Impact of Courtyard Position and Height on Indoor Air Temperature With Reference To Hot and Dry Climate in Riyadh

Mamdooh S. Alwetaishi*

Abstract**—**This paper present a study of courtyard position and height on the indoor air temperature in hot and dry climate with a specific reference to the city of Riyadh. There are several variables was investigated in association with indoor temperature such as heat transfer as well as cooling and heating loads. This location was chosen which present the harsh climate in Middle East where courtyard is consumed in order to provide more thermally comfortable environment for both indoor and outdoor. The study used TAS EDSL as a tool to carry out the research where four main locations was investigated central, northern, eastern and western facing courtyards. The study also has highlighted the influence of courtyard height on indoor temperature. The study shows that southern facing direction is not recommended in hot and warm places generally, but it is more beneficial to orient courtyard to it. This will ensure minimum amount of external exposure of sunlight on walls. As a result of this research south and north facing courtyards are recommended in hot and dry climate. Furthermore, height of two storeys courtyard building is the ideal for hot and dry in order to ensure better performance of courtyard in winter and summer.

Keywords**—** Indoor temperature, building performance, courtyard, and courtyard height.

I. Introduction

Courtyard is a building aspect that was emerged in hot regions [1]. However, it is now used in different parts of the world. Courtyard can be defined as an enclosed area which is surrounded by walls and it has no roof to cover from the top. The performance of the courtyard is fundamentally affected by solar radiation penetrated to the internal face of the external walls. Some people are of the opinion that there are many strategies in order to achieve thermal comfort in building depending on the local climate. However, in all the regions there is a need to take the advantage of solar radiation unless it aid to discomfort [2].

Thermal comfort of courtyard in buildings has been inspected by many authors such as Mohsen (1979) [3], Meir (1995) [4], Cadima (2000) [5], Muhaisen (2006) [6], Abdulbasit (2013). Most of which highlighted typical rectangular courtyard forms in hot or temperate climate. The observation of these papers justified that external surfaces of courtyard should be protected from intense solar radiation. However, the impact of courtyard position and orientation was not given enough consideration.

II. Literature review

There are several aspects that affect the performance of courtyard length, shape and height are among the most important factors that have to be taken into consideration. As far as courtyard length and depth is concerned, it is one of the subjects which affect courtyard performance it terms of solar gain and also the total energy load of the rooms surrounding the courtyard. Manioglu [7] and Abdulbasit [8] have carried out a research in hot and dry climate zone and he stated that width and depth of courtyard (CY) has a significant impact on heating and cooling load as well as solar gain. Moreover, the influence of it is greater in winter than in summer. In terms of orienting CYs, in hot and humid climate, orienting the long axis of toward northwest-southwest is recommended as well as north-south axis generally [6]. Baboli [9] has shared the same view in terms the recommended orientation of CYs. This orientation will ensure a breeze to cross the courtyard in summer and also to open access for sunlit in winter in order to warm up the CY passively.

The courtyard geometry shape has a very limited impact on amount of sunlit area to be exposed to the outer surface of CY in winter while in summer the influence is more remarkable [10]. However, As the CY plan become close to the square shape, shade on the internal surface of the geometry area increases and require more energy in summer while in winter heat demand decreases. It also has to be mentioned that the total energy consumption rise as the courtyard shape becomes longer [11].

However, regardless of the all methods discussed which aim to improve the performance of the CY, height is the leading element among the rest [6, 8 and 10]. The increase in the height of the CY reduces amount of solar radiation exposed to outer surface, hence, significant increase in self-shaded area. This influence will be extended to rooms peripheral. Muhaisen [10] has clarified the optimum height of CY according to climatic region to suite both summer and winter. In hot humid climate three storeys height, two in hot and dry and only one in cold to allow more direct solar radiation to access the CY.

In hot regions there are several techniques to make use of CYs with minimising its disadvantages such as the use of courtyards shading devices and cantilevered roofs. Canton [12] observed that in hot and dry climates courtyards should be shaded from direct solar radiation especially in summer in order to provide more thermally acceptable environment.

College of Engineering. The University of Taif. Saudi Arabia

TABLE 1 PROPERTIES OF MODELLING FABRICATION

	Layers	Width (mm)	Conductivity W/m.°C	Total U-value
External wall	Internal finishing	25.0	0.079	0.894
	Concrete block	100.0	0.317	
	external finishing	25.0	0.079	
Roof	acoustic tile panels	15.0	0.085	1.908
	Concrete block	100.0	1.13	
	external finishing	3.0	0.43	
Ground	Internal finishing	5.0	0.5	0.283
	Concrete	175.0	0.87	
	Crashed brick aggregate	75.0	0.55	
	Sand	1000.0	0.329	

III. METHODOLOGY

The research used the energy modelling simulation TAS EDSL which is considered as one of the most common used tool to predict building energy performance. There are five models to study the impact of courtyard location within a building north, south, east, west and central sided. The construction material used very simple to run the model. There are three output which was taken into consideration indoor air temperature, heat transfer and heating and cooling load. There are two main days were selected during the year. Day 1 in January which represent winter day whereas day 200 in July which represent summer day in the city of Riyadh.

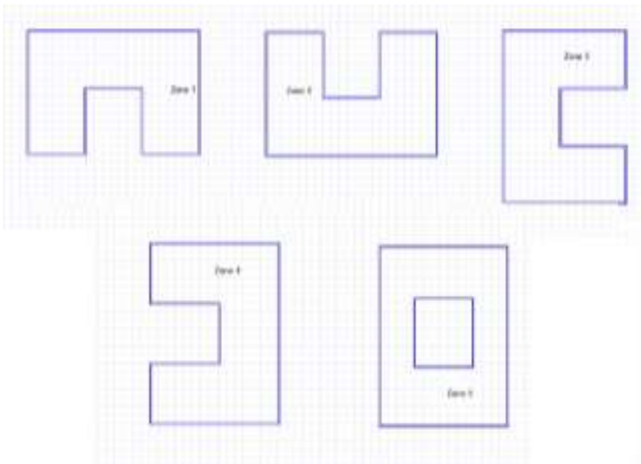

Fig. 1 Top view of models examined

Fig. 2 a perspective view of the models

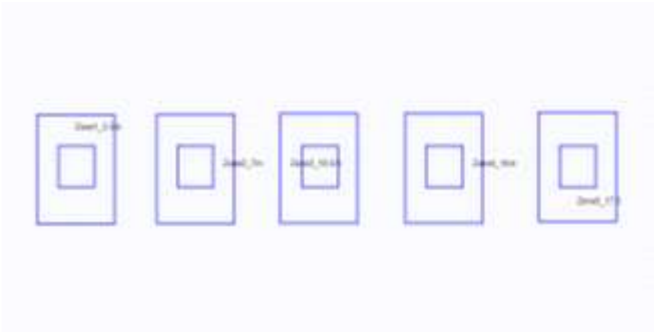

Fig. 3 Top view of model examined for the impact of courtyard height

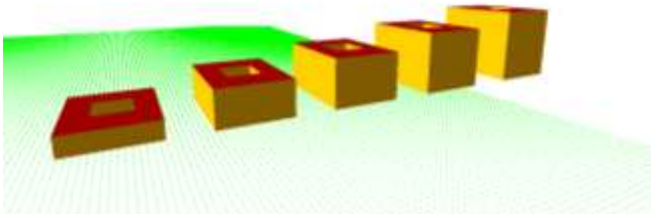

Fig. 4 A perspective view of examined courtyards for the impact of height

IV. RESULT AND DISCUSSION

4.1. Impact of design and orientation of courtyards on indoor air temperature (IAT)

As far as IAT in winter is concerned, CCY model of courtyard has the highest IAT compared to the other models. This was due to the increase in the total amount of exposed external walls to the sun which leads to rise in heat gain through opaque elements. The most ride occur in west and east sides of the eternal surfaces of the courtyard. Based on this results and discussion it can be revealed that central courtyard is not recommended in hot and dry climate where more exposed eternal wall will take place. Moreover, minimise of external elements of building fabrication has to receive more emphasise in order to avoid heat exchange between indoor and outdoor to minimum amount.

It can noticeable that IAT in summer has a substantial difference compared to winter due to the considerable outdoor temperature swing which can be as high as 20°C at the peak time. However, in terms of improvement to reduce the IAT with considering different design and orientation of courtyards, it can be said that there is noticeable different in

http://dx.doi.org/10.17758/EAP.EAP816404

between summer and winter. There is about one or 1.5°C reduction in the two tested seasons. Central allocated courtyard leads to higher indoor temperature.

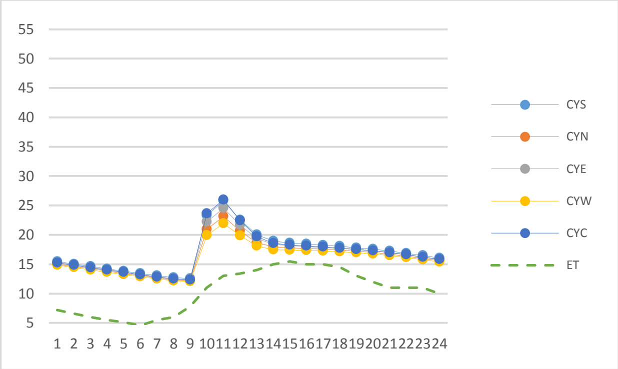

Fig. 5 Indoor air temperature of examined courtyards in winter

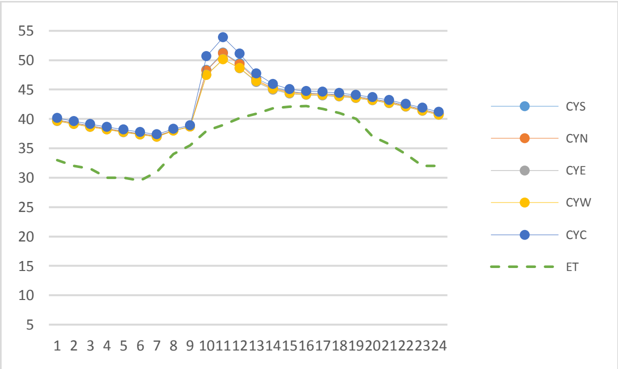

Fig. 6 Indoor air temperature of examined courtyards in summer

4.2. Heat transfer through building fabrication

The fundamental point of determining IAT is the amount of heat conduction in this building since it has no glazing system which means that the only way to transfer heat is through heat conduction meanwhile external walls in each direction.

Surprisingly, although south-facing direction is not recommended in hot and warm locations generally, it is more beneficial to orient courtyard to south direction. This will ensure minimum amount of external exposure of sunlight on walls, hence, less heat gain will occur. On the other hand, CYC is not recommended since it leads to maximum amount of heat gain. It was observed that east, west and north has similar performance.

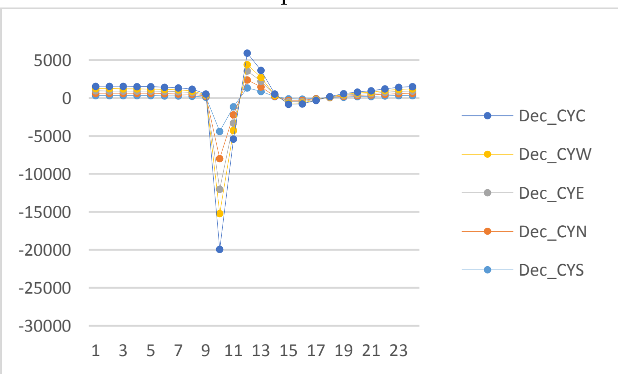

Fig. 7 Heat transfer of examined models in winter

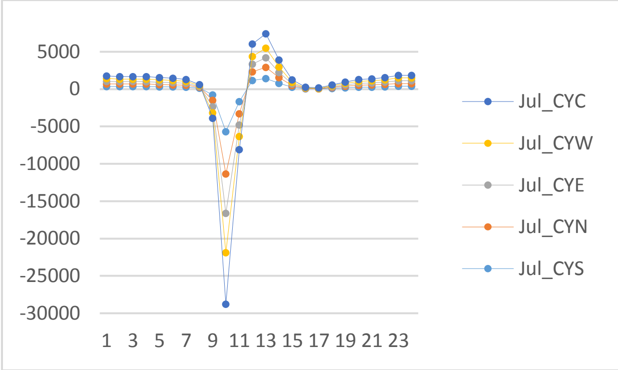

Fig. 8 Heat transfer of examined models in summer

4.3. Influence of tested courtyards on cooling and heating loads

The impact of CYC model was reflected well on the amount of cooling load in summer where the load was as high as 45133W at peak time. The maximum amount of cooling load occur between 10am and 1pm which receives maximum amount of heat conduction through external walls. This section has highlighted the three key aspects of controlling indoor air temperature as well as cooling load which is heat conduction through external walls. It is the only variable here due to the model examined has no glazing opening in order to focus on only one variable. Farther research can be conducted to examine the influence of glazing system on solar gain, hence, increasing indoor temperature.

With regard to heating load in winter, the loads can be classified in two periods. The first one is after midnight to sunrise which has the maximum amount of heating load because of the large margin in temperatures between indoor target and actual outdoor variations. The other period starts after noon time. This duration grow gradually to peak at noon time. It has to be mentioned that in the case of heating load the impact of different models is inconsiderable. As a result, summer period is the most important time to take the impact of courtyard design and orientation into consideration.

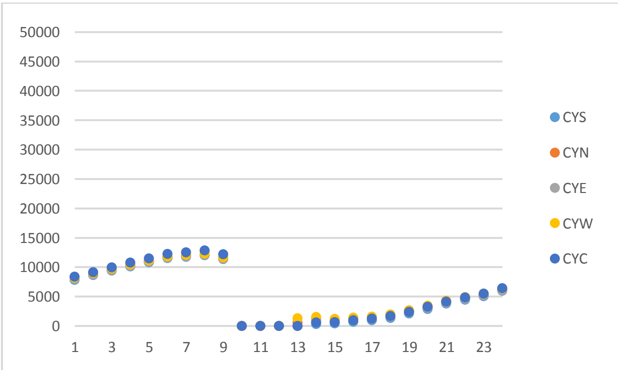

Fig. 9 heating load in winter for examined models

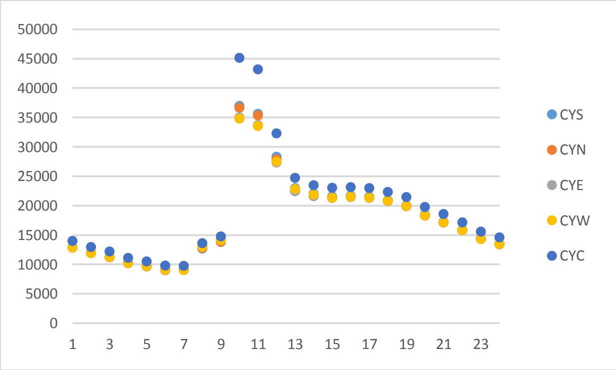

Fig. 10 cooling load in summer for examined models

4.4. Influence of courtyard height on building indoor air temperature

It can be noticed that the impact of courtyard height on indoor building temperature is remarkable in both winter and summer. The five storey building has peaked just under 30°C while the one storey building height peaked at 25.6°C. The shallower courtyard form allows more air to pass the courtyard and remover more heat during day time by convection. Moreover, this sort of shape also aid to cool down the courtyard over night as cooler air can reach the bottom of the CY easier. The same scenario occur in summer with more enormous figures. The five storey building peaked at over 60°C whereas the one storey level did at just under 50°C.

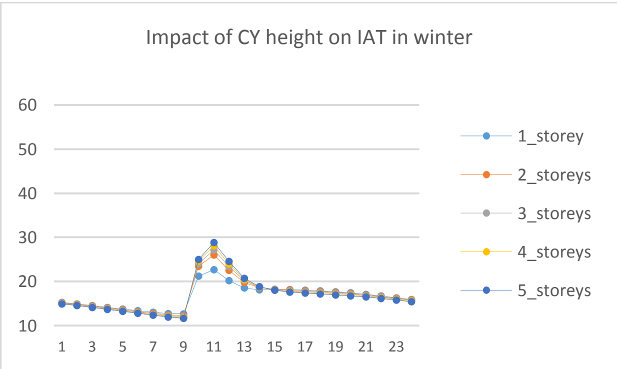

Fig. 11 impact of courtyard height on indoor air temperature in winter

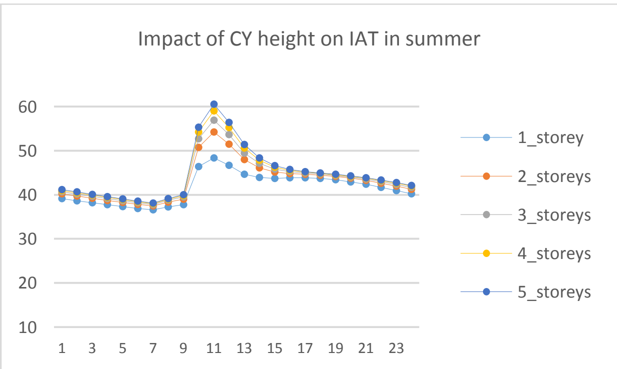

Fig. 12 impact of courtyard height on indoor air temperature in summer

V. Conclusion and Recommendations

The research focuses on the impact of courtyard on several positions located in central building with respect to hot and dry climate. It was found that central courtyard was found with highest figure of IAT due to the increase in the total amount of exposed external walls to direct solar radiation. This reveal the importance. The paper also reveal that west and east sides of courtyard are not recommended in hot and dry climate. This will lead to the conclusion that northern facing courtyard is the most appropriate. Moreover, although southern facing direction is not recommended in hot and warm places generally, it was more beneficial to orient courtyard to south direction. This will ensure minimum amount of external exposure of sunlight on walls. As a result of this research south and north facing courtyards are recommended in hot and dry climate. With regard to the optimum height of courtyard in hot regions. Most of authors are of the opinion that the deeper the courtyard, the less amount of sunlight is able to enter it, hence, less amount of temperature is expected [6, 8, and 10]. However, as Muhaisen [10] was stated that deeper courtyard is beneficial for shading in summer, but in winter shallower ones are recommended for heating in winter. It can be revealed that the height of two storeys courtyard building is the ideal for hot and dry which is supported by Muhaisen [10].

References

[1] Edwards, B., Sibley, M., Hakmi, M., & Land, p. (2006). Courtyard housing: past, present and future: Spon Press. Groat, L., & Wang, D. (2002). Architectural research methods: Wiley

[2] Moore F. (1993) Environmental control system: heating cooling lighting. New York: McGraw-Hill

[3] Mohsen MA. Solar radiation and courtyard house forms II: application of the model. Building and Environmental (1979): 14: 185-201 http://dx.doi.org/10.1016/0360-1323(79)90037-4

[4] Meir IA, et al. On microclimate behaviour of two semi-enclosed attached courtyards in a hot and dry regions. Building and Environment. 1995: 30 (4) 563-572 http://dx.doi.org/10.1016/0360-1323(95)00018-2

[5] Cadima PSP. Transitional spaces: the potential outdoor of semi-outdoor spaces a means of environmental control with special reference to Portugal. PhD thesis. The Open University, 2000

[6] Muhaisen, S., Gadi, M. Shading performance of polygonal courtyard forms. Building and environment. 41 (2006): 1050-1059 http://dx.doi.org/10.1016/j.buildenv.2005.04.027

[7] Manioglu (2015) Oral, K. Effect of courtyard shape factor on heating and cooling energy loads in hot and dry climate zone 78 (2015): 2100-2105

[8] Abdulbasit, A., Ibrahim, N., Ahmed, S., Yahya, J. Courtyard design variants and microclimate performance. 101 (2013): 170-180

[9] Baboli, F., Ibrahim, N., Sharif, D. Design characteristics and adaptive role of the traditional courtyard houses in the moderate climate of Iran. 201 (2015): 213-223

[10] Muhaisen, A. Shading performance of polygonal courtyard form. 41 (2006): 1731-1741

[11] Yasa, E., Ok, V. Evaluation of the effects of courtyard building shapes son solar heat gains and energy efficiency according to different climatic regions. 73 (2014): 192-199

[12] Canton, M., Ganem, C., Barea, G., Liano, J. Courtayrds as a passive strategy in semi dry areas. Assessment of summer energy and thermal conditions in a refurbished school. 69 (2014): 437-446

Dr. Mamdooh S. Alwetaishi. I was born in the city of Jeddah, 1983. I have a background of Architectural Engineering from Umm Al-Qura University, Saudi Arabia in 2006. After that I had a scholarship to study higher education in the UK. I had an MSc degree in renewable Energy and Architecture in 2011 from the University of Nottingham and finally I had a PhD degree from the same University in Sustainable Energy Technology in 2015.

Now, he is the Head of Civil Engineering Department at the University of Taif, Saudi Arabia since Dec 2015 until now. He has developed a lot of skills and managed to obtain the Accreditation of ABET in Jan 2016 for the department. His major area of research is on energy building performance and thermal comfort in buildings.

http://dx.doi.org/10.17758/EAP.EAP816404