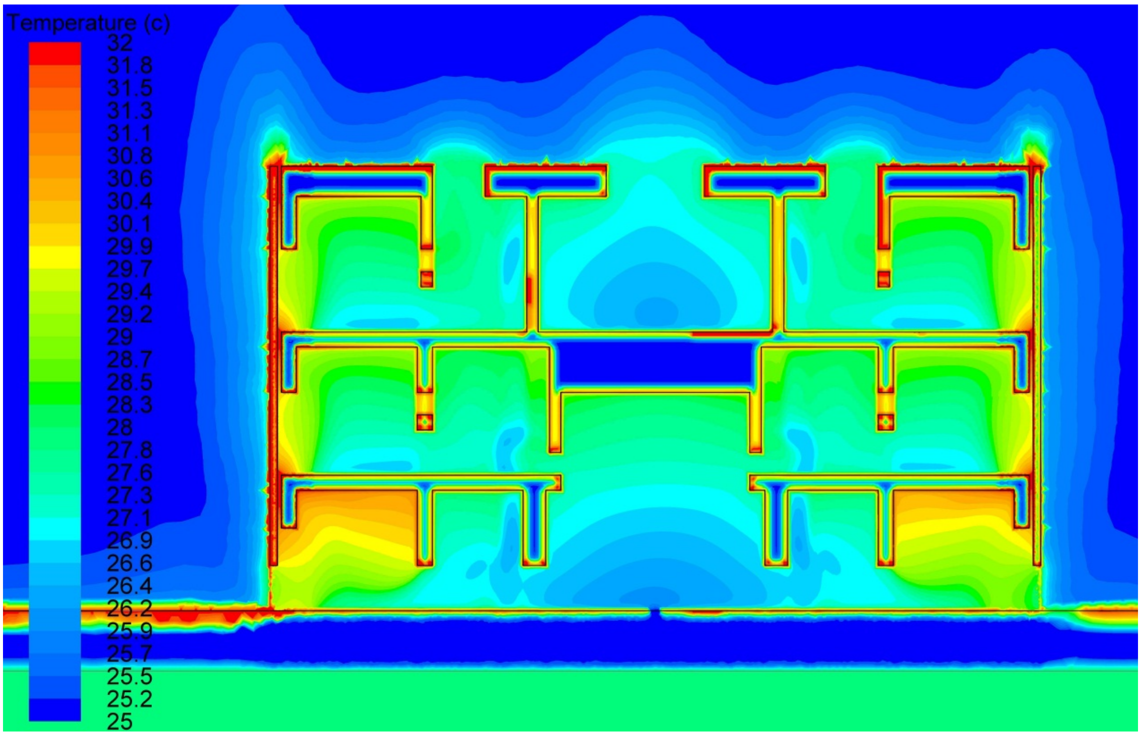

Figure 15: 3 p.m., temperature on longitudinal section.

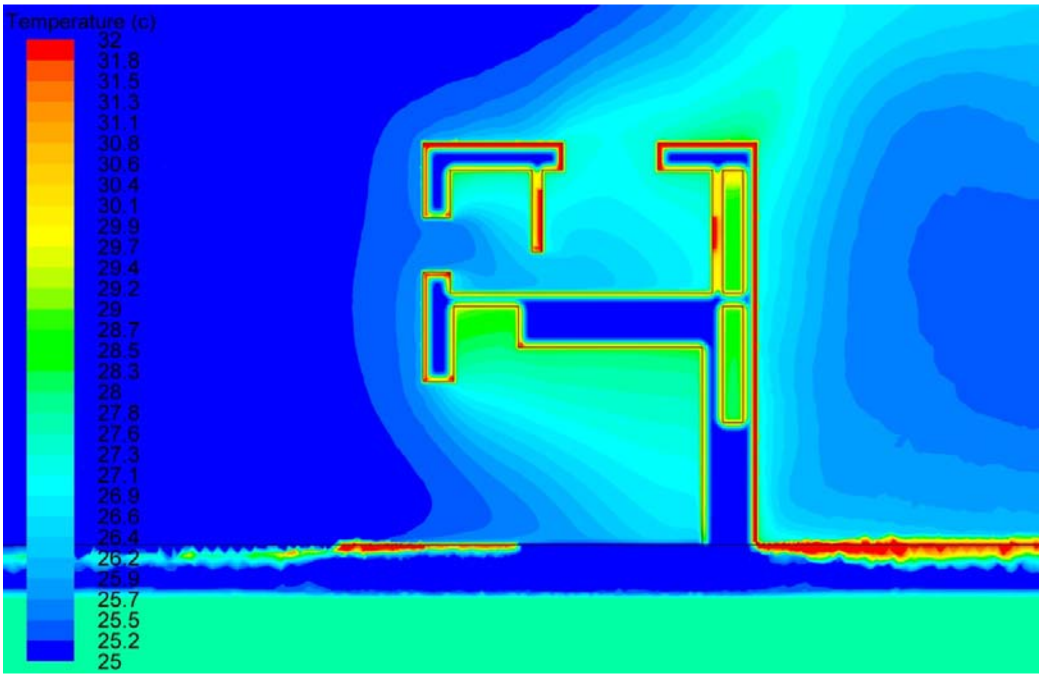

Figure 16: 3 p.m., temperature on cross section.

The upwind rooms, thanks to the shape of the openings, are the most cooled, especially the lobby (the Fountain Room), at the ground floor, and the corresponding room above, where the highest temperature is 27°C (Fig.16). From the Fountain Room, which is in overpressure due to the wind effects, the air is transmitted to the adjacent areas on the ground floor and first floor at a maximum speed of 0.85m/s. The western locals, are warmer, because the breeze comes in them with less intensity and after being heated (Fig.17).

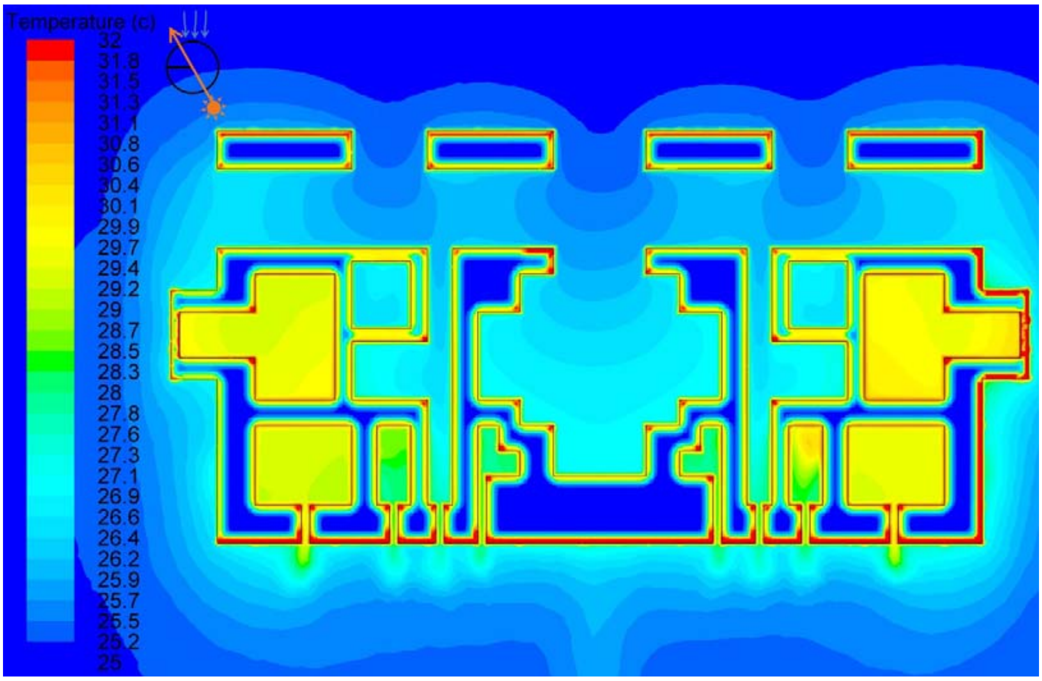

Figure 17: 3 p.m., temperature on ground floor.

During the three hottest hours of the day, the climatic conditions remain substantially unchanged (Fig.15-16).The *Salsabil* and the channels on the lateral foreparts are ineffective for the purposes of the building climate control: the particles of water sprayed from the *Salsabil* produce an evaporative cooling which relates a very small volume of air, high only a few centimeters, that is not sufficient to cool the entire air volume of the Fountain Room. The effects of the natural ventilation are prevalent and generate an overpressure which drives these particles towards the bottom wall of the room (Fig.16).

Furthermore, there is no extraction of fresh air present in the central locals by the laterals channels, because of the reduced section (120x20cm) and because of the excessive drop pressure through the openings, transmit at higher levels only the hot air accumulated near the inlet section (Fig.13), even when there is an excess of pressure caused by sea breeze (Fig.15).

Conclusions

The analysis of the results obtained from simulations on the Zisa Complex shows the thermodynamic behaviour influenced by the room position and the wall stratigraphy finalized to indoor control, as it’s possible to see in many old buildings.

It has been observed that most of the elements present in the Zisa complex respond to the functions assigned to them in literature, and some of the hypothesized phenomenon have been verified by the results (building orientation, activation of natural ventilation, the presence of thermal mass, etc.).

The assumptions that consider fundamental, for the purpose of thermal comfort, the air movement inside the building for thermal gradient or pressure gradient and the control of the solar radiation effects, have been substantiated by the obtained results.

In the more stately parts of the building, in fact, there are always good thermal conditions during the day, especially in the vestibule and in the central rooms. For this reason the devices particularly effective are the arrangement of internal and external windows, the three openings in the roof, the considerable thickness of the building envelope, the north-south orientation and the eastern large openings of the portico that allow to capture the sea breeze.

The presence of *Salsabil* doesn’t provide a positive contribution to climate comfort. This presence is probably only to satisfy decorative requirements, even if it could generate positive psychological effects, as it’s often been observed in old buildings.

It is evident that the channels in the foreparts can’t be used as "ventilation pipes" or as "wind towers". They are not able to catch the prevailing winds and to pipe them into the room, also because of their shape, since the sensors are not present and the channel is unique.

Notes

1. Art historic and professor at Palermo University. Particularly skilled in Norman art and architecture.
2. Professor of technical systems and thermo-fluid dynamic measurements at Palermo University.
3. German researcher on medieval architecture, in 1991 she made specific studies and surveys on Zisa palace of Palermo.

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