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Adaptive Comfort Criteria in Transitional Spaces. A Proposal for Outdoor Comfort †

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Abstract: Urban Heat Island (UHI) as a combined consequence of global warming and the cities diameter increase, continues to be technological challenges today. Different passive strategies related to the buildings and cities architecture design imply energy demand reduction achieving. Architectural elements such as courtyards become extraordinarily significant as passive cooling systems. The research aims to establish patterns and values of adaptive comfort in transition spaces, reflected in the thermal regulation capacity of these buildings thanks to the morphology of the courtyards, contributing also to possible state strategies for action in favor of reducing the effects of climate change.

Keywords: climate change; courtyard; adaptive comfort; Urban Heat Island; field survey

1. Introduction

There are different passive strategies in the design of the architecture of the cities that entail a reduction of the energy demand of the buildings, collaborating to user's comfort [1]. The spaces of transition between the interior and the exterior of the building, such as the courtyards, take on great importance as passive cooling systems. For people, the courtyard, in addition to an element of habitability, is a space typical of the Mediterranean culture.

To address the problem of adaptive comfort in these buildings spaces, surveys are the main necessary tool. Regarding the standardization framework, the European standard EN 15251: 2008 [2] establishes the results of this relationship, reflecting the acceptable interior temperatures for the design of buildings without mechanical cooling systems.

Another point to consider is that first investigations that have been carried out on adaptive comfort in outdoor spaces are focusing on noticeably open spaces and in connection with the city [3]. However, the most living spaces and in direct contact with the day to day of the users of the buildings are the courtyards. That is why a study that reflects the direct relationship of the measured physical parameters and the sensation perceived by the users, is fundamental especially in the warm climatic zones like the case of our country.

The results of the study, in addition to promoting well-being and energy, may reflect an evolution of adaptive comfort based on the development of perception of people.

The generation, and recovery in the current architecture, of transitional spaces such as the courtyard, characteristic of our geographical and cultural environment [4], is a fundamental bioclimatic strategy. The courtyard is, therefore, a fundamental space for cities, a fundamental synergy between architecture, culture and sustainability in which it is essential to know the comfort parameters it provides to users.

2. Materials and Methods

A significant method for verifying courtyard effectiveness in a global warming environment is to make a comparative analysis of the percentage of the courtyard's Diurnal Thermal Range (DTR) included within the comfort standards according to different DTR scopes considered. The Diurnal Temperature Range (DTR) is the difference between the maximum and minimum temperatures on a given day ($T_{max} - T_{min}$ = DTR (°C)). Conventional comfort theory relies on a steady-state model where the production of heat is equal to the heat lost to the environment, with the aim of maintaining a constant core body temperature of 37 °C. According to the Spanish regulation [5] Reglamento de Instalaciones Térmicas de los Edificios (RITE), human Thermal Comfort (TC) ranges between 21–25 °C operating temperature. Nevertheless, people take action to improve their comfort conditions by modifying their clothing and metabolic rate, or by interacting with the building's adaptive actions. As a result, there are international standards that regulate indoor adaptive comfort. However, due to the great complexity of the outdoor environment in terms of variability, both temporally and spatially, as well as the vast array of activities that people engage in, there have been fewer attempts to understand outdoor comfort conditions. In spite of this, studies on outdoor adaptive thermal comfort are becoming more frequent in the specific literature [3,4].

Figure 1 shows a graph from European Standard EN 15251-2007 [2] that specifies the indoor environmental parameters which have an impact on the energy performance of buildings. Indoor operating temperature versus mean outdoor running temperature is represented in the graph. This standard refers to indoor environmental input parameters for the design and assessment of buildings' energy performance; therefore, the graph is calculated for adaptive comfort assessments inside the buildings. Currently, an equivalent standard to evaluate outdoor adaptive comfort is not available. Considering this regulatory deficit and the fact that certain parameters such as wind speed vary considerably from the indoor to the outdoor of buildings, it is conceivable to establish the graph's effective operability beyond the 30 °C outdoor maximum temperature for the outdoor adaptive comfort evaluation. Following these criteria, and in order to exemplify courtyard comfort improvement and stake its claim for adoption by current architecture, in addition to TC values, the mean Adaptive Thermal Comfort (ATC_{mean}) and maximum Adaptive Thermal Comfort (ATC_{max}) values corresponding to the three TR considered in the present study have been plotted on the graph.

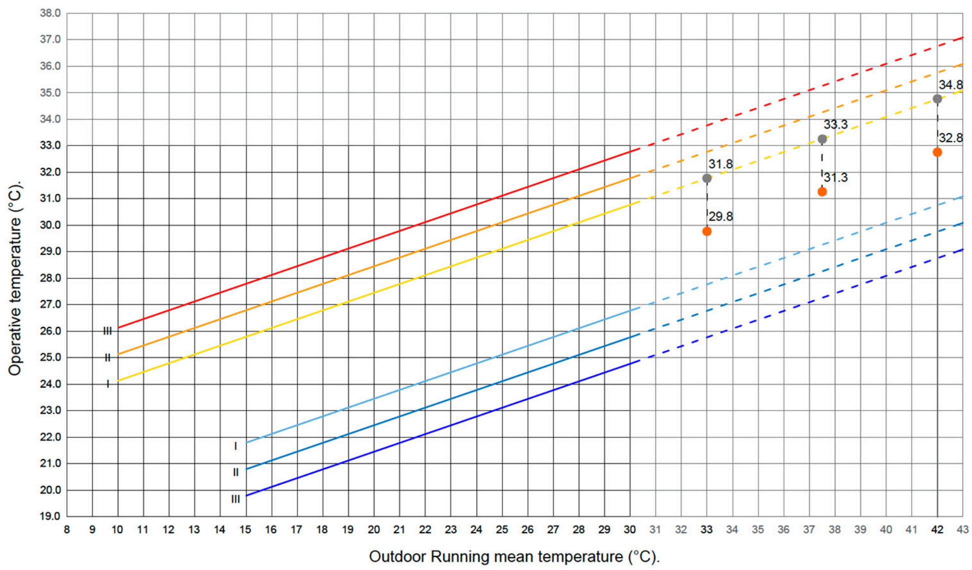

Figure 1. Adaptive Thermal Comfort graph according to the European standard EN 15251-2007 [2] ATCmean and ATCmax values for the TRs have been plotted.

The outdoor versus courtyard plotted DTR gap clearly explains actual courtyard effectiveness in terms of thermal tempering. According, a study linking four study cases with different AR and DTR and its relation with the thermal comfort of the users is shown. These courtyards are located in the same climatic zone defined by the CTE, in which the different improvements perceived by the users can be compared according to the geometric characteristics of each courtyard and the external thermal conditions.

Cases Study

In this work, we selected a range of case studies with a different AR interval. The 4 courtyards that constitute this set of case studies were each monitored for a two-week period in the cities of Seville (Seville, Spain, 37°22′58″ N 5°58′23″ W, elevation 16 m. asl.) and Cordoba (Cordoba, Spain, 37°53′30″ N 4°46′22″ W, elevation 106 m. asl.); all the courtyards were located inside buildings, which were either residential and public (Figure 2). With the aim of reducing the number of variables, courtyards with the same characteristics in terms of albedo and orientation have been selected.

Case 1 Case 2 Case 3 Case 4

Figure 2. Cases study selected monitored for two-week in the cities of Seville and Cordoba (Spain).

3. Results

As appreciated in the following figures, the outdoor DTR versus the courtyard DTR for each case study based on different TR studied are shown: TR < 35 °C (Figure 3a), TR 35–41 °C (Figure 3b) and TR > 41 °C. (Figure 3c). For each courtyard, the AR increases from left to right in each graph. The DTR gap between outdoor and courtyard DTRs increases in accordance with the AR value. For all TRs considered, the DTR gap is greater for AR > 3. The graphs also show the indoor Thermal Comfort (TC) ranges according to Spanish regulations [5], and the ATC mean and maximum values according to the adaptive comfort European standard [2].

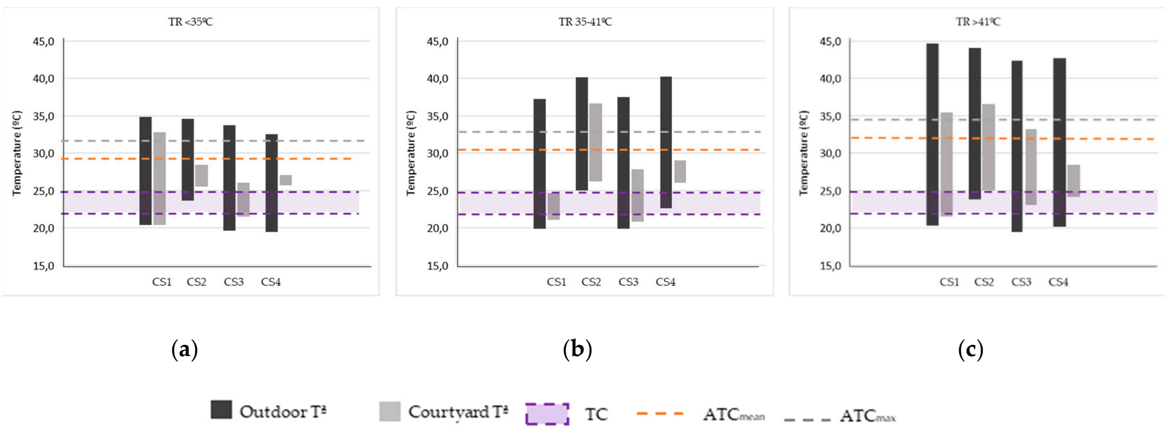

Figure 3. Outdoor versus courtyard DTR. (**a**) TR < 35 °C; (**b**) TR 35–41 °C; (**c**) TR > 41 °C.

Table 1 shows the numerical values corresponding to the previous graphs (Figure 3). As observed for each case study in the DTR gap versus courtyard AR benchmarking analysis, courtyard thermal tempering performance not only increases according to the AR but also to the MOT (Maximum Outdoor Temperature). If the courtyard DTR percentage included within the TC range is analysed, it can be observed that courtyard temperature evolution throughout a day cycle is outside the TC standard most of the time, this percentage decreasing with TR increase.

Table 1. General information of set of cases study.

Case Study	City	Climate Zoning (CTE)	Surface (m^2)	Height (m)	Aspect Ratio
CS1	Seville	B4	39.5	9	0.84
CS2	Cordoba	B4	14.6	6.3	1.66
CS3	Seville	B4	48.2	14	2.02
CS4	Seville	B4	6.4	14.2	5.77

If instead of considering the TC parameters, the reference is taken to be the thermal range determined by the ATC standard for each outdoor TR value, the results are different. As observed in Table 2, the DTR percentage for all courtyards within the standard ATC is between 34.3–100% for ATC_{mean}, and between 47.2–100% for ATC_{max}. These percentages are between 48.6–100% for ATC_{mean}, and between 58.6–100% for ATC_{max} in the TR > 41 °C. With regard to the AR, it can also be observed that in the case of AR > 3, the percentage within the ATC of the courtyard analysed is 100% for the three TR considered, and both for the ATC_{mean} and ATC_{mean}. In the case of AR 2–3, this percentage varies between 66–69% for the mean ATC, and between 67.4–97.2% for the maximum ATC.

Table 2. Outdoor versus courtyard DTR percentages within TC, ATC_{mean}, and ATC_{max}.

Case Study	TR < 35 °C			TR 35–41 °C			TR > 41 °C		
	TC (%)	ATC_{mean} (%)	ATC_{max} (%)	TC (%)	ATC_{mean} (%)	ATC_{max} (%)	TC (%)	ATC_{mean} (%)	ATC_{max} (%)
CS1 AR 0–1	13.8	46.9	60.7	11.5	39.1	50.6	8.2	27.9	36.1
	16.1	54.8	71	47.2	47.2	47.2	14.3	48.6	62.9
CS2 AR 1–2	3.6	61.8	80	0.0	31.6	44.7	5.9	29.6	39.4
	0.0	100	100	0.0	34.3	53.3	0.0	41.4	58.6
CS3 AR 2–3	14.1	47.9	62	11.4	38.6	50	8.7	29.6	38.3
	43.5	67.4	67.4	28.2	69	97.2	19.4	66	85.4
CS4 AR >3	15.2	51.5	66.7	11.3	38.4	49.7	8.8	30.1	38.9
	0.0	100.0	100	0.0	100.0	100	20.5	100.0	100

4. Conclusions

Analyzing the courtyard DTR percentage within the proposed ATC range, it can be verified that for AR > 3 the courtyard is 100% within an adequate thermal comfort zone. It can also be concluded that in the climates studied, especially in the warmest zones of the interior, deeper courtyards with AR > 3 are appropriate solutions for enhancing thermal performance. The research has provided a background to support further research and analysis on the impact of courtyard design variants of its performance. The capacity of well-being towards the courtyards users requires, therefore, the study of each one of the factors that intervene in their thermodynamic behavior.

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