NATURAL COOLING IN HISPANO-MOSLEM RELIGIOUS ARCHITECTURE: THE CASE STUDY OF THE MOSQUE OF CORDOBA

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ABSTRACT The Mosque of Cordoba is the best example of the Islamic religious buildings that survived in Spain. Its typology corresponds to a mosque of a large scale with the common plan of the early Muslim art. This model became an architectural reference for the mosques of Western Islam. The paper presents the results of measurements undertaken to assess the environmental performance of this building.

1 Introduction

The city of Cordoba is located in the valley of river Gualdalquivir. It has a latitude of 37°51' North and 110m altitude above the sea level. Its development has always been conditioned by the river. From a climatic point of view, the river Gualdalquivir tempers the extreme summers of southern Spain. The climate of Cordoba is generally considered as Mediterranean, with certain singularities. It has a continental component and its summers are characterised by their length, heat, dryness and intense solar radiation. The temperature gradient between winter and summer is approximately 20°C. During summer, the mean air temperature is about 30°C and is usually accompanied by a rain shortage.

Furthermore, there is a strong contrast in the day-night temperatures, as a consequence of the aridity of the area. The annual sunshine hours are among one of the highest in Spain and Europe: 2500 hours, while in July the global irradiance on the horizontal is around 7.500 kWh/m² per day. Another particular feature of the climate is that winds normally blow along the river direction, because of the canal effect of the valley (Fig.1).

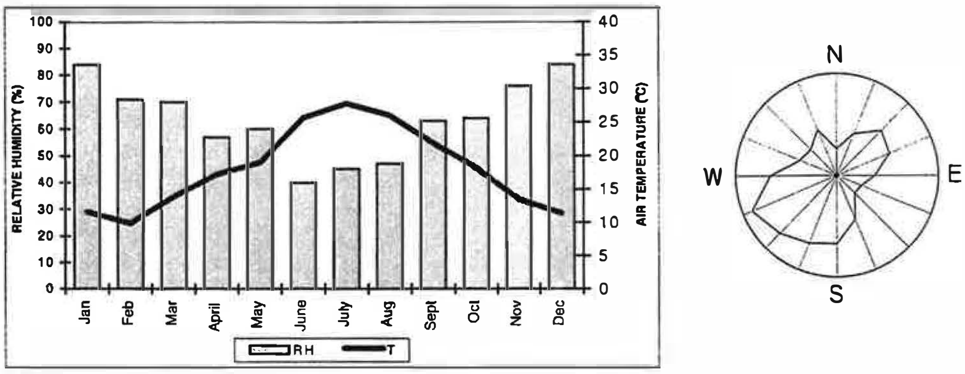

Fig.1 Annual thermal conditions and mean winds in Cordoba

1.2 Historical Introduction

Cordoba was the capital of the Umayyad Caliphat created by an escaped prince from Syria. The dynastic change in the Islamic empire from the Umayyads to the Abbasies of Baghdad allowed the young Abd-ar-Rahmān to form an independent state in the province of al-Andalus. The influence of the new kingdom would extend to the North of Africa and part of the Mediterranean area. During this Sultanate, from 756 to 1030, the region under his territorial control experienced political and social stability. Cordoba became the largest city in Europe and was compared with Constantinople and Baghdad in prosperity and cultural level. This permitted the formation of a singular and sophisticated civilisation that extended until the XV century, whilst the rest of the Peninsula and Europe sank in the dark Medieval age.

1.3 The mosque type

The Great Mosque of Cordoba was built in the caliphal period and constitutes the most important Muslim religious construction in the Iberian Peninsula. Even today, it is one of the biggest mosques in the Islamic world. For the Umayyad monarchy, this building was a symbol of its power and represented the cultural and technological level achieved. At the same time, it is the result of a symbiosis between the Visigothic and Roman heritage in the Iberian Peninsula, on the one hand, and the cultural influences that the Muslims brought from the Persian and Byzantine empires, on the other (Fig.2).

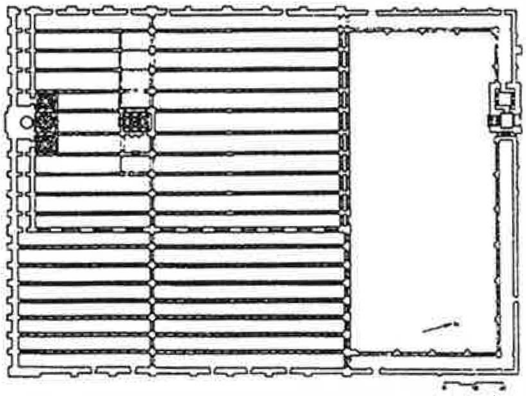

Fig.2 General plan of the mosque of Cordoba before the Christian intervention (from Moneo, R. 1985)

The construction took more than 200 years to complete and was carried out in four periods from 785 to 988. Its typological reference is the Mosque of Damascus, which also incorporates influences from the Roman basilica and some Christian architecture. However, in a mosque, the spatial idea had to be partially modified because, in this new religion, the relationship between humanity and God had also changed. The individuality of the ritual of prayer and the diffuse idea of God in Islam translates into a single neutral space without any axis or formal characterisation. An amazing uniform rectangle of 128 by 178 metres is the result of this idea. Internally, it consists just in a series of perpendicular naves to the *quibbla*, the prayer wall turned towards Mecca. The *quibbla* houses the *mihrab*, a small niche inspired by Christian apses that contains The Koran. Only four domed chapels, which are elevated above the roof level, signify the presence of the *mihrab*. In addition, they perform functions similar to skylights by introducing air and daylight into the general darkness of the sanctuary.

The complex incorporates a large patio or *sahn*. It could be used as an occasional oratory extension, but functioned as the entrance to the mosque and the antechamber of worshipping. As well as relaxing before and after prayer, the ritual ablutions formed part of its functions. Even today, the Patio of the Oranges is the largest public space in the old town of Cordoba. It is surrounded by porticoes in its three external sides and also contains abundant water and vegetation. In the past, water was conducted from a nearby spring into a cistern located at the centre. The water reservoir fed two fountains that irrigated the garden. Palm, orange and olive trees, mirth, cypress and other vegetation lay in rows alienated to the internal columns. In the time of the Sultanate, the patio and the sanctuary were united by nineteen arches, which corresponded to the end of the naves. Later on, this arcade was blocked up by Christian chapels, thus breaking the smooth line of an almost continuous open space. This intervention disturbed the narrow and intimate relationship between the interior and courtyard.

2 Environmental hypothesis of the case of Cordoba

Originally, a mosque was simply an open-air enclosure. The necessity for worship to be oriented towards Mecca forced them to build the *quibbla*. A roof was incorporated as solar control. Defining the limits of the covered sanctuary with walls was the following stage. But the early idea of a simple enclosure still persisted. Thus the mosque, independently of its cultural influences, was enriching itself and emerging as an architectural type. Therefore, in this typological evolution, some environmental strategies were assumed necessary due to the fact it still performs as a unique covered space with controlled ventilation. In the Cordoban case, however, this scheme was altered later on. In order to reconstruct its environmental performance, it is necessary to imagine it without the Christian attachments and with its patio closely linked to the sanctuary (Fig.3).

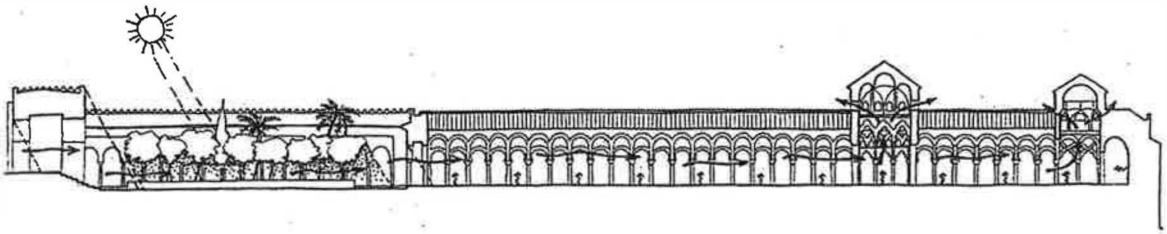

Fig.3 Environmental hypothesis through the North-South section of the Mosque

2.1 The Patio of the Oranges

The Patio's character of a transitional space between the exterior and the sanctuary would have an environmental parallelism. There, a microclimate able to mitigate the hard external climatic conditions is generated. Evaporation and evapotranspiration, from the water and vegetation respectively, and the profusion of shadow are responsible for a more moderate temperature and humidity. Two different effects contribute to the general cooling within the patio. Firstly, solar protection is the system of heat-gain control. The porticoes and the canopy created by the rows of trees keep the ground and the space under the trees always in the shade, thus avoiding the risk of overheating by sun radiation. On the other hand, evaporative cooling contributes to heat dissipation. The vegetation and water provide higher moisture content to the air, lowering its temperature. The cooled ambient would have expanded to the sanctuary through the arcade. These arches were kept open or shielded by a curtain, which acted as a thermal screen (Fig.4).

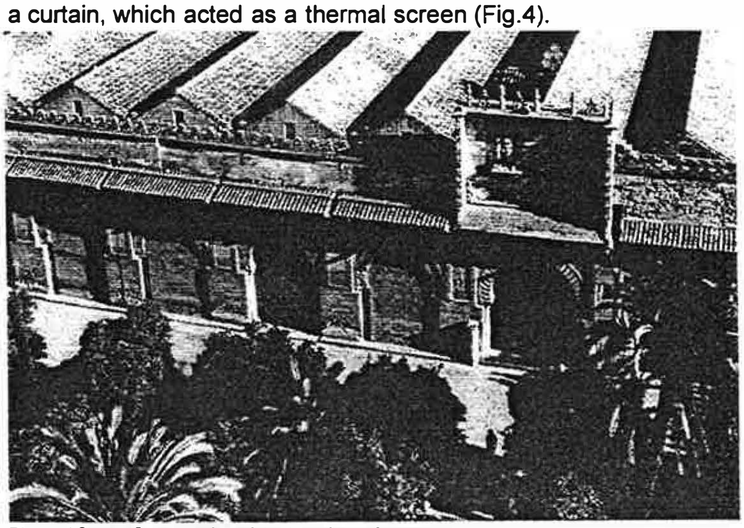

Fig.4 View of the patio with the closed naves

2.2 The sanctuary

The sanctuary is in penumbra, with few openings to the street: there is no sun penetration. The intimacy of the religious ceremonies requires that isolation. In addition to the patio link, there are some small perimeter window-lattices distributed regularly in the three external walls. Moreover, the four chapels in front of the *mihrab* are surrounded by zenith window-lattices. In this manner, cross ventilation could be established between the exterior and those lattices. This airflow was caused by stack-effect and wind pressure. The windows' position in the upper walls, and temperature difference between inside and outside drive the stack-effect. The dominant winds in Cordoba would cause a breeze from the patio to the interior most of the year. The sanctuary would have a permanent fine draught (Fig.5).

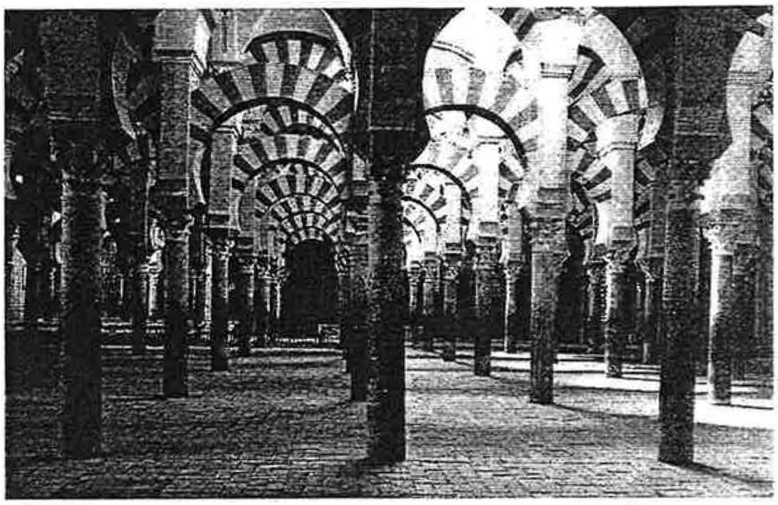

Fig.5 Internal view of the sanctuary

The sanctuary itself makes use of two strategies for summer comfort: heat-gain control and heat-dissipation effect. Heat-gain control involves, on the one hand, the thermal insulation provided by external walls and roof, and, on the other, avoidance of solar incidence. The lattices are cut out of thick walls and their elaborate patterns prevent solar penetration, as well as filtering dust. The manner in which the building dissipates heat is the most efficient way to provide freshness. In this mosque, heat-dissipation is of radiative cooling and nocturnal ventilation. Today, the ventilation rate inside is reduced because of the arcade closure. The high thermal capacity of the walls, floor and roof, however, is able to keep the air cooled in the hottest moments. During daytime, the building envelope acts as a heat sink thanks to its accumulated nocturnal coolness. The materials are, in general, of high thermal effusivity, providing high thermal inertia. The internal volume is in contact with the surrounding envelope through large surface area.

3 Analytical work

3.1 Data-logger measurements

Three humidity and three temperature data-loggers were installed at the sanctuary, patio and exterior in August 1998 during the hottest period of the year (Fig.6). The results show that internal air temperatures and humidities were very stable during the four days of the experiment in comparison those outside. The internal temperature range was between 26.5°C and 28.5°C, with relative humidities from 45% to 65%. This shows that the sanctuary provides thermal conditions of comfort for the whole period. The two external measurements are both very high, though the situation is slightly milder in the patio. There, comfort could be achieved just by increasing the ventilation rate.

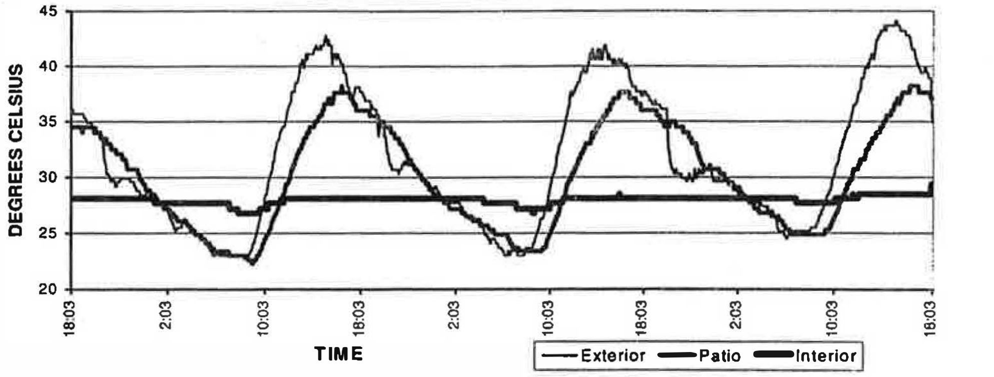

Fig.6 Data-logger-temperature readings. 18-21 August 98

The thermal inertia influence is noticeable in the delay produced in reaching the peak temperatures. This delay can be more than six hours between the interior and exterior. The Patio takes also more time to be heated because of its shaded surfaces. Applying the dry-bulb temperatures and relative humidity values, obtained on the 19 August 99 at 3 p.m., to a psychometric chart, it is possible to elaborate the following table:

Table 1 Comparison of temperature, humidity and cooling potential

	Dry-Bulb Temperature (°C)	Relative Humidity (%)	Absolute Humidity (g water/ kg dry air)	Wet-Bulb Temperature (°C)	Evaporative Cooling Potential (Tdb-Twb) (K)
Exterior	42.8	16.0	8.3	22.3	20.5
Patio	36.6	21.7	8.5	20.4	16.2
Interior	28.1	55.9	13.3	21.4	6.7

Similar absolute humidity values in the exterior and patio indicate that there is indirect evaporation cooling. It follows that there is no extra water contribution per kg of dry air. The exterior-patio difference of evaporative cooling potential indicates that 4.3 K has been cooled by means of evaporation. But the exterior-patio difference of dry-bulb temperature is 6.2 K, which is 0.9 K higher. This shows that the rest of the cooling, 0.9 K, has been achieved by the heat-absorption of the shaded surfaces of the patio.

Although the relative humidity in the patio usually drops later than the external air, the patio is unable to maintain a higher relative humidity percentage. This could be due to the disappearance of some of its vegetation and the dryness of the fountains and channels when the measurement was carried out. Also the shape of the patio is not ideal to shelter the microclimate created there and so it is quite exposed to the dry winds. In the interior, however, the moisture content of the floor and perimeter walls has substantially reduced their evaporative cooling potential. In fact, they store water in the most humid moments or take it from the ground. When internal temperature increases, the moisture of the surfaces evaporates, and materials' porosity makes that more water keeps humid the surface.

3.2 Ventilation simulation

The computer program used for the ventilation simulation was Lesocool (EPFL 1996). Internal gains were based on 100 occupants and some solar heat-gain in the morning and early evening. The program takes account of stack effect only; it does not consider airflow generated by wind. Simulation results are consistent with measurements (Fig.7). The cooling potential from night ventilation is represented by the heat-flow chart (Fig.6). A maximum of 42 kW is eliminated per hour as result of ventilation. During daytime, it is convenient to keep the building because external air can heat the interior. To keep it fresh, it is more efficient to make use of the thermal-mass influence. This situation is typical for a continental or semi-continental climate, where solar radiation is the most decisive factor in air warming.

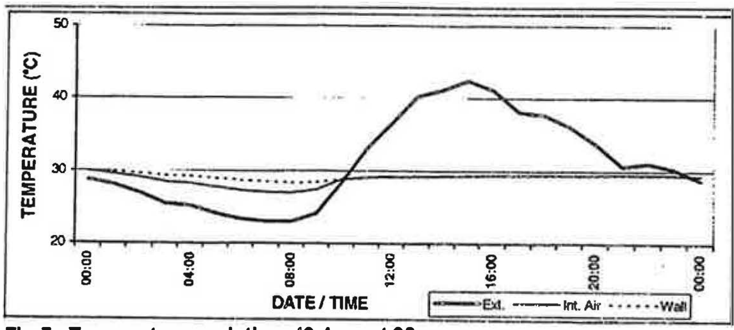

Fig.7 Temperature evolution. 19 August 98

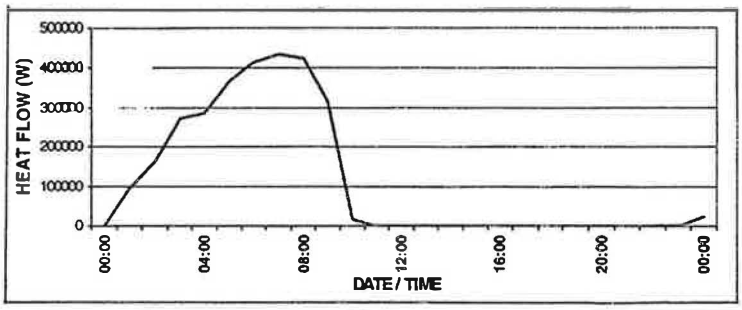

Fig. 8 Heat flow due to ventilation. 19 August 98

4 Conclusions

The Mosque of Cordoba is an exceptional example of a building well adapted to its thermal conditions. Its basic architectural pattern is enhanced with decorative effects and climatic attention. From an environmental point of view, the most outstanding lesson is the interaction between ventilation and thermal mass, as well as the layout and orientation that favour natural cooling.

Despite the fact that the sanctuary temperatures are very steady, controlled ventilation would be desirable. In the Islamic religious ceremonies, a slight air movement would produce a psychological sensation of cooling. Furthermore, airflow was absolutely necessary to remove an excess of heat-gains and moisture. Air movement, particularly night ventilation, is also indispensable in order to cool the massive structure. The bioclimatic role of the Patio of the Oranges has been at a loss with the arcade closure to the sanctuary. The narrow relationship between both spaces used to bring the modified microclimate of the patio to the interior, producing a singular architectural and environmental dialogue. Eventually, the patio would need much more vegetation and water to develop its function as a transitional space between public life and worship.

5 References

Laboratoire d'Énergie Solaire et de Physique du bâtiment (1996). *Lesocool Manual*. École Polytechnique Fédéral de Lausanne, Lausanne.

Moneo, R. (1985). "La vida de los edificios. Las ampliaciones de la Mezquita de Córdoba". *Arquitectura. Revista del COAM*, n. 256. Madrid.

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