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Omar Al-Hafith*, Satish B. K., Pieter de Wilde

School of Art, Design and Architecture, University of Plymouth, Plymouth, The UK, omar.al-hafith@plymouth.ac.uk

Abstract: Many researchers have experimentally proven the thermal efficiency of courtyard buildings in hot regions during summer. However, a limited number of studies have tackled courtyards' winter performance. In these studies, it has been stated that courtyards are possibly not efficient for winter conditions. This study aims to address this point. It investigated the impact of changing courtyards geometrical properties on occupants' thermal perception during typical winter conditions of a hot region. The study conducted a simulation experiment using Envi-met 4.2 simulation tool. Baghdad was used as a case study. Thermal comfort limits for hot regions were used as a reference. IBM SPSS statistics 23 was used to analyse variables' correlations. The results show that all courtyard forms are thermally comfortable during typical winter conditions of a hot region. Courtyards' geometry has a significant impact on their thermal conditions. The most effective property is the ratio of courtyard width to height.

Keywords: Courtyard; thermal comfort; hot region.

Introduction

This paper presents a part of a PhD study that aims to develop a thermally and energy efficient housing design for Iraq to inform potential large scale housing developments in the country. The study explores adopting the courtyard pattern, which has been advocated as a thermally efficient pattern for hot regions (Soflaei, Shokouhian, & Shemirani, 2016; Muhaisen, 2006). Experimentally, it has been shown that courtyard buildings can provide an environment with temperature less by 6 to 13 ºC than outside temperature (Edwards, 2006). Having this efficient performance is governed by air movement and solar radiation in courtyards, which depends on having courtyards designed properly (El-deep, El-Zafarany, & Sheriff, 2012).

However, some studies argue that a possible drawback of courtyards is their inappropriateness for winter because of the cold temperature (Agha, 2015). This study investigates this issue. It assessed courtyards' performance during Baghdad's typical winter. As a reference for the courtyards' assessment, occupants' comfort Globe Temperature of 22 ºC and the minimum comfort threshold of 8 ºC were defined depending on a thermal comfort study conducted by Aljawabra (2014) in Marrakech. In the absence of a thermal comfort standard suitable for Baghdad, Marrakech study was found to be of the closest context to Baghdad in term of climate and relevant culture.

Methods

This study used Envi-met simulation tool to test the thermal conditions of various courtyards in Baghdad during winter. This simulation tool was used for its inclusive and validated measurements (Al-Hafith et al., 2018; Ridha, 2017).

The research variables included dependent and independent variables. The first category was the occupants' thermal perception. The Globe Temperature (Tg) was used as a thermal sensation index for its high agreement with people's actual thermal perception (Toe & Kubota, 2011). As a measurement, its value combines the impact of air temperature, air velocity and the Mean Radiant Temperature (Song, 2011). The second category of variables included courtyards' geometrical properties and the outdoor Globe Temperature, as courtyards are outdoor spaces affected by outdoor conditions (Al-Hafith et al., 2018). The considered courtyards' geometrical properties were the ratios of courtyard width/length (W/L), width/height (W/H), periphery/height (P/H), the ground area and the courtyards' long axis orientation (Muhaisen, 2006).

In the simulation experiment, 360 different courtyards were tested (see Figure. 1). Baghdad typical winter period is during the months of December, January and February (Bilal, Al-Jumaily, & Habbib, 2013). The climatic conditions of this period for the year 2016 were obtained from the Iraqi Meteorological Organization and analysed to define typical winter conditions (see Table 1). The simulation configuration was built depending on this research's objectives and with considering settings used in previous studies (Al-Hafith et al., 2018) (see Table 1).

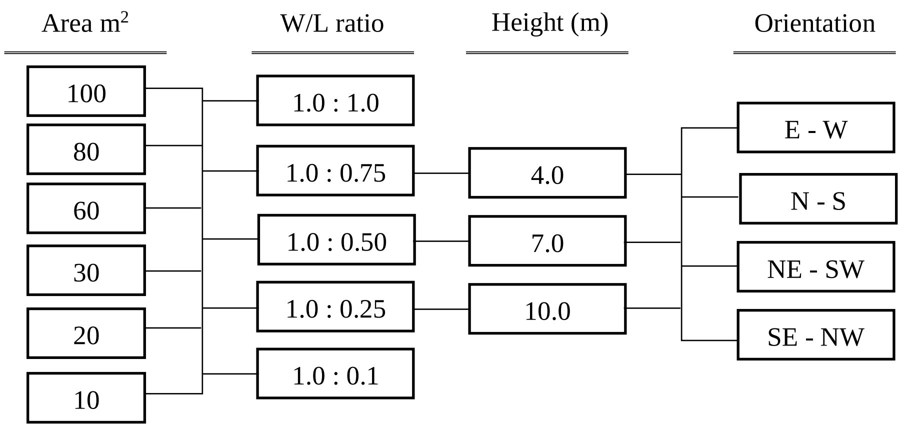

Figure 1. The tested courtyard configurations' parameters

Table 1. Simulation settings

Simulation parameters	Input	Material parameters	Input
Start date	21-01-2017	Thickness	0.30 m
Start time	00:00:00	Absorption	0.80 Frac.
Simulation time	32 (hours)	Transmission	0.00 Frac.
Output interval	30 (minutes)	Reflection	0.05 Frac.
Wind speed	2.7 m/s	Emissivity	1.10 Frac.
Wind direction	East	Specific heat	1300.0 J/(kg*k)
Roughness length	0.01	Conductivity	0.30 W/(m*k)
Max air tem. and time	19.7 ºC at 14:00	Density	1000.0 kg/m^3
Min air tem. and time	13.6 ºC at 04:00		
Max Hum. and time	89% at 04:00		
Min Hum. and time	68% at 14:00		
Lateral boundary conditions	Cyclic		

Notes

- The first six hours of simulation results were not considered as the impact of the stored heat in buildings on night thermal conditions is missed.
- All of the not mentioned software's parameters were kept as default

Findings and Discussion

The simulation results show that the Globe Temperature in all of the tested courtyards is higher than the minimum thermal comfort threshold (See figure 2). Regarding the impact of courtyards' geometry on their thermal condition, the results indicate that changing the courtyard dimensions and orientation can lead to a difference in Globe temperature of around 20 ºC. The courtyards with the highest Globe Temperature are the ones with (E-W) or (S-N) orientations and of the bigger area and lower height, as they offer higher exposure to the solar radiation.

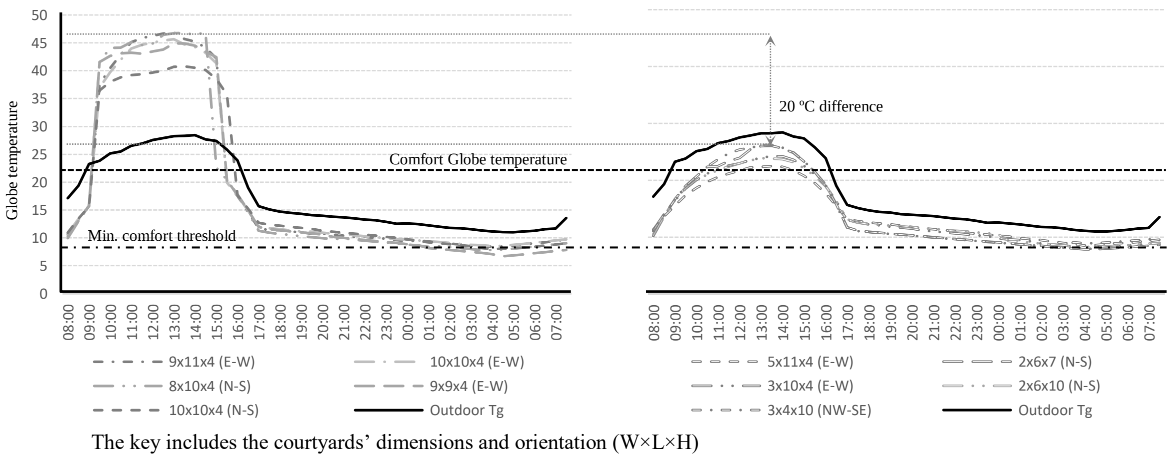

Figure 2. Hourly (Tg) in the warmest courtyards (to the left) and coldest ones (to the right)

To have an accurate assessment of the impact of courtyards' geometry on their conditions, statistical analysis was conducted using IBM SPSS statistics 24. The analysis shows that all of the independent variables have positive relations and significant correlations with the dependent variable, except the W/L ratio ($P \leq 0.05$). The most effective variable on courtyards' conditions is the ratio of W/H. However, as an outdoor space, outdoor conditions have the dominant impact on its thermal conditions (see Table 2).

Table 2. Variables correlations

	W/L	W/H	P/H	Area	Outdoor Tg
Pearson Correlation	0.11	0.096	0.082	0.056	0.848
Sig. (P-value)	0.139	0.000	0.000	0.000	0.000

These results highly agree with what has been found in the explored previous literature regarding the impact of courtyards' geometry on its thermal conditions. Regarding courtyards' winter performance, results indicate that, during hot regions' typical winter, courtyards' conditions will be within the thermal comfort limits. However, this result does not consider factors other than temperature, such as rain, which might also affect the thermal comfort in courtyards.

Conclusion

This study assessed courtyards thermal efficiency during a hot city's typical winter conditions. The results show that all courtyard forms will be within the comfort limits. The geometrical parameters of courtyards have a significant impact on their thermal conditions. These results help to increase the awareness of courtyards' thermal efficiency. They can help designers to develop more thermally efficient courtyards. For future studies, the environmental impact of courtyard buildings' various elements, other than the courtyard, needs to be investigated.

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