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COMPARATIVE EVALUATION OF PASSIVE CONDITIONING STRATEGIES FOR THE IMPROVEMENT OF COURTYARD THERMAL PERFORMANCE

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ABSTRACT

The alarming increase in global average temperatures and the adaptive capacity of humans in relation to air quality and temperature are becoming increasingly relevant. Scientific resources have focused on the thermal adaptation of building users, but little research has been done on thermal comfort in outdoor and semi-outdoor spaces in the city. This study focuses on the analysis and comparison of different passive strategies implemented in courtyards. The present investigation quantifies the comfort improvement brought by shading and misting elements in courtyards. For this purpose, a set of intrinsic and extrinsic variables that intervene in the thermodynamic behavior of the courtyard will be taken into account. The relevance of the study lies not only in the need to design energy-efficient buildings with adequate thermal comfort patterns but also in more resilient urban environments in the current climate change scenario. The main objective of the research is to quantify the implementation of other passive strategies and the results of different combinations of these. The results identified a thermal delta in the courtyard of up to 10°C cooler than the outdoor temperature, which varies depending on the different strategies implemented and the time of day.

KEYWORDS

Courtyard; architecture; comfort; climate change.

1. INTRODUCTION

The issue and effects of climate change are a concern that today's society must take into account in order to mitigate them. Thermal forecasts for the end of the century indicate an increase of several degrees in average temperatures in cities (Santamouris et al. 2001). The latest studies carried out by the Intergovernmental Panel on Climate Change (IPCC) show that the data for southern Spain are not very encouraging. Moreover, CO2 emissions are one of the most relevant causes of climate change to be taken into account, and buildings cause 40% of CO2 emissions in Europe (Matthews et al. 2009). The measures needed to face this problem are becoming highly restrictive, so contributions from any discipline are essential for nations to comply with new requirements. One of the main objectives to mitigate climate change regarding architecture is the design of Nearly Zero Energy Buildings (NEZB). Reducing the energy demand of buildings is possible thanks to different passive strategies in the architectural design of cities and their morphology (Bitan 1988). Courtyards have gained importance in cities mainly affected by global warming, such as Seville, acting as highly efficient passive cooling systems, used in vernacular architecture in hot areas. Depending on their construction and design characteristics, they help remarkably as thermal regulators of buildings' and cities' temperatures, mitigating the urban heat island effect (UHI) (Carnielo and Zinzi 2013). The so-called UHI effect occurs mainly in large cities, due to the built mass, producing an overheating of urban areas. During summer heat waves, some cities have reached more than a 10°C difference between the rural periphery and the urban area temperatures.

The tempering potential of courtyards is a value to be taken into account in cities with warm climates. This has been assessed and demonstrated for less extreme climate zones (Nasrollahi et al. 2017; Taleghani et al. 2014). The thermal gap achieved with the outside is the main parameter to take into account when assessing this temperate potential. The effectiveness of courtyards depends on the intrinsic and extrinsic characteristics of each courtyard. Some internal ones, such as geometry, aspect ratio (AR), orientation (Oktay 2002), the presence of vegetation or water, degree of exposure to wind (Safarzadeh and Bahadori 2005), constructive finishes (albedo) (Taleghani 2018), shade elements (Cindel et al. 2018), stand out, but it is the external environment that determines the tempering capacity to a greater or lesser extent.

The microclimate of the courtyard contributes to the energy savings of the building by tempering adjacent rooms. It also allows the users of these spaces to be thermally comfortable most of the day in the warm season (Diz-Mellado, Galán-Marín, and Rivera-Gómez 2020).

The implementation of passive strategies in courtyards can improve their indoor microclimate in a controlled way. The inclusion of vegetation (Diz-Mellado et al. 2020), albedo variations, the presence of water sheets (Pearlmutter and Berliner 2017; Hweij et al. 2017), or nebulizers (Ulpiani et al. 2019; Ulpiani, di Perna, and Zinzi 2019) or the placement of shading elements (Shashua-Bar, Pearlmutter, and Erell 2009) are some of those that have been tested so far (Soflaei et al. 2017). Some of them are inexpensive and easily available bioclimatic strategies.

A new line of research that has not been addressed so far is the comparison of different passive strategies and their combination such as the effect of a common shading element (an awning) on the partial or total surface of the courtyards, during 24-hour cycles or only in the daytime period, and the presence of nebulizers. This research, therefore, aims to test the tempering potential of courtyards in extreme summer temperatures, and the effect of passive shading strategies and misters. The study focuses on a case study in the city of Seville, which is a city characterized by the presence of many of these spaces. The assessment of the courtyard microclimate is analyzed, first without any strategy, then with a 24-hour shading element, then with a shading element during daylight hours, and finally a combination of a daytime shading element and foggers. This is a comparative analysis with very similar outdoor climatic conditions. The ease and speed of assembly as well as the cost-effectiveness of these strategies make the results of the research a fundamental aspect against climate change.

2. MATERIAL AND METHODS

2.1. Location and climate description

In this section, the local climate of Seville (Seville, Spain, 3722058" N 558023" W, 16 m a.s.l.), in Southern Spain, is analyzed in detail and a case study is selected for investigation.

Seville is the capital of Andalusia, an autonomous community of Spain with an area of approximately 14,036 km2. Seville covers 140.8 km2 and has an average height above sea level of approximately 7m. The city of Seville is located on the fertile plain of the Guadalquivir, a river that goes through the city from north to south. It has 688.711 inhabitants, making it a medium-sized city in Spain and the most populated city in Andalusia. Seville is one of the warmest cities in Spain. It has a Mediterranean climate and is very warm in the summer months.

In the research, parameters such as the Diurnal Thermal Range DTR (Equation 2) are used (Lee et al. 2018; Lim, Hong, and Kim 2012). DTR is the difference between the minimum and maximum temperature values captured in a given observation time, usually a 24-hour cycle (Qu, Wan, and Hao 2014; Braganza, Karoly, and Arblaster 2004).

$$T_{max} - T_{min} = DTR\ (°C) \qquad (2)$$

Between the summer and winter months, there is a great variation in temperatures, but there are also large variations in DTR, reaching 12-13 ºC in winter and 16-17 ºC in summer. Winters are generally mild, with few days registering 0ºC and little rainfall. In summer, temperatures can occasionally exceed 40 ºC in the hottest months. Due to climate change, as we mentioned earlier, it has been recorded that summer is lengthening in time, as the heat starts earlier in the year and leaves later, so the climate in Seville works as two seasons, winter and summer, with a short period with a mild climate such as spring and autumn.

According to IPCC projections for the coming decades (IPCC 2018), heat waves are becoming more frequent in the city of Seville, and will increase considerably. Summer temperatures are regularly high in this southern and inland area of Spain. The Spanish Código Técnico de la Edificación (CTE), the building standard (Documento Básico 2017), classifies Seville's climate as B4, which indicates mild winters and high summer temperatures. According to the Köppen classification, it is classified as category Csa, characterized by hot, dry summers with low rainfall.

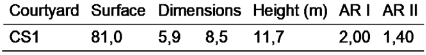
Seville is a city in which most days are sunny, so there is special importance in protecting oneself against solar radiation, and that is why the use of shading elements is a fundamental part of this city.

2.2. Case study

The object of study of this research is an educational building built in 1959, located in a consolidated urban environment. It consists of a basement, ground floor (gf), gf + 1, gf + 2, and upper floor. It is a building composed of 3 volumes of different heights (Fig. 1). The courtyard under study serves offices and classes?, and its characteristics are specified in the Table 1.

The influence of the geometry on the thermodynamic behavior of the courtyards is of great importance according to previous research (Rivera-Gómez et al. 2019) and is defined as the ratio between the height (H) and the width (W) of the courtyard, known as the aspect ratio (AR) (Equation 1). In the case study, two ARs (I and II) are considered, one for each side of the courtyard considering them as simplified parallelepipeds.

$$AR = H/W \qquad (1)$$



Courtyard	Surface	Dimensions		Height (m)	AR I	AR II
CS1	**81,0**	**5,9**	**8,5**	**11,7**	**2,00**	**1,40**

Table 1. Geometric data of the case study

Figure 1. Case study courtyard

2.3. Field monitoring campaign

A plan of field monitoring campaigns is designed to measure the temperature in the case study courtyard.

The thermal evaluation using temperature and humidity sensors is carried out at different heights to be able to appreciate and analyze the thermal stratification with greater precision, as in previous campaigns considerable thermal differences have been observed at the different levels of the courtyard. The thermal stratification is influenced by internal parameters of the courtyard such as its orientation, geometry, or construction characteristics, as well as by external factors such as the season of the year and the climatic zone.

The monitoring plan is carried out for July 2021, with outdoor temperatures typical of the warm season. The monitoring campaigns are divided into four parts: courtyard monitoring without implementation of passive strategies (A); implementation of shading elements during 24h (B); implementation of shading elements (Fig. 2b) during daylight hours (8.00 am - 9.00 pm) (C); implementation of nebulizers (6s/min) (Fig. 2c) in combination with shading elements during daylight hours (D). The planning of the monitoring campaigns is in Table 2.

Monitoring Campaign	Passive Strategy	Date	Time frame
A	-	12/07 – 15/07	24 h
B	Shade Element	16/07 – 19/07	24 h
C	Shade Element	20/07 – 23/07	8.00 am – 9.00 pm
D	Shade Element + Nebulizers	24/07 – 27/07	8.00 am – 9.00 pm + 6 seg/min 24 h

Table 2. Planning of the monitoring campaigns

A weather station model PCE-FWS20 is located on the roof of the building to monitor outdoor data related to temperature, humidity, wind speed and direction, and precipitation (Fig. 2a). All these data were recorded in a control center located inside a nearby office inside the building. Simultaneously, three temperature and humidity sensors were placed on a string at different heights to capture the thermal stratification of the air. The sensors were protected from direct solar radiation with a ventilated shield, according to previous research. In the case study, the sensors were placed at the base of the string at a height of 3.0 m, 5.0 m, and 7.0 m above the courtyard floor, model TESTO174H temperature recorders. With the measurements outside and inside the courtyard, the Thermal Delta (TD) between the courtyard and the outside can be determined (Rivera-Gómez et al. 2019).

$$TD(°C) = OT - CT \qquad (3)$$

TD is a factor consisting of the difference between the outdoor temperature on the roof of the building and the temperature in the courtyard measured by a sensor placed at a certain height above the ground for a certain time. It is a very useful factor for assessing the tempering potential of the courtyard.

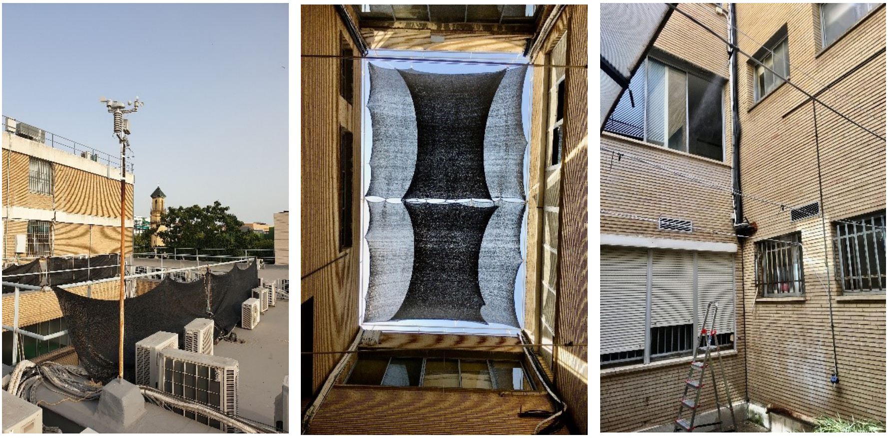


Figure 2. Location of the measurement instruments. a) weather station PCE-FWS 20, b) data loggers TESTO 174H, c) nebulizers at 2.00 m (6 seg/min)

3. RESULTS AND DISCUSSION

This section shows the results of the different monitoring campaigns (A-D) carried out inside the courtyard. Two selected days from each type of campaign are shown in figure 3. The days have been selected according to the outdoor temperature, choosing the days with the most similar outdoor temperature for future comparison of the implemented passive strategies. The results shown in Figure 3 are divided into four blocks (A, B, C, and D), representing the four monitoring campaigns carried out. In dark color, the monitored outdoor temperature on the roof of the building, and in other colors the temperature and humidity of the sensors placed inside the courtyard.

Figure 3 shows considerable thermal stratification between the TESTO174H sensors. The thermal stratification between sensors varies between 1-2 ºC in consecutive sensors separated by 2.00 meters. This thermal stratification is different in campaign D, where the temperature of the lowest sensor is significantly different from the one at 5.00 meters. As for the relative humidity, the trend is the same in campaigns A, B and C, increasing considerably with the implementation of the foggers in campaign D, especially during the day. The temperature at the lowest sensor is similar, with a noticeable increase in temperature at higher elevations. Figure 4 shows the average results of temperature and humidity inside the courtyard.

Figure 4 shows that the tempering potential of the courtyard increases when a shading element is implemented, being similar in campaigns B, C, and D. In terms of DTR, the average outdoor thermal variation is 18 °C, while in the courtyard it varies between 8 and 4 °C. To assess the microclimatic potential generated by each passive strategy implemented, one day has been selected from each of them. Figure 5 shows the TD achieved in each campaign with respect to the average yard temperature.

The hourly TD is shown in Figure 5a, and in Figure 5b, the maximum TD achieved during the day is expressed as positive, and the maximum TD during the night, when the courtyard is warmer than outside, as negative. The TD achieved in campaign A is 5.5°C during the day and -2.4°C during the night. By implementing a shading element for 24 hours in campaign B, the TD is 9.5°C, improving by 4°C due to the presence

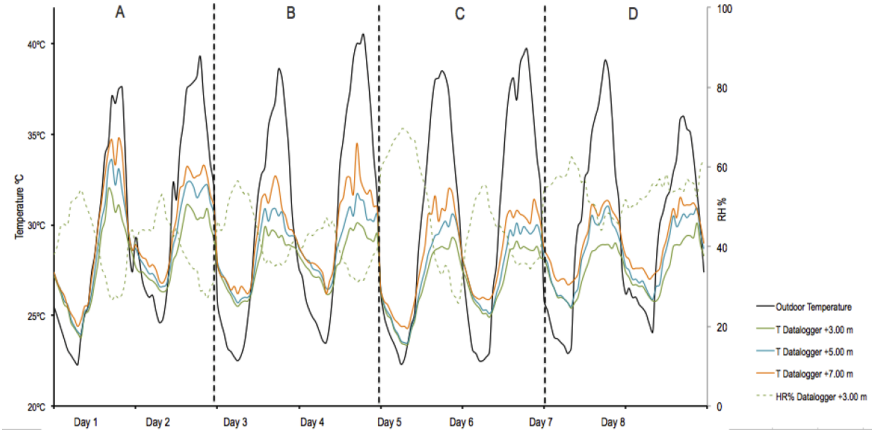


Figure 3. Results of selected days in monitoring campaigns

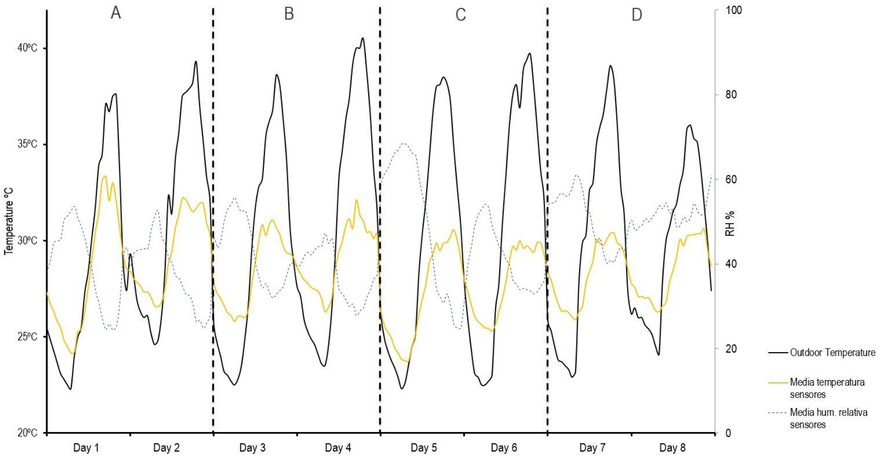


Figure 4. Results of average temperature and humidity in the courtyard

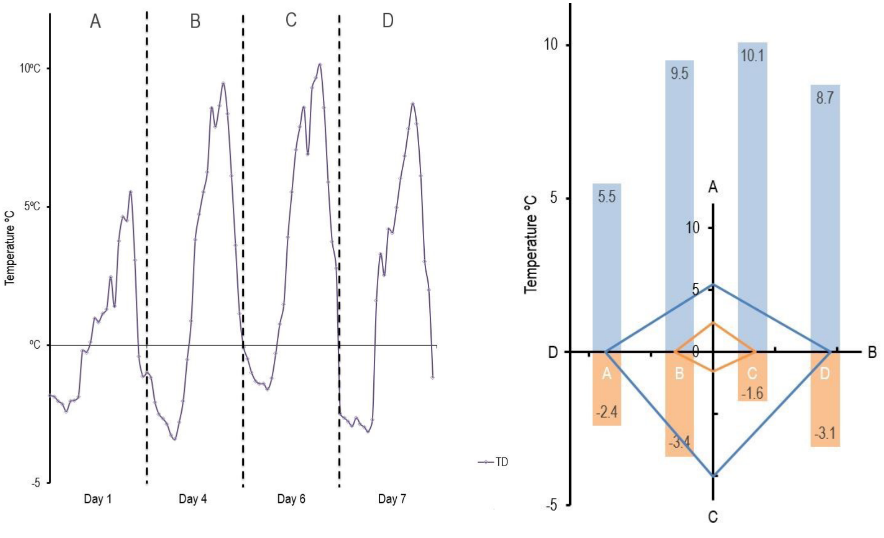


Figure 5. TD results for four selected days a) overall TD 20, b) diurnal and nocturnal TD

of the shading element. However, during the night, the TD is -3.4 ºC, significantly affecting the courtyard temperature during the night period. In campaign C, the TD is 10.1ºC, significantly higher than in the previous case. During the night period, when the shading element is removed, the courtyard manages to cool down, almost balancing with the outside temperature. The presence of foggers in campaign D has not produced any improvement in combination with the shading element in the daytime period. During the night, the courtyard does not cool down, with the foggers producing a similar hot air pocket as the shading element in campaign B.

4. CONCLUSIONS

The thermal tempering achieved in buildings by the influence of the microclimate generated in the courtyard is a real fact of scientific interest. Vernacular architecture in the Mediterranean climate has been characterized by the presence of these spaces as the spatial core of buildings.

The implementation of different passive strategies applicable to these spaces is important due to the improvement achieved in the temperate potential of the courtyards. In this research, the implementation of shading elements and misters has been tested during several monitoring campaigns.

The selected case study manages to temper the temperature in this space by more than 5ºC during daylight hours. However, the implementation of a shading element provides up to an additional 5ºC, achieving a TD of more than 10ºC. However, foggers have not brought significant improvements.

During the night, these passive strategies were also compared, achieving space cooling in the campaigns with the removal of the shading element during the night hours.

This research aimed to compare different passive strategies applicable to the courtyard. Ultimately, the implementation of shading elements during the day plus night-time removal is the most suitable passive strategy for this case study. The limitations of this research have been the lack of a new campaign in which only misters are implemented to test their effect on their own. In future lines of research, it will be possible to carry out this comparison in courtyards with different geometries and climatic zones to detect which passive strategy is more suitable for each type of courtyard in each climate.

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