Natural air conditioning design

Pool and Wind Tower,
Borujerdi House, Kashan, Iran
(photo: J. Maudlin).

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Natural air conditioning design is a sustainable strategy to meet the need of ensuring indoor environmental quality, by helping to establish indoor temperatures and humidity levels within acceptable values and guaranteeing an adequate natural ventilation flow rate.
The adjective 'natural' is to indicate that, according to the holistic perspective of sustainability, having indoor environmental quality conditions must necessarily be accomplished through passive strategies, so as to minimize the contribution of machines powered by pollutant sources. In this way the three sustainable pillars will be simultaneously met: the social, by promoting the well-being and the satisfaction of basic needs; the environmental, by preserving the biological quality; the economic, through the exploitation of natural, free and renewable resources.
Natural air conditioning design can be metaphorically defined as a dialogue: between human living and comfort needs, on the one side, and the natural climatic constrains on the other. The natural conditioned (or free running) building is the mediator who tries to reconcile the positions of the contenders.

Design architecture with natural air conditioning solution

Designing natural air conditioning means making choices about specific design variables on which the activation of the passive mechanisms that guarantee the comfort status regarding climatic conditions depend. According to scientific literature (Givoni, 1976; Szokolay, 2006; Wienke, 2008), these passive mechanisms are:

- *Building envelope / Control of environmental heat transfer*: to optimize building heat gain and loss through the building envelope.
- *Sun control*: to determine when to permit the penetration of solar radiation, to meet the heating needs, and when to prevent it, to avoid overheating in the warmest seasons.
- *Natural ventilation:* to control and promote the intake of external air without using mechanical ventilation, it has the threefold purpose of:
  1. maintaining the air healthiness (pollution, relative humidity);
  2. refreshing air and removing heat from building structures (night ventilation in the warmest seasons);
  3. enhancing thermal comfort by providing perceptible air movement (Royal Institute of British Architects, 2010).
- *Moisture control*: to prevent condensation and other phenomena of discomfort by decreasing the moisture content in confined environments, increasing the rate of moisture evaporation in hot-dry climates improves the thermal comfort sensation and the air healthiness.

Bellow are some of the design variables that influence the above mentioned passive mechanisms:

- *Building site*: the building's surroundings affect the passive mechanisms in many ways. Among those the most significant are protecting from or exposing to the prevailing winds, shadowing, or increasing relative humidity (Consortium RehabiMed, 2007) (fig. 1).
- *Building shape and orientation*: this is the external surface/volume enclosed ratio of the building envelope, also known as index of compactness, and the prevailing orientation and length in plant of the building sides in respect to the sun's motion; both these variables affect the intensity of the heat transfers between building and environment (fig. 2) (Grosso, 2005; Szokolay, 2006; Wienke, 2008).
- *Envelope materials and colours:* this refers to the thermal properties of the building's envelope in terms of thermal insulation and thermal inertia (Consortium RehabiMed, 2007; Grosso, 2005; Oliver, 2003; Szokolay, 2006). The thermal properties of the building's envelope are also determined by its finishing color, which has specific properties of absorption or reflectance of the solar heat (fig. 3) (Oliver, 2003; Szokolay, 2006).
- *Internal organization and functional distributions:* these variables regard awareness of the relationship between level and type of occupancy of a space and its geometrical characteristics, such as size and orientation (Grosso, 2005; Wienke, 2008).
  North exposed rooms are always colder than south exposed ones and east or west exposed rooms are lit and heated by the sun in particular moments of the day (Wienke, 2008).
  Orientation of rooms also determines the exposition to prevailing winds, which means activation of natural ventilation (Grosso, 2008; Royal Institute of British Architects, 2010) or thermal loss. The internal subdivision affects the ventilation, too, with respect to the greater or lesser number of obstacles encountered by the air flow passage, (Grosso, 2008; Royal Institute of British Architects, 2010).

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- *Openings*: openings are the most sensitive building elements in terms of heat transfer, both due to the low insulation capability of windows and the air input (Grosso, 2005). They guarantee the maximum exploitation of solar heat gains, (Wienke, 2008), and they also determine the activation of a natural ventilation mechanism (Grosso, 2008).
- *Special architectural elements:* architectural elements that are designed to provide bio-climatic contributions in addition to the strategies that can be adopted by the basic design variables of a building.
- In this category are listed: shadowing systems (porches, blinds, greenery, hit and miss brickwork), semi-open spaces to allow outdoor living in mild climates (courtyards, porches, galleries) wind-catcher and moisture control systems for hot arid climates (Iranian *malqaf*, greenery, ponds, fountains) and many others (Consortium RehabiMed, 2007; Fathy, 1986; Oliver, 2003) (fig. 6, 7, 8).

Climate characters and urban morphology in the Mediterranean region

By studying the Mediterranean vernacular settlements we find ourselves confronted with an extraordinary amount of lessons on the theme of living in harmonious balance with nature. The 'traditional knowledge system' (Laureano, 1995), which is a large amount of knowledge accumulated in time by the Mediterraneans through expertise, was subjected to continuous improvements and enhancements, with the purpose of trying to make the most of the weather conditions and the natural elements, if possible to turn them to their advantage, even where these conditions seemed to be extremely hostile, as in the case of deserts. Studying the Mediterranean vernacular settlements and discovering both how to face and how to stay in balance with the natural environment (natural form, climate, terrain) is a first step towards the resumption of the old continuity. Mediterranean regions, in relation to W. Koppen's classification of climatic zones (Olgyay & Olgyay, 1963) include both areas with mild climate and areas with warm-dry climate. Studies carried out in relation to different climatic zones (Dolllfus, 1954) indicate that environmental issues are more characteristic than those given by the geographic region. This assumption defines an overriding importance of the relationship between built form and climatic instances. Let's consider for example the roofs of buildings, as they are charac-

Fig. 1 Below slope houses in Setenil de las Bodegas, Spain (photo: L. G. F. Cannas).

Fig. 2 Courtyard houses oriented toward South, Quartu S.Elena, Sardinia, Italy (photo: A. Sanna).

Fig. 3 Bright buildings envelope colors in Procida, Italy (photo: M. Achenza).

Fig. 4 Below ground warehouse, Ischia, Italy (photo: M. Achenza).

Fig. 5 Different openings distribution regarding different oriented façades, San Gavino, Sardinia, Italy (photo: Ass. Naz. Città della Terra Cruda).

Fig.6 South side porch as sun control system in a courtyard house in Samassi, Sardinia, Italy (photo: Ass. Naz. Città della Terra Cruda).

terized in different climatic areas rather than in regional identities. Since belonging to a particular climate zone necessarily involves the assumption of identifying characteristics in the construction of the shape, it is interesting to note that in the two Mediterranean climatic zones the shape and type of the settlements arise in connection to the sun-wind relation, particularly in two urban structures: the compact city in hot-arid regions and the city of Hippodamian derivation in mild climatic zones.

In hot arid climates, such as the Mediterranean regions of North Africa, the Sahara desert oases in Egyptian, Libyan, but also Moroccan territories, settlements take a compact form. It is a city-building that takes advantage of the volume effect to mitigate high temperatures, that is able to interact with a climate characterized by a fairly long hyper-heated yearly period, with dry air and severe daily heat excursion. The use of water in public and private spaces is important for the effects of evaporation, which mitigates the very high temperatures. In these regions, houses tend to have a cubic shape, high thermal inertia and heavy building materials. The patio type is the most suitable for this climate, the courts are in fact reserves of fresh air, where cooling wells and gardens serve as the lungs of urban life. The walls of the introverted houses provide shade to the living spaces and to the narrow, winding and sometimes covered roads. The covered road is an important urban design element as it responds to the need to avoid glare and provide shaded and cool breaks around the village. Covering the roads also favors the creation of zones of low and high pressure that give rise to air motions triggering the Venturi effect.

The need of fresh air governs the plan of the city in places such as Marrakesh, Tunis, Damascus, where the narrow winding streets assume the same function as the courts, retaining all possible breaths of fresh air that settle during the night, in the same way as it happens in chessboard cities with wide boulevards (Fathy, 1986). While this first type of urban structure is completely adherent to the character of hot-arid climates (not surprisingly it has traditionally characterized the historical city fabric), the same cannot be said of chessboard urban planning because of the needs related to traffic, nonetheless it is widely used in contemporary urban design.

The main wind types in urban areas are: high winds, micro-climatic winds influenced by the topography and the configuration of the

Fig.7 Old *bagdir* in Fahraj, Iran (photo: F Pecchio).

city, and wind movements created by the city itself. It is clear that the last two are the usable winds, that can be canalized and deviated, and increased through architectural forms and the mutual relations between them. The more the center of the city is subject to overheating the more convective motions tend to make the air raise, and if the urban plan is a chessboard without sufficient green areas, which may serve as healthy lungs, the hot air full of dust and car fumes form a dome of pollution above the city center (Fathy, 1986): what today we call a 'heat island', a phenomenon unfortunately well known to contemporary cities.

Natural ventilation strategies in mild climate zones and Hippodamian cities

Many Mediterranean regions have a temperate climate, which is characterized by significant seasonal variations, with the consequent need to capture solar radiation and protect from winds in winter and to provide shelter from the sun and catch the breeze in summer. From the theoretical point of view this climate zone has the opportunity of taking advantage of a free urban plan, with buildings that blend with nature and open spaces (Olgyay, 1963).

It is interesting to note that Hippodamian planning has been applied since ancient times both in arid regions with a hot-dry climate and in regions with mild climates (Ischia, Cumae, Sicily, Naples). Of course the choice was not made following climatic characters, as it happened in the case of the compact city. And to understand the appropriateness we need to match the orthogonal grid to the choice of the orientation of the Cardo-Decumanus system, and then, consequently, of the rows of terrace houses. It is generally accepted today that the optimal orientation of houses in these climates is facing south, because this provides the best exposure to sunlight during the winter and allows easy shading in summer. Such an approach requires streets, the Cardi, and rows of terrace houses extended along a east-west direction, and main arteries, the Decumani, aligned in north-south direction. We find only in some cities an orientation of the streets (and rows of houses) from east to west, for example in Heraclea on Latmos (Asia Minor), Apamea (Syria), Olynthus, Priene and Rhodes.

In many other cities the orientation is different, and it is also observed how the urban scheme has been applied indiscriminately to sites in strong and medium slopes as well as to those on plains, near the coast or on a low hill. The problem of the orientation of the roads with respect to the wind has been considered by Hippocrates but also by Vitruvius, who indicated also an operational mode, actually very approximate, showing the recognition of a problem evidently not yet solved, and delegated only to passive cooling systems applied to individual buildings.

The city of Priene, called 'Solar City', with its north-south Cardi and east-west Decumani, must have certainly adopted into the buildings technical-constructional devices able to mitigate the effects of the excessive solar radiation due to exposure to the south, creating situations of comfortable environmental micro-climate.

Indoor air movements in vernacular architecture

The study of vernacular architecture gives us essentially two possible ways to produce natural air ventilation in buildings:

1. Use flows generated by pressure differences

The wind that hits a building determines areas of high and low pressure between upwind and downwind sides, with a pattern of flows that depends on the geometry and size of the building rather than on the air velocity. In vernacular architectures we can observe how these pressure differences are used to channel and change the air flows, essentially in two ways:

Fig8 Moisture control and shading system in a patio, Andalusia, Spain (photo: L. G. F. Cannas).

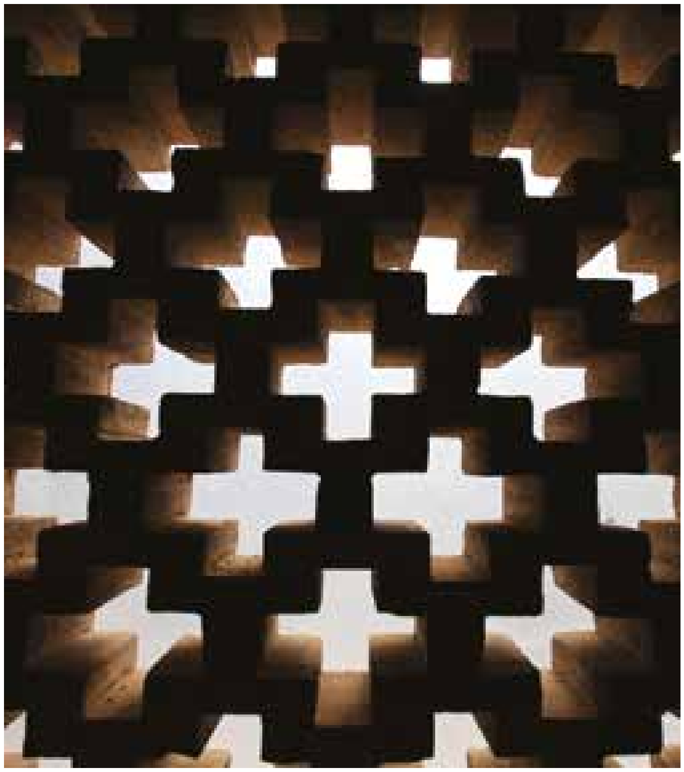

Fig.9 *Harouniye Mashrabiya* A adobe screen inside the Harouniye just outside Mashhad, Iran (photo: S. Alnuweiri).

a) by obtaining specific flows of the internal ventilation (cross ventilation): the ventilation flows between the upwind and downwind sides are directed through the external configuration of the openings, and are obviously more effective when the entry openings are in the high pressure side and the out openings in the low pressure side: the greater the pressure difference the faster is the flow. Except the size, also the position of the openings and the internal partitions that interact with the air flow are determinant. The air flow analysis in vernacular architecture often determines shapes and proportions of entire sections of buildings.
b) by taking advantage of the 'Venturi' effect: the Venturi effect is obtained when the pressures between inlet and outlet have the maximum possible difference, producing therefore the maximum air flow speed, or using a small low opening upwind and an very large upper opening downwind. There are very interesting solutions designed in vernacular architecture after this principle, and in particular: the lodges (*maqaad*) between the courtyards of the palatial architecture in Cairo and a very interesting use made by Fathy for the project of a *loggia* in the village of New Gourna. The *loggia* opens into a courtyard on the downwind side and is almost closed in the upwind side with a wall having two rows of small openings. The airflow over and around the building produces a low-pressure area on the downwind side while inside the lodge air suction is caused by the Venturi effect. For the same purpose a sequence of small holes, called *claustra*, are often used in vernacular architecture in all Mediterranean countries, offering various decorative patterns according to the different regions. They represent the precursors of the screening panels in use in contemporary architecture.

2. Exploiting convective flows

The convective flow exploits temperature differences, generating a 'chimney effect', which is most powerful the bigger the temperature difference and the bigger the difference in height between the point of release and that of air expulsion. The most interesting example of the usage of this principle in vernacular architecture is certainly the *malqaf-Qa'a* system in the Arabic-Egyptian house, which has also given rise to various experiments in contemporary architecture.
The need for a device especially designed to capture the prevailing breezes evidently arises when the orientation and placement of the house does not allow flows generated after pressure differences. It is no coincidence that these devices are present mostly in urban en-

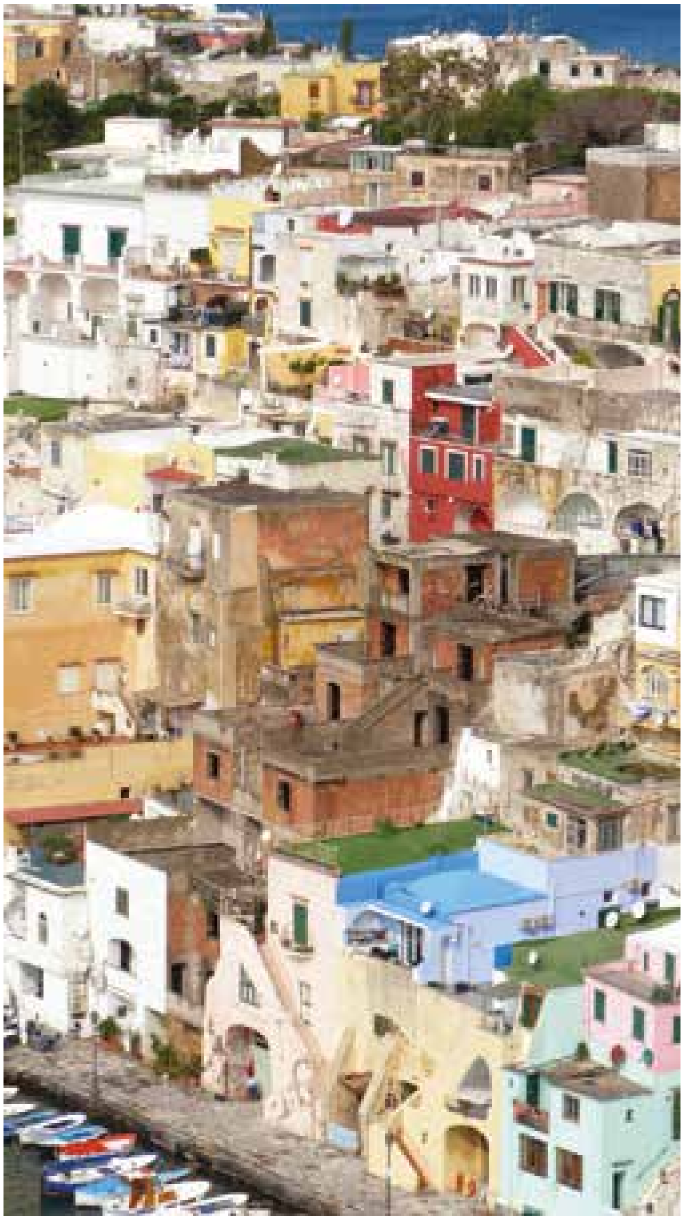

Fig. 10 Procida, Italy (photo: M Achenza).

vironments, where the location, placement and volume of buildings is predetermined, or in buildings where the optimal sun orientation collides with the proper one in respect to the winds. The malqaf has ancient origins (it dates back to the Eighth century. BC, and was certainly used by ancient Egyptians). It raises to catch the high winds of the city and consists in a high turret, which can be single-or multi-directional depending on the direction of the breezes and regional traditions.

In the system of the house in Cairo the air that the *malqaf* picks up becomes a flow thanks to the extractive function done by the *Qa'a*, the central space of the house, whose roof and section are designed to operate as a powerful wind-escape. The flow is enhanced and accelerated along the way, through a large number of accelerator mechanisms placed on the stream channel of the malqaf, but also within the Qa'a (it is worth noting the important role played by water in the basins and fountains, which also bear a strong symbolic value). On the other hand one of the examples of a primitive use of convective air flows, less sophisticated but equally effective, can be found in the Roman house, in particular in the *tablinum*, crossed by the breezes whose flow is accelerated by temperature differences that are created between the sunny and shady peristyle atrium, as it is in the takhtabush, between the courts of the houses of medieval Cairo, which, not coincidentally, were always one shady and humidified by the vegetation and the other sunny and warm.

Lessons from vernacular heritage to contemporary natural conditioned buildings

It is not appropriate to blind copy the example of the historical vernacular architecture for the natural air conditioning design. The historical vernacular buildings were the product of social and technological conditions very different from those of today, designed to meet comfort standards that were also quite different. For example, regarding the average climate of the Mediterranean basin, Butera says that the comfort temperature for inner winter conditions was 16°C, in contrast to the 21-22 °C we find necessary today (Grosso, 2008). This was due essentially to the much more active lifestyle (Grosso, 2008). Beyond questions of detail, it is possible to take useful indications by studying vernacular architecture for the natural air conditioning design, provided that the designer is able to decline those principles from time to time as a function of peculiar needs. To conclude, it is worth mentioning that the most useful lesson that could be learned from vernacular architecture is the ability to choose the best possible bio-climatic strategies in relation to other constrains. As it is not possible to pursue only the best natural air conditioning strategy, it is necessary to learn the art of compromise with which vernacular architecture skilfully combined social needs (economic activities), techniques (local resources, landscape) and, in fact, climate control.