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Impacts of Courtyard Geometrical Configurations on Energy Performance of Buildings

Abdulbasit Almhafdy[1], Norhati Ibrahim[2], Sabarinah Sh Ahmad[2]
[1] College of Architecture and Planning, Qassim University,
Buraydah, Qassim, Saudi Arabia
[2] Faculty of Architecture, Planning and Surveying, University Teknologi MARA
Shah Alam 40450, Selangor, Malaysia

a.almhafdy@qu.edu.sa, norhati102@yahoo.com, sabar63@uitm.edu.my
Tel: +966 559192077

Abstract
The courtyard is an architectural design element often regarded as microclimate modifiers. It has the potential of improving comfort conditions within the outdoor courtyard space and the enclosing indoor spaces. Harnessing the optimum benefits of courtyards depends on several conditions namely the orientation and configurations of the courtyards, as well as the treatment of the external surfaces of the enclosing building envelopes. As three variables of orientation, number of floors and wall envelope have not been investigated in a single study, therefore, this parametric study was performed to investigate the microclimatic influence of varying courtyard geometric configurations and its enclosing facades in hot and humid climate using IES<VE> simulation tools. The study observed the environmental impact regarding thermal performance and energy consumption of the enclosing indoor spaces. The results suggest optimum conditions to harness the potential of courtyards to lower energy consumption of buildings in the tropics.

Keywords: courtyard; thermal performance; energy consumption; simulation

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1.0 Introduction

In essence, courtyards are originated from the ancient architecture of the Middle East and early Europe as well as other primeval civilizations (Al-Dawoud, 2006). Courtyards, in particular, their physical forms, have been continuously influenced and characterized by social and environmental forces in different eras, regions and climates towards successfully addressing the occupants needs. Over many years ago, the basic form of courtyards has been modified to fulfill many environmental and social attributes such as geographical settings, micro-climatic parameters, site restrictions, building orientation and functional activities for development of modern courtyards with adapted formal shapes (Y. Wang, 2006). In this line, considerable attempts based on theoretical investigations, field studies and simulations are observed to further enhance the effectiveness of the sustainable energy performance of courtyards in current and future built environments (Reynolds, 2002; Saeed, 2007).

Recent studies reveal that courtyards have numerous benefits with views to social, cultural, economic and environmental dimensions. Reviewing recent studies, it is postulated that the majority of recent research implementations have mainly pointed out that the main reason of courtyard application in buildings is to respond to the climate requirements; hence, it represents the significant role of the environmental dimension (Al-Masri & Abu-Hijleh, 2012; Aldawoud, 2008; F. Wang & Liu, 2002). Based on that, looking into the focus of this study, the quality of environmental performance can be affected by modifying the design variants of courtyards including size, enclosed wall envelope, orientation, exposure (Al-Mumin, 2001).

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2.0 Definitions and Interpretations

The courtyard is an enclosed area surrounded by buildings or walls and opened to the sky (Edwards, Sibley, Hakmi, & Land, 2006). According to (Architecture, 2014), it is stated that *"Courtyard is an open area enclosed by walls or rooms, not accessible to the general public. Usually there is a wrought iron, brick, or stone fence around the areas not confined by buildings"* From another viewpoint, according to (History, 2014), courtyard is defined as *"An area open to the sky and mostly or entirely surrounded by buildings or walls; a high interior usually having a glass roof and surrounded by several stories of galleries or the like"*

The emergence of courtyard goes back to 3000 BC. It has been mainly used in settlements to bring in natural environments while enjoying privacy and safety. Back to 500 AD, the house building designed with multi courtyards that linked through corridors. Later on, the courtyard has also been used to accommodate various functional spaces such as kitchen, families gathering area, as well as dedicated spaces for events such as festivals and even for keeping animals (Lewcock, 1986).

From time to time, courtyards appear in public buildings for diversified functional purposes based on the multi-courtyard concept. After that, the integration of courtyards is observed with different configurations of design variants such as shapes, walls, opening and other parameters. This background scrutinizes the generation and the evolving cycle of new ideas for the design of modern courtyards (Reynolds, 2002).

Implicitly, the design variants of courtyards including length, width, height and ratio depend on the type of functions and vary among regions and in some cases, among houses or buildings owners (Al-Masri & Abu-Hijleh, 2012). The respective differences depend on the social and cultural conditions, financial standards and most importantly, environmental characteristics embracing geographical and micro-climatic conditions as elaborated in the following sections.

Indeed, the courtyard is an environmental element as open space within buildings, cluster or urban fabric, fulfilling various functions, social requirements, and microclimatic needs (Jamaludin et al., 2018 Saeed, 2007). The importance of courtyards is due to their location in centralized focal areas of the building or urban setting. Design variants like arcades, colonnades for producing shading enhances the thermal and visual comfort within the courtyards while integration of landscapes with water bodies, various plants, shade and light, play a fundamental role in the optimization of the environmental performance of these spaces plus improving the social interactions, productivity, working life and ultimately, well-being (Berkovic, Yezioro, & Bitan, 2012). Reviewing recent studies (J. Rodríguez, 2018; Acosta, Navarro, & Sendra, 2013; Kim, Yang, & Kang, 2014), it is deduced that the design of courtyards could be highly influential in providing thermal, visual and acoustic protections, alongside their potentials for promoting social activities. Hence, to provide the optimum level of comfort, and enhanced environmental performance, this study draws attention to the consideration of assessing geometrical configurations of courtyards and versatile alternatives and scenarios during the early design stage (Almhafdy, Ibrahim, Ahmad, & Yahya, 2013). From another perspective, it is identified that the passive cooling system is predominantly an inherent part of courtyards for enhancement of the environmental performances. In this regard, the impacts and interrelations of various aspects such as ventilation (Rajapaksha, Nagai, & Okumiya, 2003), spatial features (Safarzadeh & Bahadori, 2005), solar heat and shading (Muhaisen & B Gadi, 2006; Muhaisen & Gadi, 2006), thermal comfort (Aldawoud, 2008), energy efficiency (Aldawoud & Clark, 2008) and geometrical configuration must be fully taken into consideration prior to any practical implementations (Al-Mumin, 2001).

This paper focuses on courtyards for its role as an environmental modifier, particularly in the context of tropical climate. The argument is that while courtyards have been investigated by many researchers, there remain gaps for further research to document its design factors and assess the impact of courtyard design tendencies on the energy consumption of the surrounding buildings, i.e., the attached built volume.

Many studies have pointed out that the main reason for using a courtyard in a building is to respond to the climate requirements. Based on that, the courtyard can be affected by several factors such as wall envelope, orientation and number of floors.

Thus, this paper explores the thermal performance of a selected courtyard as a building element, under various design settings of exposure, orientation, internal opening percentage and window wall ratio (WWR). This is accomplished through a relative study of a courtyard's thermal performance using parametric study.

3.0 Methodology

Despite the limitation of previous studies mainly focusing on the examination of the fully closed (O-shaped) courtyards, in this parametric study, three different configurations of courtyards including O, U, and L shaped courtyards are investigated and analyzed based on the identified key design variants as elaborated and demonstrated in the following sections.

3.1 Modeling Approach

The focal point of the simulation process is to analyze the energy performance of courtyards and their effect on the energy consumption of the adjacent rooms for the proposed model and the respective options. A 3D computer model is created using IES <VE> software to investigate the energy performance of courtyards. The 3D computer model represents a classic enclosed four-sided courtyard.

This courtyard is square in plan with the basic size of 4m × 4m. The courtyard is centrally located within a 12m × 12m building footprint (See C shape in Figure 1). The design requirements including materials of the building, model generating and timetable are considered for the simulation process. Easily obtainable weather data in the format of APL in IES <VE> is used for the selected location of Kuala Lumpur. The simulation resolution is in 1-hour increment. The building materials are selected to represent a heavy construction. Adjacent spaces height is 2.7 from floor to ceiling and the acoustic tiles are selected for the interior finishing of the ceiling.

Regarding the enclosed wall of the courtyard, a curtain wall design elements of glass is selected as a wall envelope. The floor is of concrete with carpet interior finish 0.15m thick. Moreover, the internal environment is modeled as fully conditioned.

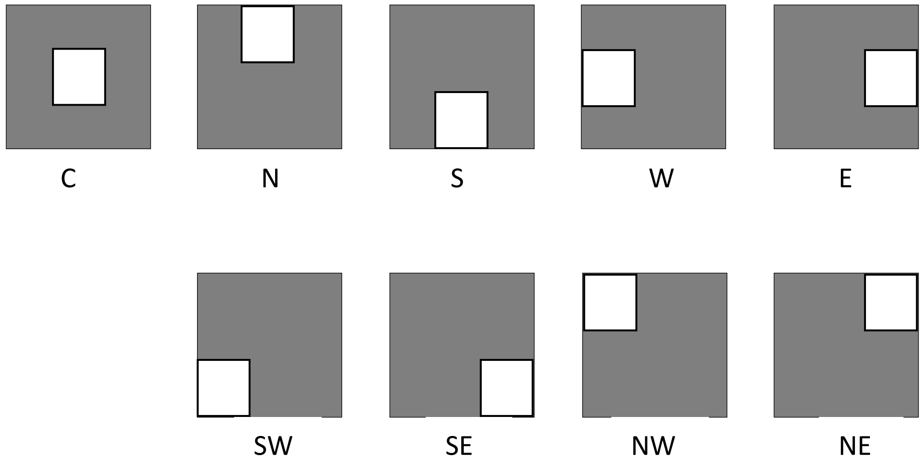

Figure 1. The different positions and orientations of courtyard used in this study

3.2 Analysis

As shown in figure 2, five main design variants are investigated in this study and they are as follows:

- **Form:** As illustrated in figure 2, three different shapes of the courtyard are investigated as O, U, and L shapes. The location and direction of each courtyards are accordingly explained in the orientation section.
- **Glazing Types:** Four glazing types are selected and investigated for internal courtyard walls including single clear, double clear, double low-e and triple glazing.
- **Window wall ratio (WWR):** Two ratios are selected for this study, 30% and 65% as they are most common in architectural practices.
- **Number of Floors:** The simulation will be run on each floor, in particular from 1 to 10 floors.
- **Orientation:** The models are oriented in nine directions and with different geometries depending on the respective direction. The central (C) courtyard is four-sided, the north (N), south (S), west (W) and east (E) are three-sided and northeast (NE), northwest (NW), southeast (SE) and southwest (SW) are two-sided.

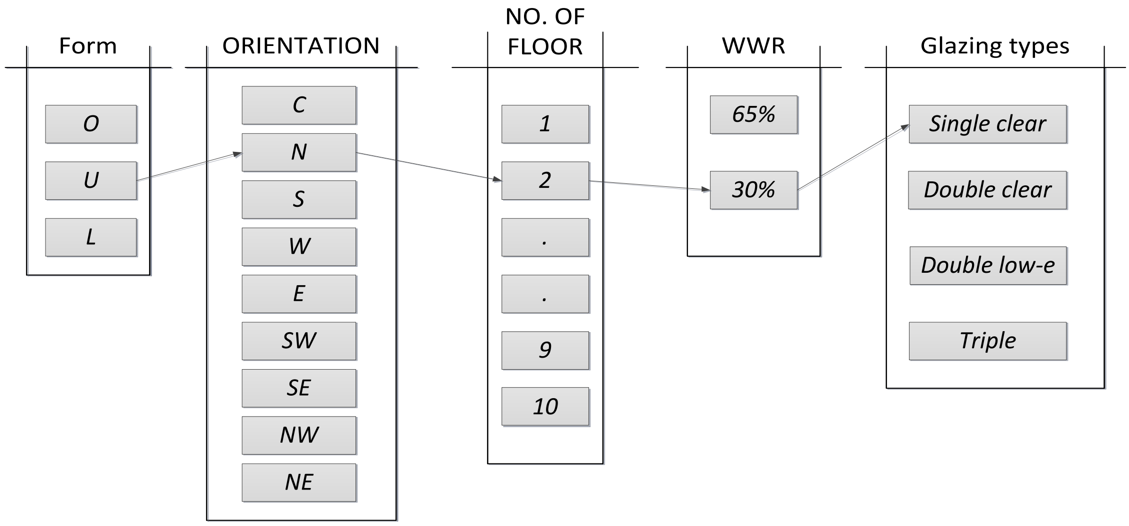

Figure 2. Different design variants scenarios tested in simulation software

4.0 Findings and Discussions

Findings indicate that the energy performance of courtyards has significant differences based on the glazing type and WWR, unlike orientation that shows slight differences.

4.1 Glazing Types

Figure 3 explicitly represents that courtyard C surrounded with walls fitted with single clear glass recorded the worst energy performance as the glazing is not insulated causing high heat exchange between the courtyard and the outdoor ambiance.

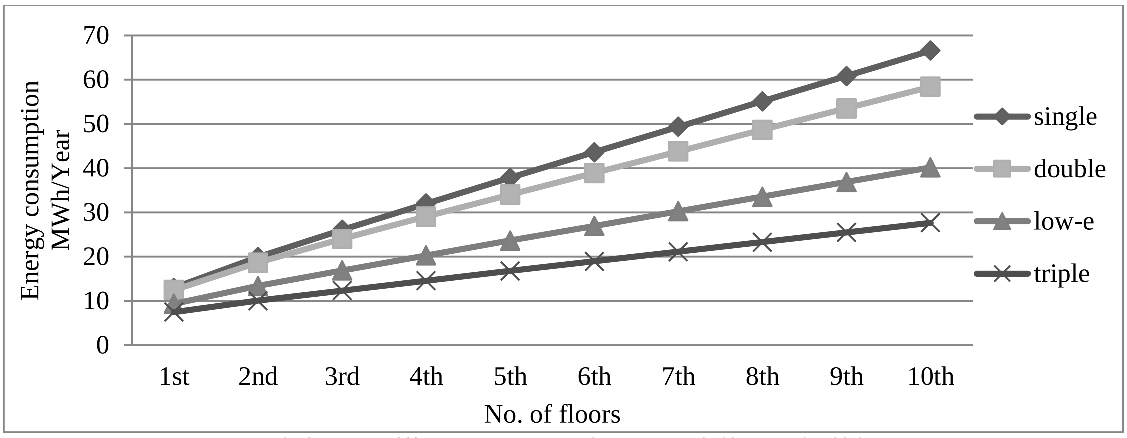

Figure 3. Courtyard (C) glazing energy performance at 65% WWR for 10 floors

As shown in table 1, the courtyard C's energy performance of different type of glazing with 65% WWR of glazing compared with the performance of the same courtyard C which have single clear glass with the same WWR of glazing at 10 floors. Besides that, the double clear glazing provides more of a barrier to temperature exchange between the indoor and outdoor environment. Thus, applying double clear glass on the surrounding walls shows better energy performance than courtyard with single clear glass. The double clear glass reduces the total energy consumption by 12.29% at 10 floors (Table 1). In an upward trend, the use of double low-e glass on the courtyard walls shows optimized energy performance than courtyard having double clear glass. Courtyard walls fitted with triple glazing encompass the most significant effects on the energy performance due to the minimization of energy consumption by 58.45% (Table 1).

Table 1: Courtyard(C) energy performance compared with energy performance of courtyard having single clear glass with 65% glazing at 10 floors.

Courtyard (C)	Energy Consumption [MWh/Year]	Reduction in Energy Consumption (%)
Courtyard/single clear glass	66.57	
Courtyard/double clear glass	58.39	-12.29
Courtyard/double low-e glass	40.19	-39.63
Courtyard/triple glass	27.66	-58.45

On the other hand, when the WWR in courtyard C is reduced from 65% to 30%, there is a significant decrease in energy consumption as the heat exchange between the courtyard and the outer environment is less (Table 2). The energy performance of four types of glazing illustrates an upward trend from single clear glazing being the worst and the triple glazing as the best (Table 2). Courtyard(C) with double clear glazing saves 10.47% of the total energy consumption at 10 floors over the same courtyard which have single clear glass. The energy consumption is reduced by 31.94% with double low-e glass and 46.37% with triple glass at 10 floors (Table 2).

Table 2: Courtyard(C) energy performance compared with energy performance of courtyard having single clear glass with 30% glazing at 10 floors.

Courtyard type	Energy Consumption [MWh/Year]	Reduction in Energy Consumption (%)
Courtyard/single clear glass	40.90	
Courtyard/double clear glass	36.61	-10.47
Courtyard/double low-e glass	27.83	-31.94
Courtyard/triple glass	21.93	-46.37

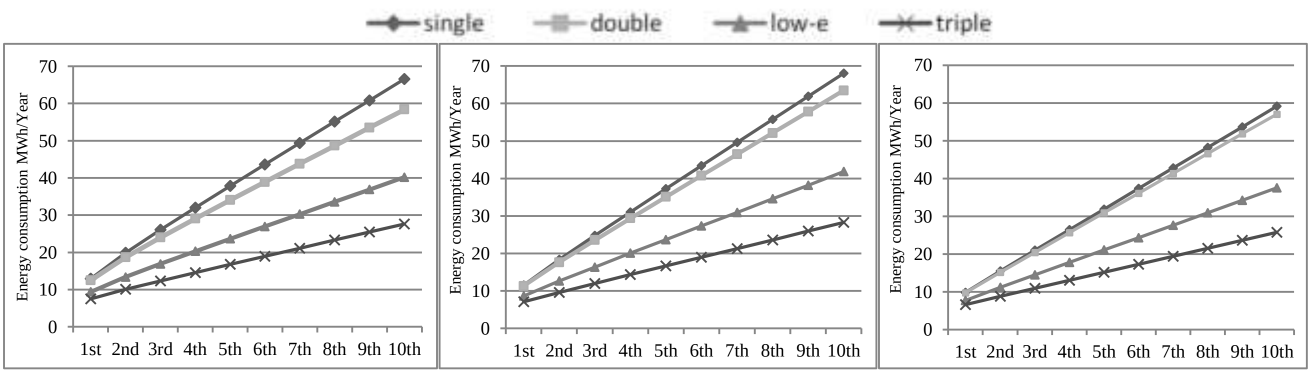

Figure 4. Energy performance in different location and orientation of courtyard

The other courtyards that are three-sided (N, S, E, W) or two-sided (NE, N, SE, SW) have almost the same trend of energy performance, however, the last have less due to the less WWR of glazing. More discussions about these courtyards are provided in the third variable which is orientation.s

4.2 Number of Floors

Based on the simulations, the results rationally prove that as the number of floors increases, the consumption of energy increases in tandem. Figure 4 shows three different graphs of courtyards' energy performance (C, E & SW). As shown in the graphs, the relation between energy consumption and number of floors are in ascending order. It is clear that the line representing the single clear glass is ascended rapidly while the line representing the triple glass is less ascending in comparison to the single clear glass. However, the identified difference between single clear glass and double clear glass is very slight, but it is increased as the number of floors is increased.

4.3 Orientation

The central (C) courtyard is four sided. The North (N), South (S), West (W) and East (E) courtyards are three-sided; while North East (NE), North West (NW), South East (SE) and South West (SW) are two-sided.

Table 3. shows the reduction in energy consumption of all types of courtyards that have different WWR and directions compared with energy performance of courtyards having single clear glass with 65% glazing at 10 floors.

Although the WWRs of courtyards are the same (65%), the energy consumption of courtyard (E) is the worst while courtyard (N) is the best. The energy performance of the courtyard with walls made up of 10 floors with 65% WWR of triple glass is reduced by 58.00% for (N), 58.45% for (S), 58.47% for (E), 58.36% for (W) when compared with the same courtyard with single clear glass.

Table 3. Reduction in energy consumption of all types of courtyards that have different WWR and directions compared with energy performance of courtyards having single clear glass with 65% glazing at 10 floors.

Courtyard	Area of the facadem2	WWR of the courtyard with 65% at 10 floors		Energy consumption of single clear	Reduction in energy consumption		
		Window percentage %	Wall percentage %		double clear	low-e	triple
C	48	31.2	16.8	66.6	-12.3	-39.6	-58.5
N	36	23.4	12.6	66.2	-7.1	-38.2	-58.0
S				66.7	-7.0	-38.3	-58.1
E				68.1	-6.8	-38.5	-58.5
W				67.3	-6.9	-38.5	-58.4
NE	24	15.6	8.4	59.7	-3.4	-36.6	-56.2
SE				60.2	-3.4	-36.6	-56.7
NW				59.1	-3.5	-36.6	-56.5
SW				59.4	-3.5	-36.6	-56.6

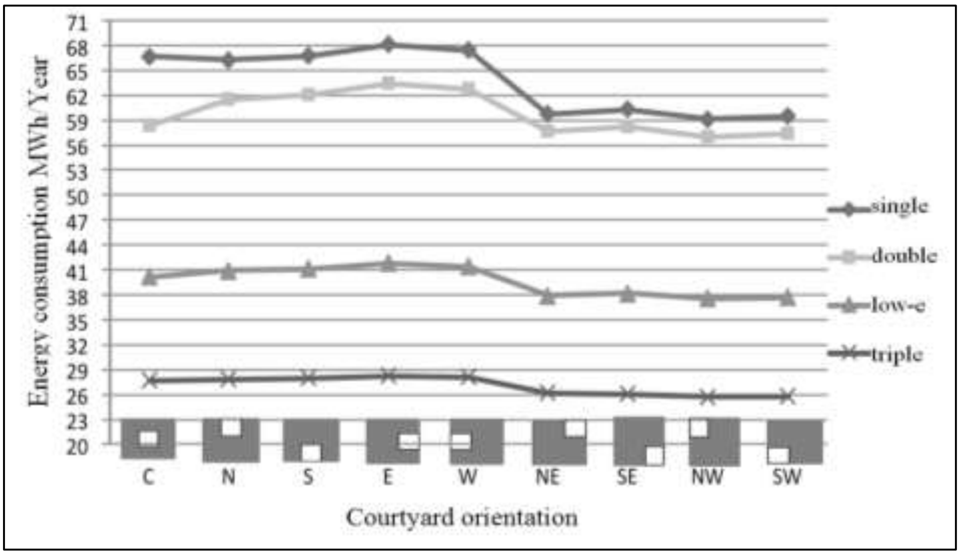

Figure 5. Energy performance of all courtyards types and their energy consumption at 10 floors for four types of glasses with 65% WWR

Moreover, Although the courtyards oriented to the secondary directions (NE, NW, SE and SW) have less percentage of glazing "e.g., 50% less glazing compared with (C)" as they are two-sided, Figure 5 demonstrates that the reduction of energy performance is very low in comparison with the other courtyards (C) or (NE, NW, SE, and SW).

Table 3 indicates the two-sided courtyards that orient to the secondary directions (NE, NW, SE, and SW). Hence, the energy consumption of the courtyard (SE) is the worst while the optimum energy consumption belongs to the courtyard (NW). The energy performance of courtyards with walls made up of 10 floors with 65% WWR of triple glass is reduced by 56.17% for (NE), 56.50% for (NW), 56.74% for (SE) and 56.58% for (SW) compared to the same courtyard with single clear glass.

On the other hand, although courtyard (C) has more area of the facade (four-sided) compared to the others, it remains the best in terms of energy performance. Likewise, although courtyard (C) encompasses the largest WWR compared to the others courtyards, slight differences are the recorded between them regarding energy consumption.

5.0 Conclusions

The energy performance of courtyards has significant effects based on many variables such as shape, orientation and wall enclosure. Although the courtyard (C) has more WWR of glazing, thermal performance was better than others that have less WWR of glazing. Simulation results of courtyards with the cardinal directions shows courtyard (E) has performed better than the others. However, for the intercardinal directions, the courtyard (SE) performed the best. In general, the more enclosed the courtyard, the less energy consumption were observed.

6.0 Future Work

The study was based on the simulation process only; an interesting direction of future work can go for fieldwork to apply data collection process that can help for the validation purposes. another direction can focus on the integration of thermal and daylight in the courtyard design aspects.

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