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Simulation of courtyard spaces in a desert climate

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Abstract

Within the global trend of looking for energy efficient and environmentally comfortable buildings, the courtyard pattern has been investigated by many authors as an interesting solution for hot regions. Computer simulation tools have been used for this purpose, as they provide wide-ranging possibilities that cannot be obtained in field experiments, including assessing different building design variants under identical climate conditions. However, simulation of courtyards remains challenging, as courtyards are building spaces that are partly open to the outdoor climate and typical building simulation tools are not designed to cope with such situations. This research investigates the capabilities of DesignBuilder in simulating the courtyard thermal behavior. DesignBuilder has been selected due to its wide use amongst architects and building service engineers, and because of its inclusive measurements and validated accuracy. Software simulation results have been compared with real life measurements. The results show that DesignBuilder simulation results are quite different from measured results, raising doubts over the applicability of the software in this specific context.

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Keywords: DesignBuilder; Simulation software; Courtyard pattern; Baghdad

1. Introduction

Since the energy problem in the 1970s, there has been an increasing worldwide interest in designing more environmentally responsive buildings to reduce the energy consumption, keep the environment and have thermally comfortable buildings [1]. In order to achieve this aim, researchers and designers have widely used computer simulation as the main approach to develop and determine buildings' energy performance. This approach provides the opportunity to evaluate and determine the impact of various factors on buildings performance in an early design stage, in different scenarios and without the limitations of field experiments [2, 3]. Therefore, a large number of simulation tools, such as Energy Plus, IES-VE, TRNSYS and DesignBuilder, has been developed and are now widely used for this purpose [4, 5]. However, the validity and the accuracy of simulation results remains a critical issue [6]. Among the challenging situations in which simulation tools' capabilities to simulate accurately are still

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questionable is the prediction of the performance of semi-outdoor spaces such as a courtyard and an atrium. The reason is that such spaces are affected by a number of complicated and integrated internal and external factors, while most simulation tools are designed for a regular situation with rooms that are fully enclosed [7]. This study aims to investigate this challenge. It examines the DesignBuilder simulation tool's capability to simulate courtyard buildings. The reason for choosing this building pattern and this simulation tool is the significant environmental performance of the former [8, 9 ,10], and the wide use of the latter [11, 12].

Regarding the courtyard pattern, it has been advocated for being a thermally efficient pattern for the hot climate regions [8, 9, 10]; it has been shown by many studies that it provides, relatively, a thermally comfortable indoor environment without needing mechanical cooling. For instance, Mohammed [13] showed through an experiment that there are cases where the outside temperature is 35ºC, whilst the maximum temperature in a courtyard space is 30ºC and in a similar closed space in a non-courtyard house it is 40ºC. Al-Saud et al [14] demonstrated through another experiment in a courtyard house in Saudi Arabia, that the courtyard can provide conditions where the internal temperature is lower than outside by up to 9ºC, even without any mechanical cooling. Analyzing the courtyard pattern performance shows that it depends on two strategies to achieve this performance: protecting buildings from heat gain and having sufficient natural ventilation [15, 16]. During the day time, buildings are protected from the direct solar radiation and outside conditions by being attached and shielding each other, which helps to avoid having excessive heat gain [17, 18]. In the night, courtyard surfaces radiate their stored heat (accumulated during the day) to the sky, which helps to remove surplus heat [19]; this causes pressure difference that stimulates air movement, which further helps to cool the space. The light hot air in the courtyard and the surrounding spaces goes up to be replaced by cold one through the courtyard by the buoyancy and wind forces [7, 20, 3].

DesignBuilder, on the other hand, is a simulation tool that provides a user-friendly interface to the Energy Plus simulation engine, making it a tool of choice for various professionals such as architects and building services engineers. It produces a comprehensive simulation that takes into consideration a wide-ranging of local sub-hourly climatic and environmental factors. Its accuracy has been validated by BESTest procedure, which is developed by the International Energy Agency and considered by many agencies for validating computer simulation tools [11,12]. In this research, a model of a courtyard building was built and DesignBuilder was assessed according to its ability to simulate the courtyard space environmental performance.

2. Research aim and methodology

DesignBuilder includes a toolset called 'Draw void perimeter' that can be used to model a courtyard, but it considers the modeled courtyard as an unmeasurable external space. Accordingly, to determine the possibility of using DesignBuilder for simulating courtyards, this research considers using alternative ways to model the courtyard space. It explores the validity of results for the courtyard and the surrounding spaces' conditions when the 'Draw void perimeter' tool is used as well as in the case of the other alternatives.

To achieve this aim, DesignBuilder was used to simulate a real courtyard house in Baghdad, which won the first prize as the best environmental design in Iraq in 1992. DesignBuilder simulation results were compared with the real life thermal measurements of the selected house taken from a previous study. The real measurements included the outside temperature, the hourly air temperature in the courtyard and the maximum and the minimum air temperature in a number of internal spaces on the 27th of August [18]. With considering reflecting all of the house properties to have comparable results, six different configurations were modeled and simulated in which everything is identical, but six ways were used to model the courtyard space. To show the software abilities in simulating the courtyard space thermal behavior, the research considered using only natural ventilation as a cooling strategy without any mechanical cooling. The simulation captures the air temperature with a focus on relating the temperature with the cooling impact of shading, natural ventilation and surfaces radiation to the sky, which are the main courtyard cooling strategies. As there are several undefined and unpredicted factors that might affect the thermal conditions in the real measurements, such as people activities, having simple mechanical cooling or heating sources, the research focused on the comparison of the thermal pattern, not the absolute values.

3. DesignBuilder simulation

3.1. The selected courtyard house: Description and modeling

The selected building is a two stories house with a courtyard and two wind-catchers. Its design considers the properties of Baghdad's traditional courtyard houses, which aims to reduce building exposure to the solar radiation and support night natural ventilation. For the former, a number of environmental design strategies were used including using highly insulating materials for the envelope with small openings to the outside, attaching the building to the surrounding buildings from three sides and using plants and shading devices. Regarding the latter, two wind-catchers were used to work with the shaded courtyard and the outside garden to stimulate night natural ventilation [18] (Fig. 1).

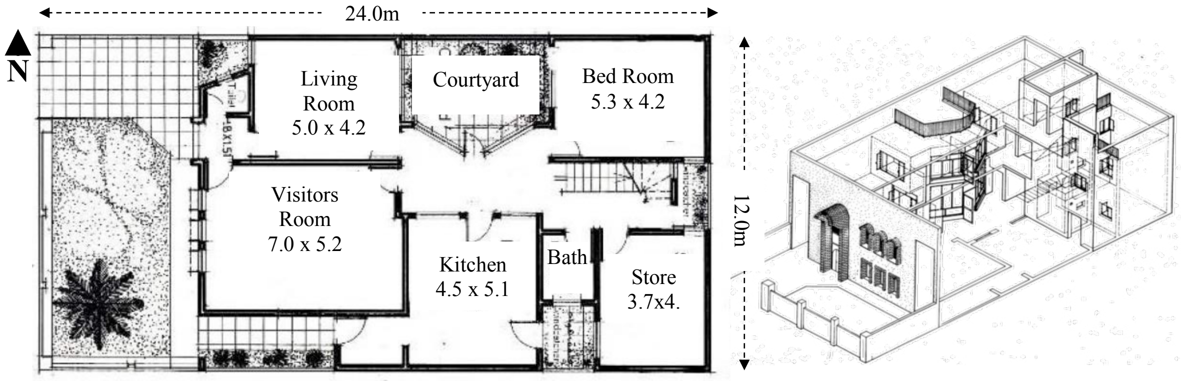

Fig.1. The selected courtyard house in Baghdad [18]

This house was modeled in DesignBuilder with considering the actual spatial layout and physical properties. But, as it is not clear how to model a measurable courtyard space in the software, six different configurations were modeled and simulated. The first configuration was modeled using the 'Draw void perimeter' tool, which the software provides to draw a void within a building block to represent a courtyard. In the second option, the courtyard was model as an internal space with a roof opened through a 'hole', which is a 'perfectly clear glass' with 'an air flow path' that can be drawn using 'draw hole' tool to make an opening in a surface between two spaces [21]. The third option is very similar to the second one, but the roof is opened through totally and permanently opened windows. In the last three options, the courtyard was modeled as a compound space of two spaces: The first was modeled in the center as an open space using 'Draw void perimeter' tool. The second space is an internal space around the central open space in a form of a half meter strip opened to the open space through its walls by, respectively, totally and permanently opened windows, holes and totally and permanently opened doors (Fig.2).

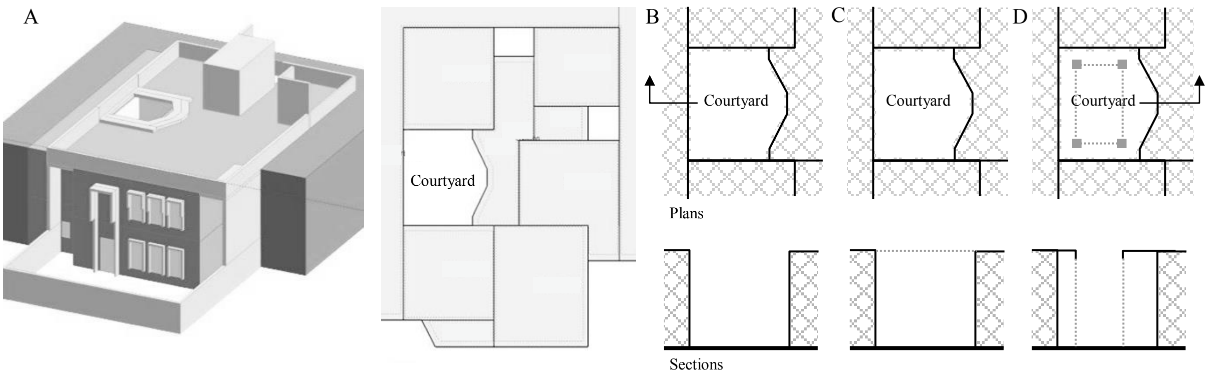

Fig.2. (a) The model form and spatial layout; (b) the first courtyard option, (c) the second and third options; (d) the fourth, fifth and sixth options

3.2. The selected courtyard house simulation

The thermal behavior of all of the six configurations was simulated for the 27th of August, which is the same date of the real measurements. For the simulation purpose, they were simulated as totally free running buildings. The 'Calculated natural ventilation' option was used in the software as this option considers the impact of wind and buoyancy forces on air movement. In the six models, internal windows were set to be shaded, and with 35% openable area to be opened during the night, which was done to reflect the real house conditions. But, in the five models where the courtyard was modeled as an internal space, all of the courtyard's walls or roof openings were set to be permanently and totally opened to reflect the real courtyard configuration.

4. The results

To determine the accuracy and the validity of the software simulation results, the actual courtyard performance needs to be analyzed first. In the real life performance, the courtyard air temperature is relatively high between 18:00 o'clock and 22:00 o'clock as a result of courtyard's surfaces heat radiation and the hot air coming from the surrounding spaces. By the last night hours, between 2:00 o'clock and 5:00 o'clock, the temperature starts to decrease as surfaces continue to radiate the stored heat, and because of having the cold air replacing the hot one through the natural ventilation. The courtyard reaches its coolest temperature by 10:00 o'clock, when the courtyard still has the stored cold air during the night, in one hand, and is still protected from the direct solar radiation, on the other hand. After that, its temperature increases by the impact of solar radiation and having higher outside temperature. Then, the temperature decreases by the sunset to have the same cycle repeated again [15, 18]. Comparing this performance with the simulation results shows that all of the simulated options have different performance. They are mostly affected by the outside temperature; their air temperature increases to its highest peak by the mid-day and decreases in the night to reach its minimum value by 6:00 o'clock. This does not indicate the impact of the heat radiation and ventilation during the night and the impact of shading during the day time. However, a significant difference can be noticed between in the courtyards' conditions in the five measurable options. Options (2) and (3) have higher temperatures than the other five options. Analyzing their ventilation performance shows that these two options have no heat loss through the external natural ventilation, which might be traced back to that the software has weakness in simulating air flow through big horizontal openings [21] (Fig.4). This prevents them from releasing the hot air, which changes the courtyard to be a thermal store [18], while in the other three options, external natural ventilation helps to get heat loss during the night time.

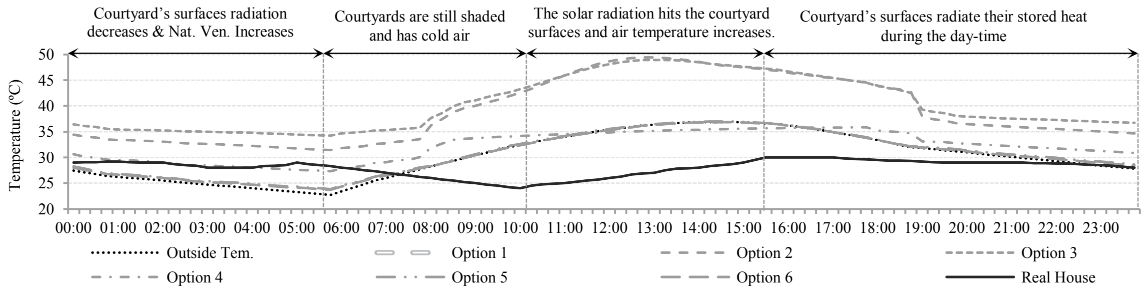

Fig.3. The air temperature in the tested options and its interaction with the main effective environmental factors

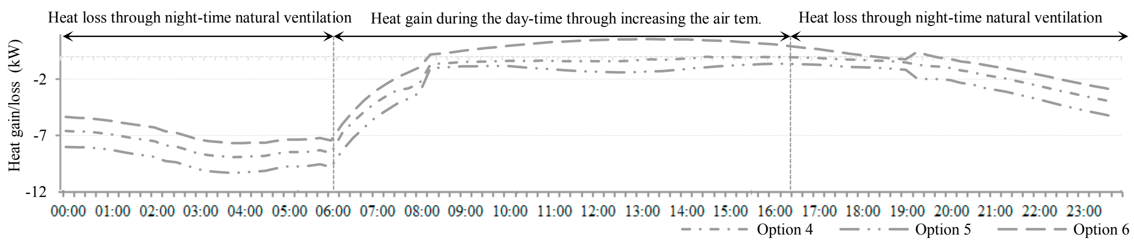

Fig.4. Heat gain and loss in (KW) in the courtyard spaces resulted from the external natural ventilation

Looking at the courtyard interaction with the surrounding spaces shows that options (4), (5) and (6) are closer to the real life performance in term of natural ventilation than options (2) and (3). The simulation results in (Fig. 5) show that the former three options' courtyards get heat gain during the night time due to the air exchange with the surrounding spaces, by which the courtyard surrounding spaces discharge their hot air to the courtyard to be replaced by cold one through the buoyancy force. This cannot be seen in options (2) and (3) where the difference between their spaces and the courtyards' air temperature is much less than the difference in the other three options (Fig.6). This low level of ventilation in options (2) and (3) leads to having higher air temperature in these two options' spaces (Fig.7). The first option's courtyard surrounding spaces air temperature pattern is similar to options (4), (5) and (6), but with lower values. Although this option's courtyard conditions are unmeasurable, building on the other options performance analysis, the lower values might be due to the higher ventilation level as the spaces are directly opened to the courtyard.

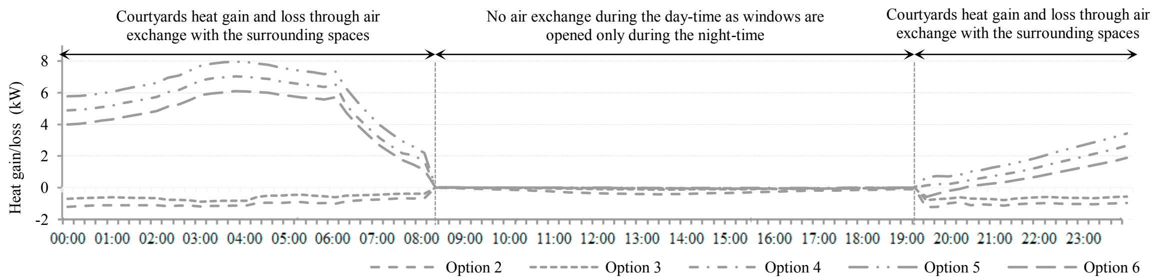

Fig.5. Average heat gain and loss in (KW) in the courtyards resulted from the air exchange with the surrounding spaces

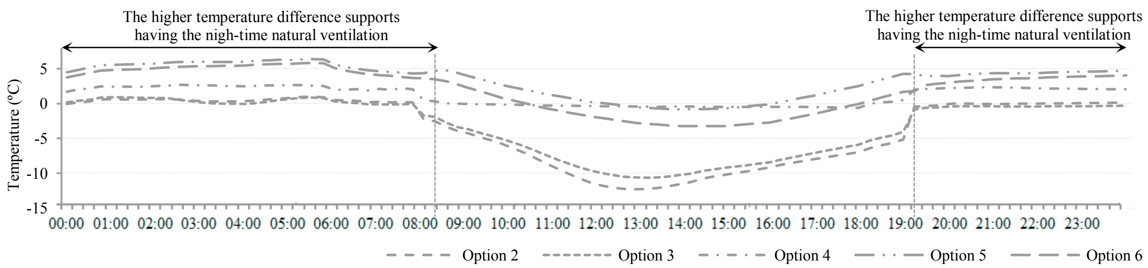

Fig.6. The difference between the average air temperature of the internal spaces and the courtyards
(Average spaces Air Temperature – Courtyard Air Temperature)

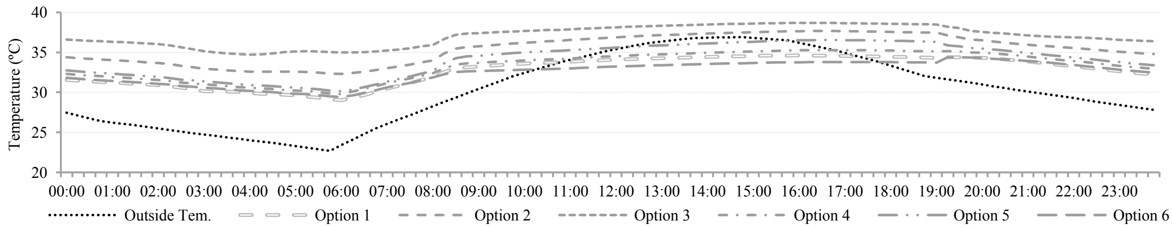

Fig.7. The average air temperature in the courtyards surrounding spaces

Building on this analysis, it can be said that DesignBuilder is not appropriate to simulate the courtyard space. Although the simulation results indicate reasonable air movement between the courtyard and the internal spaces, in options (1), (4), (5) and (6), they do not reflect the actual courtyard thermal behavior. They show that it is mostly affected by the outside temperature, which is not the case in the real life, as what have been discussed earlier.

5. Conclusions and Recommendations

Within the effort to investigate and analyze the courtyard pattern for being an energy efficient and environmentally comfortable pattern for hot regions, this study investigates the possibility of using DesignBuilder, which is one of the widely considered simulation software, to simulate the courtyard building thermal performance, with a special focus on the courtyard space. The results showed that, although DesignBuilder provides a tool to model the courtyard space and has validated simulation systems, it has difficulties simulating the real courtyard space behavior. The simulation results seem to indicate that the software does not fully capture the impact of surfaces heat radiation and natural ventilation during the night and shading impact during the day time on courtyards' thermal conditions, which are among the main environmental strategies of the courtyard building. This leads to having results showing high heat gain and high air temperature as well as skewed performance pattern. Accordingly, this research recommendation is that modeling and simulating the courtyards thermal behavior remains tricky in DesignBuilder, and the same might be applied to other simulation software.

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