NATURAL COOLING IN HISPANO-MOSLEM RESIDENTIAL ARCHITECTURE: THE CASE-STUDY OF THE COURT OF THE LIONS AND THE COURT OF COMARES IN THE ALHAMBRA (GRANADA)

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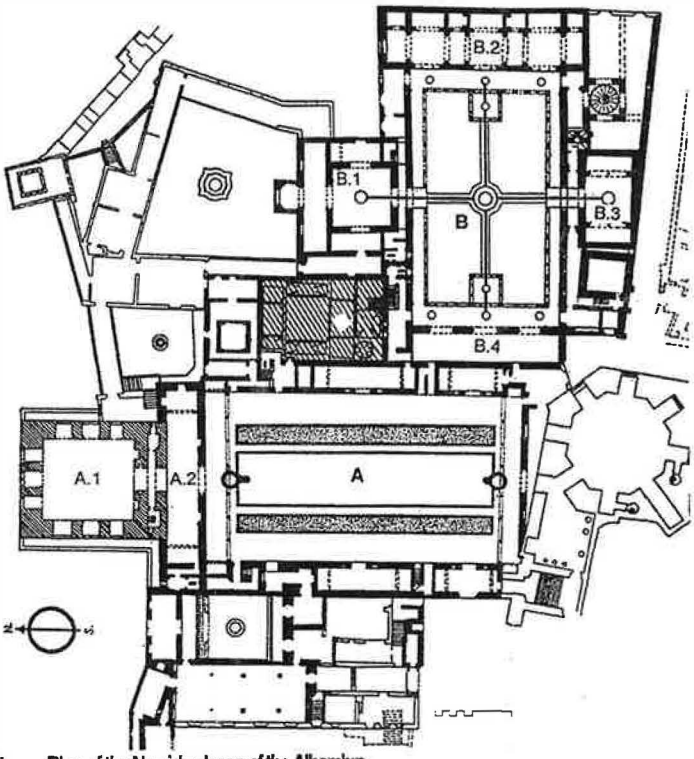
ABSTRACT The XIV-century Palaces of the Lions and Comares constitute the principal residential complex of the Alhambra in Granada. Both are distributed around gardens enclosed in courtyards, originally with abundant vegetation and water. This paper includes a series of measurements carried out in the rooms and the courtyards in order to contrast the different microclimates, as well as some solar-penetration diagrams. It also focuses on the analysis of the Hispano-Moslem residential type in relation to its environmental performance.

1 Introduction

Granada is located at 37°10' N latitude and 683 metres above sea level. The altitude gives a continental component to the climate, thus winters are cool with average temperature between 6 and 10°C. Dominant winds come from the South and their median annual speed is around 5 m/s. That makes Granada the coldest location in southern Spain. Summers, on the other hand, have the character of that latitude: long, dry and hot, they often have uncomfortable temperatures due to the strong solar radiation. Granada's location is protected from sea breezes, which could moderate its extreme thermal fluctuations. As a consequence, by afternoon, temperatures rise above comfort. As regards topography, Granada is surrounded in its south and east sides by a range of high mountains, the Sierra Nevada, where snow keeps most of the year. The town is located in the fertile plain that spreads out from the hill of the Alhambra, below Sierra Nevada. This low-lying land is watered by two rivers with their springs in the nearby mountains.

The Alhambra is a fortress that occupies a small hill and dominates its surroundings. The 75 metres of difference altitude between the rest of the town and the Alhambra make it possible to use the fresh mountain-winds for ventilation. Within the Alhambra, a small city was established to serve the monarchy (Fig.1). Its nucleus was constituted of six palaces with functions of court and residence. Unfortunately, only two palaces remain to this day: the Court of Comares, or Myrtle, and the Court of the Lions. Their constructions were carried out during the last Muslim sultanate in the Iberian Peninsula (1238-1492). To the North side of the existing fortress, the Nasrid-dynasty kings attached these two palaces to enjoy the views over their kingdom's capital and its fertile plain. The first built was Comares (Fig.2). It has the typical residential disposition, but on a large scale. Its courtyard includes a large pool framed by myrtle hedges. As with the Lions, vegetation used to be plentiful according to chronicles. Plants and trees were partially removed because of the moisture effect on the foundations. Thus these patios were actually enclosed gardens. The construction of the Court of the Lions started immediately after the Comares (Fig.3). The sense of privacy and sophistication of the last Nasrid architecture is reflected in the complexity and originality of this Court. Its biaxial patio has, at each extreme of the small axis, two *qubbas*, or towered chambers, one in the North (Hall of the Two Sisters), and one in the South (Hall of the Abencerrajes). At the ends of the perpendicular axis, there are two more chambers: the Hall of the Kings (a three-

qubba-addition) and the Hall of the Muqarnas. A continuous portico protects the four façades of the patio. Water canals emphasised the cross-shape of the Patio. It flows from the sources in the interiors to the central fountain along the canal-axes.



A. Court of Comares
A.1 Hall of the Ambassadors
A.2 Hall of the Boat

B. Court of the Lions
B.1 Hall of the Two Sisters
B.2 Hall of the Kings
B.3 Hall of the Abencerrajes
B.4 Hall of the Muqarnas

Fig.1 Plan of the Nasrid palaces of the Alhambra

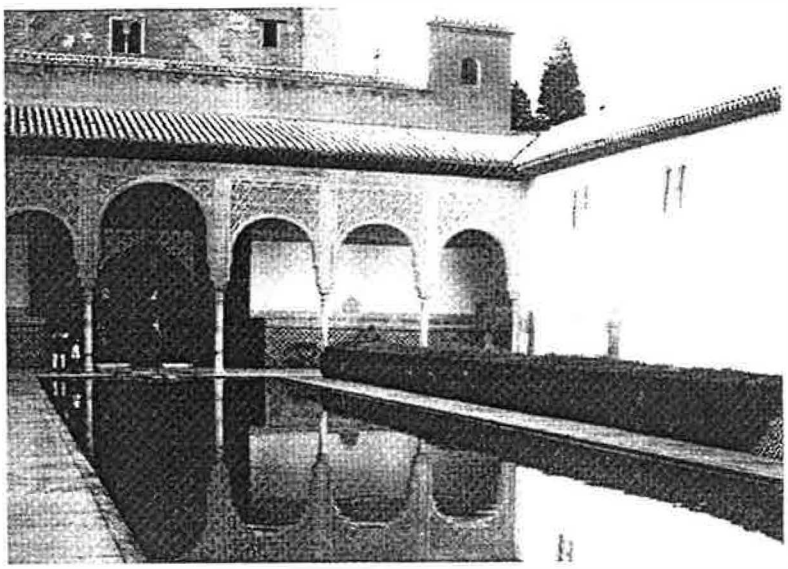


Fig.2 Court of Comares

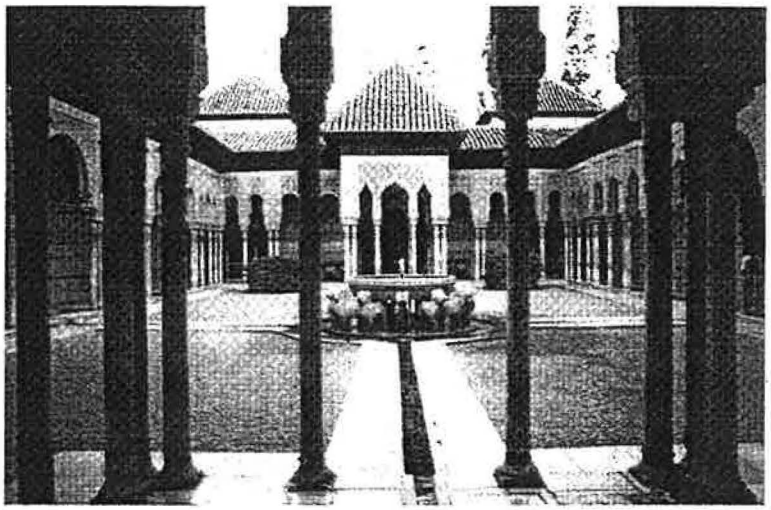


Fig.3 Court of the Lions

2 Passive cooling strategies

2.1 The Hispano-Moslem residential architecture

Islamic residential buildings in Spain have a similar layout. Both, houses and palaces are distributed around a courtyard elongated along the North-South axis. The different orientation of rooms around the patio allows alternative uses, depending on the season and the time of the day. Despite this spatial flexibility, the main apartments tend to face South.

There are various interpretations about the origin of this disposition. In general, before the Muslim rule, the courtyard pattern applied commonly in the Middle East, Persia, and Anatolia. It would have been the result of an environmental adaptation in these regions. But the most important influence, especially in the Mediterranean area, comes from the Greek-Roman house, whose *peristylium* was adopted as the patio form. In any case, after eight centuries of Islam in Spain, the domestic type acquired its own character and singularity.

The Hispano-Moslem dwelling is closed to the exterior for privacy. Thus, the patio became the most important part of the house. Household life developed around it as a distributor and an open-air "living room". Patios always contain vegetation and water elements: fountain, pond or canal, as well as one or two porticoes. The main difference between houses and palaces is the scale as their features and proportions remain the same. The house is larger or smaller depending on the social class of the owner. Another singularity is that palaces add a special architectural element, the *qubba*, basically a throne chamber shaped as a tower. The *qubba* always includes perimeter and zenith lattice-windows to ventilate and illuminate. At the same time, it constitutes the most important and symbolic part of the palace, which is perceptible in its decoration, illumination and broad vistas.

2.2 Solar defence

In the Palaces of the Alhambra, solar protection is obtained by reflecting sun rays with clear colours and, especially, preventing sun entrance to the interiors. This technique involves small controlled openings, protective devices such as porticoes and the general building orientation with respect to the sun.

A common method of defence from sun and use of its energy in winter was facing to South. Main apartments were always located in the North patio wings and thus, pointing to South. Moreover, deep porticoes give extra protection to their walls and openings. In summer, in this latitude at midday, the sun is almost overhead and, consequently, does not penetrate into rooms. At the same time, southern orientation does allow warming the interiors in winter. This situation occurs in Comares, where main rooms are in the North wing and protected by a deep portico. Its elongated patio also favours solar penetration in winter (Fig.4).

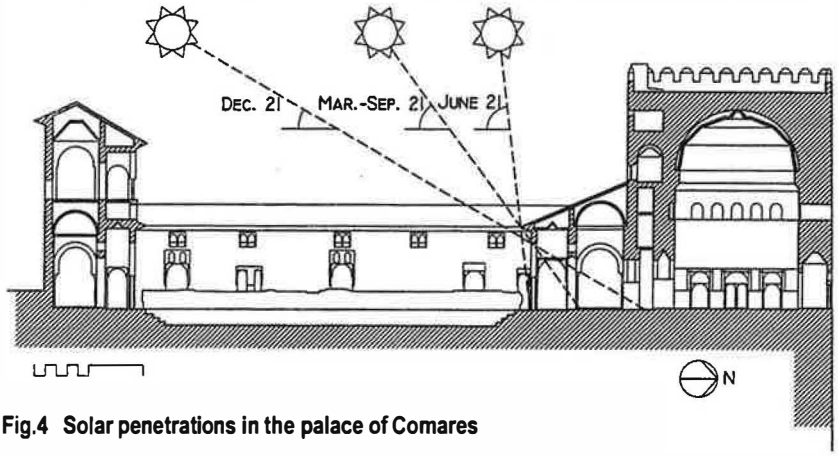


Fig.4 Solar penetrations in the palace of Comares

In his "Treatise of Agriculture", the XIV-century reporter Ibn Luyûm defines the conditions of an Andalusian country-house, including some orientation advice: *"Choose the dominant position to built a house and garden, to keep better watch and defend it. It should face the midday sun, the door should be placed laterally and the well or pool should be slightly raised, or better still, instead of the well there should be a canal running water under the shade of trees and plants."* (Eguaras Ibañez, J. 1988). Although Luyûm recommended South orientation, in the Lions, the main axis changes to the East-West. But an internal perimeter portico protects the rooms according to the sun-inclination. For example, in its North and South wings, it is around two metres, whereas in the East and West, is about three and a half metres deep. Furthermore, these wings are shorter and have extra-protection from two small pavilions.

2.3 Heat dissipation: ventilation, evaporation and radiation

Despite solar protection, by the afternoon interiors can become hot. Heat dissipates by passive cooling techniques such as ventilation, evaporation and radiation. Furthermore, the building design optimises cooling effectiveness.

Apart from the bioclimatic character the gardened patio has itself, the way the rooms are laid out influences their thermal conditions. Thus, the addition of the *qubba* is essential, as well as, the portico that normally placed between the *qubba* and the patio. A characteristic sequence of patio-portico-tower is established. In the Palace of Comares a room is also inserted between the tower and portico. Regarding the Lions, two of these series are set up in the North and South wings respectively. The environmental hypothesis attributed to this sequence is that the *qubba* functions as ventilation tower for the complex. Due to its shape and upper fenestration, airflow is generated from the patio to the tower windows. It is caused by stack effect, venturi effect, and by the wind pressure, when favourable. These three effects bring the patio's microclimate into the interior, which is even more cooled when it crosses the shadowed portico and tower. The massive constructions emit coolness by means of their high thermal capacity. Therefore, the portico performs as a thermal buffer between patio and interior. Ventilation also removes internal heat gains and, by night, the accumulated heat in the walls and roofs.

Both patios modify their microclimates using water, vegetation and shaded areas. The water of the pond of Comares and of the canals, jets and fountain in the Lions produces evaporative cooling. Vegetation cools air by evapotranspiration, shades floor-surfaces, and shelters the moisture generated underneath. On the other hand, a patio with a high height/length ratio provides more shaded surfaces, always with lower temperatures than the illuminated ones. At the same time, a deep volume is more able to protect its microclimate from the hot air that flows over it. The Patio of Comares is quite open and so badly sheltered, whereas the Patio of the Lions keeps fresh air bags better due to its closer shape. Porticoes and vegetation also provides a large amount of shadow.

The pond of Comares is 1.7 m deep and its area is 252 m², occupying most of the patio. This outstanding water-volume provides a high thermal capacity to the pond and cools the air in the patio basically by:

- Evaporation of the water of its surface into the adjacent air. The high exposure helps the evaporative process.
- Reduction of solar reflection. The water, due to its high thermal mass, accumulates the energy of the sun almost without any transmission to the air.
- Water temperature is normally lower than air temperature. That produces a thermal conduction and radiation to the air (Guerra, J. 1991).

In the Lions, on the other hand, water is always in movement. Fountains, jets and channels spray water thus increasing the contact surface with the atmosphere. The larger it is the higher the possibility of evaporation. Here the lack of thermal capacity of the water reservoir is compensated by water renewal, which prevents it from heating.

As a conclusion, the thermal mass of the thick walls cools the interiors by means of radiative cooling effect; the increase of moisture content of the air cools patios by the evaporative cooling effect, and ventilation, on the one hand, eliminates internal heat gains and, on the other hand, transfers the patio microclimate to the rooms. Therefore, the combined action of these three criteria is the cause of the general natural cooling.

3 Fieldwork, simulations and findings

In both case studies, windows and doors are permanently open because they are visited monuments. Therefore, the monitoring was carried out with all the rooms opened.

3.1 Solar study

Sun movement was analysed along a mid-summer day (21st of June) in the morning, midday and afternoon (Fig.5).

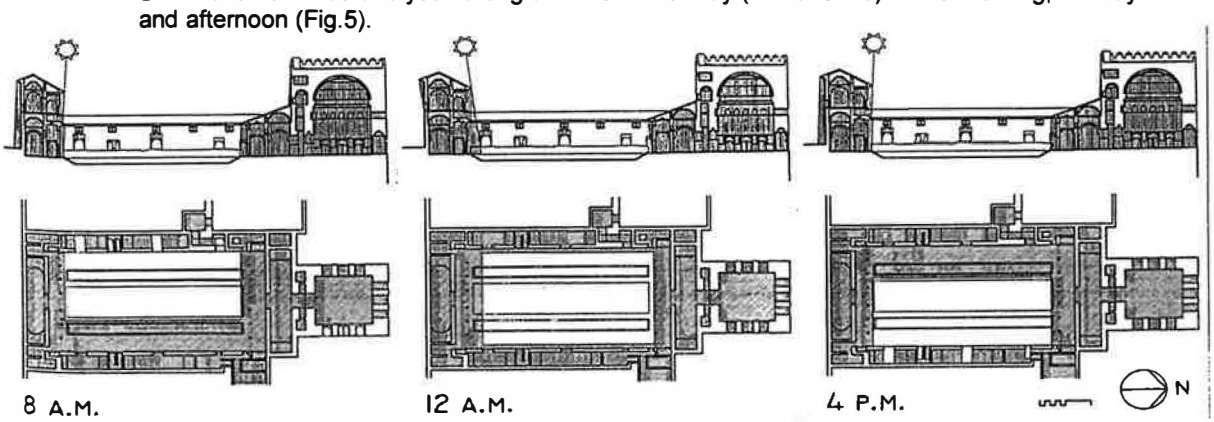


Fig.5 Solar-access diagrams in the Palace of Comares. 21 June

The North-wing-apartments are protected from the sun during the whole day. Furthermore, its portico provides extra protection. The thick walls of the tower, the unique space with windows, prevent solar penetration. There are also upper windows through which sun can come in, but dense lattices filter it. The high location of the lattices does not allow the sun to reach the floor but only the internal walls. At midday, the patio is totally sunny, however, rooms are not. That occurs because sunbeams fall almost vertically in summer. Nevertheless, in order to avoid overheating in the patio, more shaded areas might have had, especially, by means of vegetation, more plentiful in Muslim times.

The lateral façades have also a risk of over-heating, particularly the West by the afternoon, due to the lower summer sun. This makes the West and East elevations the most unfavourable. Usually, the East and West patio-wings in Hispano-Moslem buildings do not have any rooms, but if they do, then their openings are just the unavoidable ones. In equinox and winter seasons, however, sun heats the North chambers due to the smaller sun-inclination and the elongated proportion of the patio. Every room in these buildings is duplicated on the first floor.

3.2 Temperature measurements

A) Court of Comares

Over a period of three days, four data-loggers registered temperatures in the patio, Hall of the Ambassadors and the Hall of the Boat (here located in a lateral, without draught exposure) and are compared to the external logger (Fig.6).

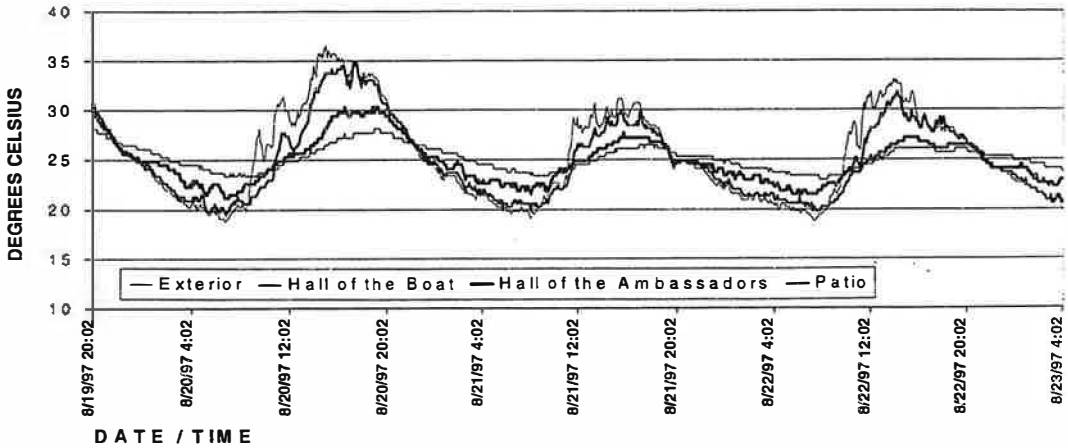


Fig.6 Data-logger-temperature readings in the Court of Comares

The maximum temperature difference outside inside is 8K in the Hall of the Boat and 6 K in the Ambassadors. The internal temperatures behave more steadily with respect to both, high and low temperatures, but the differences are larger when they are higher. The most stable temperature corresponds to the Hall of the Boat, which is the less affected by airflow and more by the thermal capacity of the structure.

During the peak moments, temperature differences between patio and exterior are around 3K. By the afternoon, both air temperatures become similar because the high reflectivity of the clear surfaces of the patio increases its temperature.

Another conclusion is about the temperature delay produced in the internal spaces. It occurs in no less than four hours; even in the points more exposed to the air movement. This is due to the important radiative cooling effect in this Court. High effusivity materials and massive structures make it easy to emit to absorb the heated air.

B) Hall of the Two Sisters. Court of The Lions

The three loggers placed in these apartments in October 97 are affected by cross ventilation. The instruments in the interior were situated as follows: one in the main hall and another in the rear rectangular room (Fig.7).

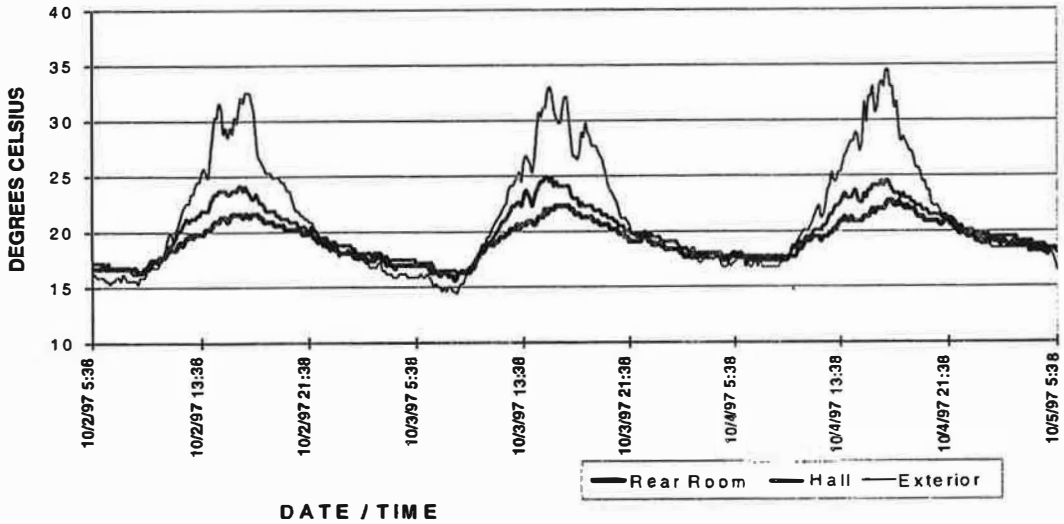


Fig.7 Data-logger-temperature readings in the Hall of the Two Sisters. Court of the Lions

The environmental response is similar to the previous case. though here cooling is even higher. The maximum temperature differences obtained go from 8 to 11°C approximately. Again, the recorded spread in high temperatures is better than in lower ones. The cooling from the patio is gradual: the most remote logger registered the lowest temperatures. When the air stream reaches this point, air has been already cooled by the heat-absorption of the surfaces than envelop the space. Therefore, the thermal-mass effect has a quite considerable secondary cooling power. That is also noticeable because the internal temperatures are always behind the externals. On the other hand. the patio freshness is achieved by means of the evaporation and the profusion of shadow that take place there. These variations can be appreciated in the series of spot measurements carried out in this Court.

3.3 Spot measurements

Spot readings were taken in order to relate temperatures, humidities and air velocities, as well as, to find out their evolutions in several locations. This series was undertaken at four different times of the same day in the Court of the Lions and through the section that includes the Hall of the Abencerrajes and the Two Sisters (Fig.8)

The patio microclimate shows less fluctuation than the external and is closely related to the conditions of the internal spaces. Rooms are, in general, opened to the patio and thus affected by its environmental conditions. At 1.30 and 6 p.m., relative humidity values in the patio and the rooms are similar and substantially above the external ones. At 10.30 p.m. humidity levels inside-outside balance and in the morning the humidity is higher outside. Evaporation is produced precisely when the solar radiation in the patio is stronger. Solar radiation absorbed by the patio surfaces heats the adjacent air and compensates partially for the evaporative cooling. More vegetation within the patio would provide shadowing and, at the same time, increase the cooling effect.

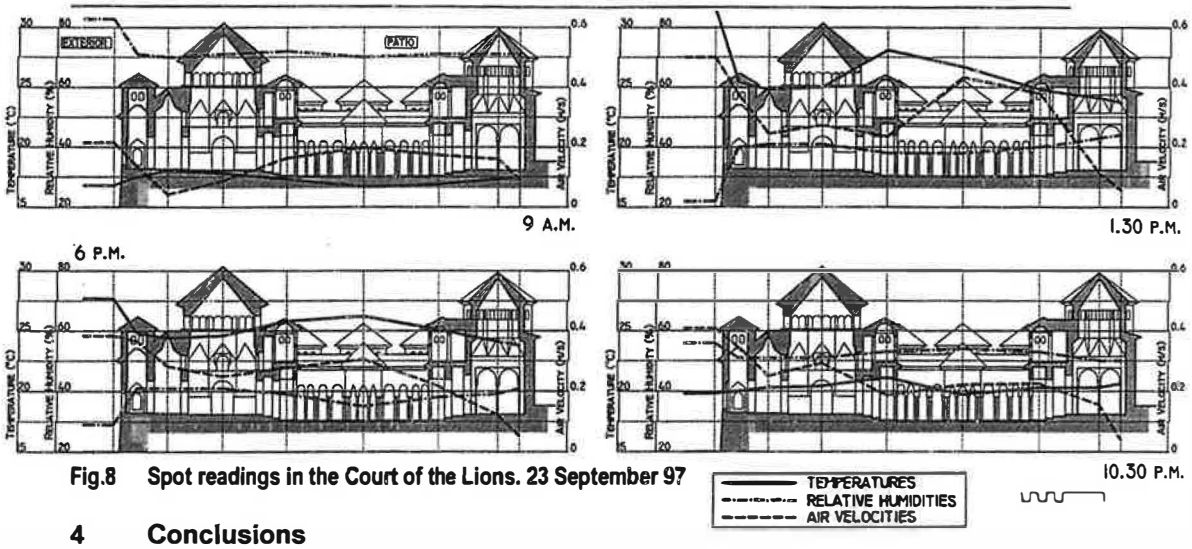


Fig.8 Spot readings in the Court of the Lions. 23 September 97

4 Conclusions

The most significant environmental achievement of this architecture is the effective combination of the cooling strategies: ventilation, radiation and evaporation, as well as solar control. The separate actions would not give such good cooling results. On the other hand, the form of the building favours these natural mechanisms, for instance, the patio-portico-tower sequence. Moreover, the spatial and functional flexibility gives the possibility of a more versatile thermal response. Independently of these physical improvements, the buildings were conceived to produce the maximum aesthetic effect. That can be seen in the manipulation of daylight, decoration, colours, sounds, smell, vistas, etc.

The treatment of the private outdoor space also deserves a reflection. The outstanding use of the patio was only possible because it adapted to the adverse external climate. Its surrounding rooms are opened almost exclusively to the patio and benefit from its mitigating thermal capacity.

But this adaptation is not just the result of applying few isolated techniques. Nevertheless, passive cooling strategies were integrated in the architectural formalisation as well as in the design process. On the other hand, these strategies are not circumstantial in the case of the Alhambra; its palaces are, on the contrary, the culmination of a continuous environmental analysis from the early Hispano-Moslem buildings.

5 Acknowledgements

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6 References

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