PLANNING MALAYSIA:
Journal of the Malaysian Institute of Planners
VOLUME 22 ISSUE 4 (2024), Page 385 – 396

MODELLING STUDY ON CENTRAL COURTYARD SHADING STRATEGY IN TROPICAL CLIMATE REGION MALAYSIA

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Abstract

A courtyard is an open multi-functional space and an effective daylight passive design strategy in a building. However, to have a courtyard in a tropical country, it had to deal with the issue of visual discomfort, which requires some consideration in adaptation to the climate condition. These visual comfort issues include inconsistent light distribution, inappropriate illuminance levels, glare, and a lack of shaded areas. The focus of this research paper is to address the solution of shading strategies towards the visual discomfort issues associated with courtyard spaces. The solution is done by modelling study method on courtyard ratios and courtyard configuration to determine the effect on the internal courtyard percentage shaded area. This research aims to explore the potential benefits of using courtyards as a daylight shading design as a strategy in buildings. Besides, it is also to examine courtyard design variables in enhancing visual comfort, particularly in the context of commercial building design in Malaysia. Kuala Lumpur is chosen to represent the tropical climate region. The aim is achieved by identifying optimum courtyard ratios that can improve daylight, shading, and visual comfort that make courtyards functional and usable spaces. Results show that a small and deep courtyard is found to be best suited to tropical climate conditions with the configuration of the courtyard's height being double the size or more than the size of the courtyard's width. This courtyard ratio is able to produce a full shaded area during daytime. While courtyard length does not have any impact on the percentage of shaded area, wide and narrow courtyard need to adapt to the tropical climate constraint by having aided shading strategies such as multi-layered height of trees, independent covered structures like a canopy or gazebo, shading panels, awnings, and extended roof overhangs.

Keywords: Courtyard, Shading Strategy, Commercial building, Visual comfort

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INTRODUCTION

Courtyard can be one of the passive design strategies for commercial building design in solving massive design issues and acting as a central hub of public activities (Mee, 2021). Other than thermal comfort, achieving good visual comfort carries the same crucial consideration in designing a space or a building. Despite the significant advantages of courtyards, research initiatives towards courtyard design requirements are scarce (Markus et al., 2017), especially in terms of daylight and visual comfort. As courtyards are imported from hot and dry regions (Edwards et al., 2006), there is a need for adaptation to tropical climate conditions. The allowable natural lighting in tropical climate regions might not work independently facing hot and intense solar radiation, which consequently causes discomfort and overexposure (Guedouh & Zemmouri, 2017). This leads to visual discomfort issues for occupants who like doing activities in outdoor protected areas such as courtyards.

One of the visual discomfort issues identified at the courtyard includes inconsistent distribution of light. According to Indoor Environment and Well-Being-The Saint Gobain Building Science Handbook (2016), inappropriate illuminance whether too little or too much light can have a negative effect on the visual performance of the user when doing certain tasks such as reading, typing, and eating. Due to the inconsistency of light distribution, it leads to an uncontrolled illuminance level in the courtyard area. The other issue is glare as a courtyard is an open space exposed to direct sun exposure. According to Fekry, Elshazly and Almrazky (2015), the difficulty of doing various activities in an open space due to sun exposure led to an increase needs for specialised indoor space for other activities independently such as a hall and entertainment area. Besides that, issues of a lack of shaded areas are also part of the constraints that are affected by the tropical climate. Courtyard open space with a lack of shades always left empty or treated with minimal architectural and landscape elements leads to courtyard dysfunction, thus defeating the purpose of its existence in the first place (Madihah et al., 2022). All of these constraints contribute to the aim of the research, which is to seek an architectural approach that can help improve daylight, shades, and visual comfort that makes the courtyard a functional and usable space but is adapted to the tropical climate in Malaysia.

This paper identifies courtyard strategies for achieving visual comfort. By identifying courtyard criteria that relate to visual comfort, shading strategy as one of the visual comfort parameters is focused in order to investigate **c**ourtyard configuration to optimize shading, daylight, and visual comfort in tropical regions. The investigation examines the ranges and ratios of the courtyard that have a significant effect on the shaded area cast in the courtyard. Then, by studying the ranges, courtyard ratios that can achieve optimal visual comfort performance at the central courtyard are suggested.

LITERATURE REVIEW

Courtyard Criteria

Courtyards originated from the hot and dry regions (Edwards et.al., 2006) and have evolved in architecture for many centuries, from the 10th millennium B.C. until today in a modern world, expanding from both Eastern and Western countries. Starting from a small courtyard house, it later developed into a larger building such as a university or institutional building (Rong & Azizi, 2023). Though it has evolved in terms of its functions, courtyard characteristics and criteria share similarities across all regions. Literature review and observation of all commercial buildings with courtyards around Kuala Lumpur and Selangor were conducted, analysed and summarised. From these studies, it is concluded that the criteria for a courtyard consist of form, orientation, layout, ratios, elements, wall treatment, material, and colour. Based on its significant effects, only these criteria are selected: form, orientation, layout, and ratios.

Courtyard Form

In terms of courtyard form, it comes in two categories. The first category is based on forms (square, rectangular, circular, curvilinear, and others) and the second category is based on shape (O, U, L, T, Y, and others) (Ranjit, 2019). Rectangular and square forms are the most commonly adopted for a courtyard, even though there is no particular form that is considered the most suitable (Almhafdy et al., 2013).

Courtyard Orientation

In terms of orientation, one of the most important factors that affects the duration of sunlight in building design is site layout. There are two main issues affecting site layout: orientation and overshadowing (Paul, 2011). The factors with a direct impact on courtyard micro-climatic behaviour include the location of the sun, the direction of the wind, the shading effect, and radiant heat (Bagneid, 2006).

Courtyard Layout

Meanwhile, for the layout criteria, the spatial layout of the courtyards can be divided into four categories: centralised layout, decentralised layout, serial layout, and combined layout. In centralised layout, the courtyard space is at the core and becomes a central point of design. Decentralised layout is where the courtyard is surrounded by buildings, structures, and plants, with the buildings being scattered in the courtyard and connected by corridors. The serial layout is derived from the layout by organising spaces through a series of courtyards with a strong spatial sequence. The combined layout merges the first three layouts, with a courtyard system not only visible in the overall layout but also in its different sections (Sun et al., 2019).

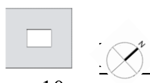
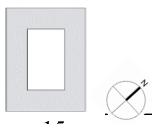
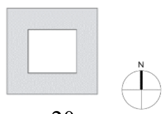
Courtyard Ratio

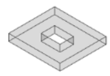
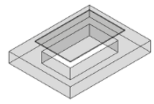
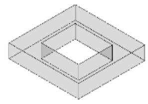
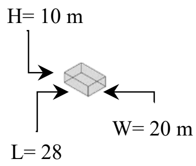
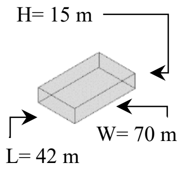
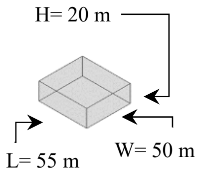
Mohsen (1979) developed a geometrical descriptor to have a better understanding of the courtyard's geometrical influences through several ratio descriptors, that are: R_1 as the ratio of perimeter to height (P/H), R_2 as the ratio of width to length (W/L), and R_3 as the ratio of the area of the top opening to the area of the ground (At/Ag). Besides that, Reynolds (2002) also described the courtyard descriptors as AR which is equal to the ratio of width to height (W/H), which is called the Aspect Ratio.

Comparative Studies

Every commercial building in Kuala Lumpur and Selangor with a courtyard was identified, observed, and analysed. Then, suitable case studies were selected based on the preset criteria. Three buildings that have been selected and meet the criteria are The Linc (Kuala Lumpur), Bangi Gateway (Selangor), and Tamarind Square (Selangor). However, each case study has its own constraints in the daylight shading strategy; each of the courtyards has been either covered by a roof or planted with trees. In solving the problem of the constraint, a based model was synthesised for the simulation method by building a courtyard model that can meet the optimum courtyard criteria.

Table 1: Courtyard criteria comparative case studies.

Criteria	The Linc	Bangi Gateway	Tamarind Square
Courtyard Plan			
Nos of Storey			
Building Height	10 m	15 m	20 m
Total Site Area	3.67 acre	6.0 acre	14.5 acre
Total Plan Area	8 860 m2	17 000 m2	33 000 m2
Courtyard Area	890 m2	2 940 m2	7228.5 m2
Courtyard Type	Open courtyard enclosed by 4 blocks	Covered courtyard enclosed by 4 blocks	Open courtyard enclosed by 4 blocks
Courtyard Form	Cube type	Flat Type (Square plan)	Cube type
Courtyard Layout	Decentralised	Centralised	Centralised
Courtyard Orientation	North West	North west	North
Courtyard Opening Ratio	10%	17 %	21.9 %

Criteria	The Linc	Bangi Gateway	Tamarind Square
Building massing			
Courtyard massing			
Courtyard Configuration	Small and deep	Wide and shallow	Wide and deep
Courtyard Ratio (Width: Length: Height)	2:3:1	10:6:2	5:5.5:2

RESEARCH METHODOLOGY

Simulation

Based model was developed for the purpose of comparative studies. From the comparative studies, shop lot is found to be the preferred approach as perimeter space in commercial building with courtyard. Shop lot size was constructed with the size of 6096 mm x 24384 mm (20 ft x 80 ft) based on the standard size of shop lot in Malaysia. Each side of the courtyard perimeter consists of four shop lots. Thus, this configuration creates a square shape of courtyard with the size of 24384 mm x 24384 mm with corridor all around in 3000m length, following the reference size of the smallest courtyard taken from comparative case studies, The Linc, Kuala Lumpur. Meanwhile, the high of each floor was set at 4m, for floor-to-floor height, referring to the standard height of commercial buildings in Malaysia.

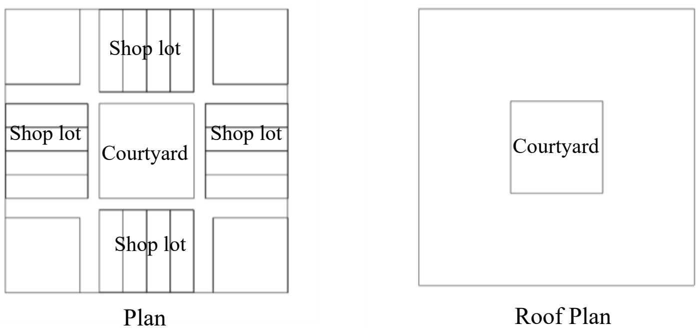


Figure 1: Based model layout for courtyard simulation

Study Parameters

The location of the study was set out at the capital city of Malaysia, Kuala Lumpur. The tropical region of the Earth is generally defined geographically as the area between 23.5° to the north latitude and 23.5° to the south latitude from the Equator. The city is located in west-central Peninsular Malaysia, with a latitude of about 3º North of the Equator (3ºN, 101ºE). The study was conducted on two different days in March and December, as in both days the sun represents the two extremes. March represents the highest noon altitude and December represents the lowest noon altitude (Zain et al., 2002). The two days fall on Sunday for each month, as Sunday was considered the most peak day for commercial buildings to be operated throughout the week.

Figure 2: Map of Malaysia and location of Kuala Lumpur
Source: mapsofworld.com

The simulation timing set up is from 10 a.m. to 10 p.m. based on commercial opening hours. However, only from 10 a.m. to 6 p.m. is the daylight exposure hour. Then, the time period for each simulation was divided into four phases of time in a day during the most peak hours. The phases were according to the dining hours: late breakfast (10 a.m.-11a.m.), lunch (12 p.m.-3 p.m.), tea (4 p.m.-5 p.m.), early dinner (6 p.m.). This dining hour was considered a simulation period because it is a peak hour for public to come and visit the commercial building and a crucial hour to consider the shading strategies for outdoor dining space at courtyard.

There are three variables involved in this research, namely courtyard height, courtyard orientation, and courtyard ratio. For courtyard height, the height is set at 2 storeys as the minimum height and 6 storeys as the maximum height. Each story height was set at 4 meters for floor-to-floor height level. For the second variable, courtyard orientation was examined in two stages. The first stage was to orient the courtyard towards North, South, East, and West. Then the simulation results were compared to the second stage of courtyard orientation that is facing towards North-East, North-West, South-East, and South-West. The last variable is courtyard ratios, and the ratios were divided into two ratios. The first ratio, R_1, is a ratio of courtyard width to building height (W:H). Height in this simulation case is referring to the height of one block that casts shade area at the courtyard, while the other 3 blocks will remain constant. The height was added consistently according to the ratio of 1:0.5 to 1:>2 as per Table 2. The second ratio, R_2, is a ratio of courtyard length to building height (L:H). In this case, the procedure was done by simulating the model into four ratios. Two sets of simulation models were set at constant length but with different heights, as per Table 3. The first set of the model height was set at same as the courtyard length, while the second set of the model height was set at twice the courtyard length.

R_1 = Ratio of courtyard width to building height (W:H)
R_2 = Ratio of courtyard length to building height (L:H)

All of the simulation models were facing north except the simulation variable that involves courtyard orientation. The simulations that involve simulation are oriented towards eight main sun path orientations (North, South, East, West, North-East, North-West, South-East, and South-West).

Table 2: Relationship between Courtyard Variables and Study Parameter

Ratio		R_1, R_2	-	-	-	R_2
Height		**2 storeys**	**3 storeys**	**4 storeys**	**5 storeys**	**6 storeys**
Orientation	North	•	•	•	•	•
	South	-	-	-	-	•
	East	-	-	-	-	•
	West	-	-	-	-	•
	North-East	-	-	-	-	•
	South-East	-	-	-	-	•
	North-West	-	-	-	-	•
	South-West	-	-	-	-	•
Time	10 a.m.-11a.m.	•	•	•	•	•
	12 p.m.-3 p.m.	•	•	•	•	•
	4 p.m.-5 p.m.	•	•	•	•	•
	6 p.m.	•	•	•	•	•

ANALYSIS AND DISCUSSION

The simulation was done by determining the variables that affect shading percentage cast on courtyard floor area. There are three variables involved in this modelling study. The variables are courtyard height, courtyard orientation, and courtyard ratio. These variables are a sequence from one finding to another. First, the modelling study was done on height variables. In this study, the highest height was chosen to study the orientation variables to see the effect on courtyard area. Finally, the findings on both variables lead to the final modelling of the courtyard ratio to find out the optimum ratio that provides the highest percentage of shaded area at the courtyard.

Independent Variables 1: Courtyard Height

The courtyard height simulation result is as per Figure 2. From the simulation, it is to find out that the percentage of shading area cast on the courtyard floor area is increased as the height is increased. Shadow is cast the most for 6 storey height and the least at 2 storey height. Shadow is cast full (or almost full) in the morning during late breakfast time (10 a.m. -11a.m.), during tea and early dinner time (4 p.m. – 6 p.m.) only for 4 storey height to 6 storey height, covering the whole courtyard area, but not for 2 storeys and 3 storeys. Meanwhile, during lunch hour (12 p.m. until 3 p.m.) the least shadow cast at the courtyard area is at 2 p.m., while the most it can reach is only half of the courtyard area. It is justified by the sun path position being at the centre and straight with no obstruction of any building block.

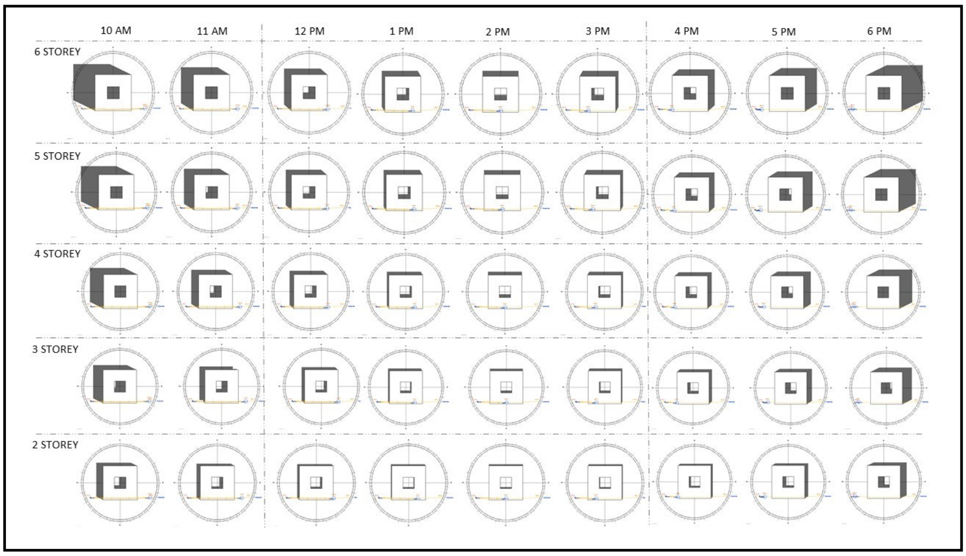


Figure 3: Courtyard height variable simulation result

Independent Variables 2: Courtyard Orientation

The courtyard orientation simulation result is as per Figure 3. From the simulation, it is to find out that the percentage of shading area cast on the courtyard floor area remains constant though the orientation is changed. For instance, during the brightest hour at 2 p.m., the percentage shadowed area is 50% for every sun path position. The percentage is not affected by the changes in the courtyard orientation, but only the position of where it is cast is different. For north-oriented courtyard, the shadow is casted at the bottom part of the courtyard area, while for south-oriented courtyards, the shadow is cast at the top part of the courtyard area. For east-oriented courtyards, the shadow is cast at the right part of the courtyard area, while for west-oriented courtyards, the shadow is cast at the left part of the courtyard area. The percentage of shaded area of all orientations remains the same. This result also remains consistent for North-West and North-East as shown in Figure 3.

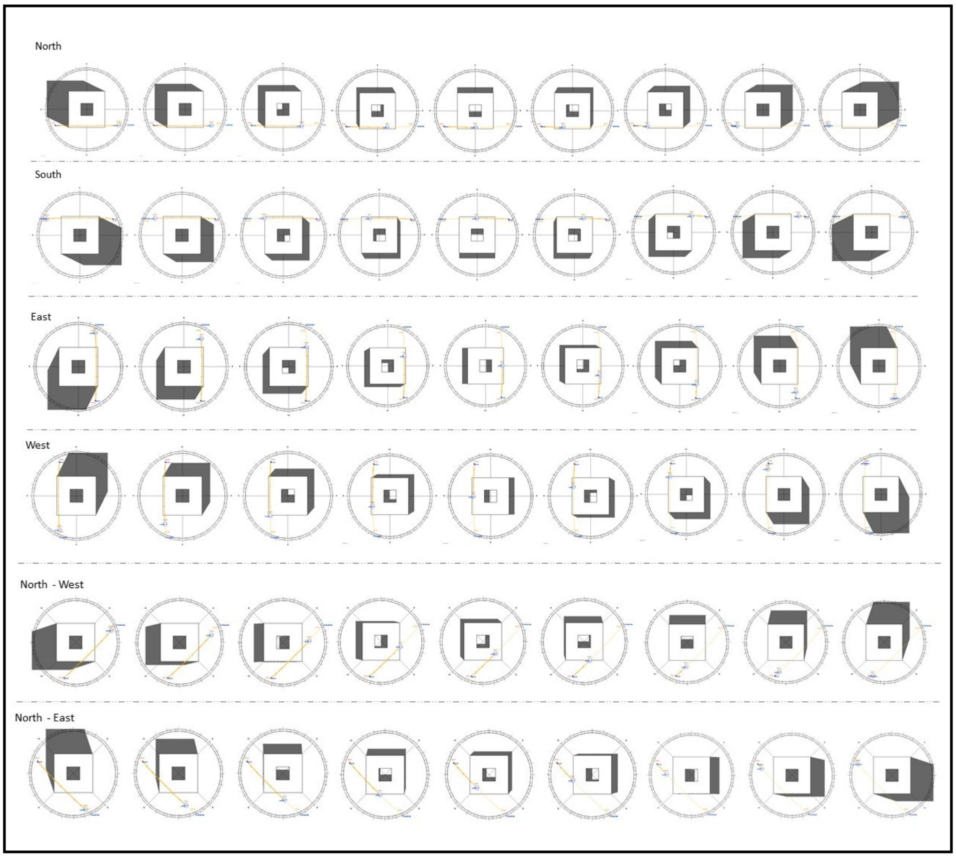


Figure 4: Courtyard orientation variable simulation result.

Independent Variables 3: Courtyard Ratio

The courtyard ratio simulation result is presented in Table 2 and Table 3. From the simulation, it is to find out that the percentage of shading area cast on courtyard floor area is increased as the ratio is increased for simulation R_1. Meanwhile for R_2, the percentage of shaded area remains the same though the length is changed. For R_1 simulation result, when the ratio is 1:1, the percentage of shaded area cast only reaches up to 50%, which means a ratio less than 1:1 will achieve less. Meanwhile, the courtyard only achieved 98% shaded area by the ratio of 1:2. This result indicates that when the ratio is more than 2 (1:>2) only the courtyard floor area will be shaded up to 100%. In this case, as the courtyard is 24m in width, to achieve the ratio of 1:>2, the height needs to be more than 48m.

By the simulation with floor-to-floor level set at 4m per floor, it reaches 100% shaded area at 52m. For R_2 simulation result, as the length is changed from 1:1 to 2:1, no difference is detected in the percentage of shaded area. When the courtyard length is equal to 24m and the height is adjusted at 24m and 52m, the percentage is constant at 50% for both cases. While the courtyard length is equal to 48m and the height is adjusted at 24m and 52m, the percentage of shaded area resulted in 100% for both cases.

Table 3: Courtyard ratio simulation for R_1

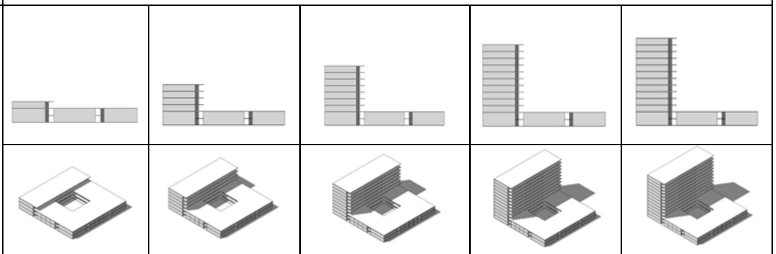
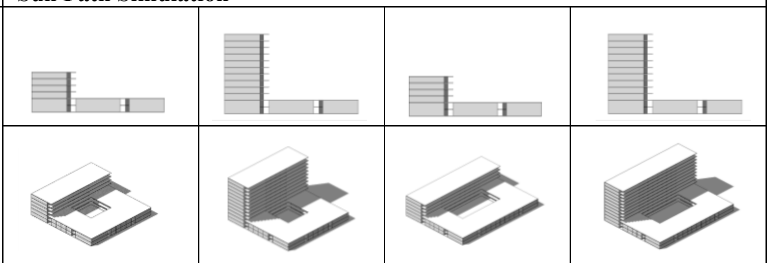
Configuration	Sun Path Simulation				
R_1 = Ratio of courtyard width to building height					
Ratio	1:0.5	1:1	1:1.5	1:2	1:>2

Table 4: Courtyard ratio simulation for R_2

Configuration	Sun Path Simulation			
R_2 = Ratio of courtyard length to building height				
Ratio	1:1	1: 2	2: 1	2:2

CONCLUSION

From this research, it is found that a good strategy for courtyard design in a tropical climate is to design the courtyard with a small size (W x L) but deep in height, as it provides cool shades. Courtyard ratio for width: height (W:H) = 1:2 or 1:>2 is needed to cover all courtyard area with shades at all times (from 10.00 a.m. to 6.00 p.m.). Thus, the courtyard can be functional in the avoidance of glare without any aided shading strategy. Meanwhile, wide and big courtyards will allow more exposure to sunlight in tropical climate conditions. Therefore, it is not advisable to design in such a way as it will not provide enough shade. However, if the courtyard ratio does not meet the ratio of 1:2 or 1:>2 due to design constraints, another aided shading strategy is needed. Added shading strategies suggested to adapt to the tropical climate are multi-layered height of trees, shading panels, awnings, extended roof overhangs, and independent covered structures like a canopy or gazebo.

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Received: 18th Feb 2024. Accepted: 15th July 2024