International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:12, No:5, 2018

Toward Sustainable Building Design in Hot and Arid Climate with Reference to Riyadh City, Saudi Arabia

M. Alwetaishi

Abstract**—**One of the most common and traditional strategies in architecture is to design buildings passively. This is a way to ensure low building energy reliance with respect to specific micro-building locations. There are so many ways where buildings can be designed passively, some of which are applying thermal insulation, thermal mass, courtyard and glazing to wall ratio. This research investigates the impact of each of these aspects with respect to the hot and dry climate of the capital of Riyadh. Thermal Analysis Simulation (TAS) will be utilized which is powered by Environmental Design Simulation Limited company (EDSL). It is considered as one of the most powerful tools to predict energy performance in buildings. There are three primary building designs and methods which are using courtyard, thermal mass and thermal insulation. The same building size and fabrication properties have been applied to all designs. Riyadh city which is the capital of the country was taken as a case study of the research. The research has taken into account various zone directions within the building as it has a large contribution to indoor energy and thermal performance. It is revealed that it is possible to achieve nearly zero carbon building in the hot and dry region in winter with minimum reliance on energy loads for building zones facing south, west and east. Moreover, using courtyard is more beneficial than applying construction materials into building envelope. Glazing to wall ratio is recommended to be 10% and not exceeding 30% in all directions in hot and arid regions.

Keywords**—**Sustainable buildings, hot and arid climates, passive building design, Saudi Arabia.

I. Introduction

THERE are several techniques to control a building's energy performance passively, for example through courtyards. Courtyards emerged in hot regions. However, it is now transferred across the world for various reasons [1]. The thermal satisfaction of courtyards in buildings was assessed by many authors globally [2]-[5]. They are mostly looking at the typical rectangular courtyard shape in hot or temperate climates. The most common revelation is that outer surfaces of a courtyard have to be shaded from direct solar radiation. There are various aspects that influence the execution of a courtyard; length, shape and height are among the most important factors. Manioglu [6] and Abdulbasit [7] conducted some research in hot and dry climate regions and they have realized that width and depth of courtyard (CY) has a considerable leverage on energy loads. With respect to CY orientation, in hot and humid regions, orienting the long axis of CY towards the northwest and southwest is preferable, similarly to north-south axis as well [5], [8].

M. Alwetaishi is with the Department of Civil Engineering, College of Engineering, Taif University, Saudi Arabia (phone: +966-12-727-2020 Fax: +966-12-727-4299; e-mail: m.alwetaishi@tu.edu.sa).

The shape of the CY has bounded impact on the amount of sunlit areas exposed to the outer surface of CY in winter, whereas in summer the impact is more noteworthy [9]. However, considering all methods discussing which target to improve the performance of the CY, elevation is the leading aspect [6], [8], [10]. Similarly, a recent study done in Baghdah [10] and Iran [11] are also supporting this. Canton [12] has observed that in hot and dry regions, CY should be protected from direct sunlight especially in harsh climates of summer to provide a more comfortable environment.

Insulation is one of the most effective processes for high energy efficiency in buildings [12]-[17]. It is also important to obtain comfort satisfaction, and it reduces any unwanted heat loss [18]. The density of the material is associated with thermal conductivity. Higher insulation density resulted in lower thermal conductivity (k-value); hence, better performance of the insulation is expected. One variable which influences thermal insulation is thickness [19], it will result in a decrease in the energy consumption for cooling and heating, however, this will lead to an increase in the cost of building construction. As a result, optimum thickness is a must where the efficiency of building fabrication and cost could meet. Reference [20] has pointed out that the optimum orientation thickness in warm climates for south, north, east and west are: 3.6, 3.1, 4.0 and 4.0cm, respectively.

II. Methodology

The research uses one of the most powerful energy building tools (TAS EDSL). There are three major building designs and techniques which are using CY, thermal mass and thermal insulation. The same building size and fabrication properties have been applied to all designs. However, the CY design opening is looking toward the hall of the court while the other two face the outdoors. This is the result of the design technique. The research has taken the city of Riyadh as a sample of the hot and dry climate of Saudi Arabia.

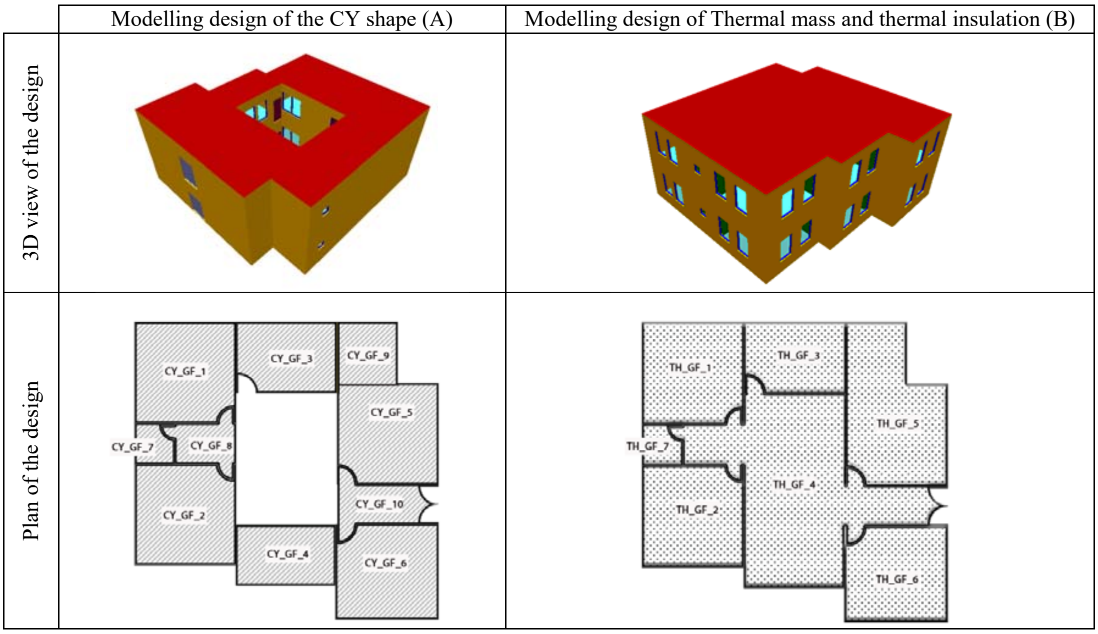


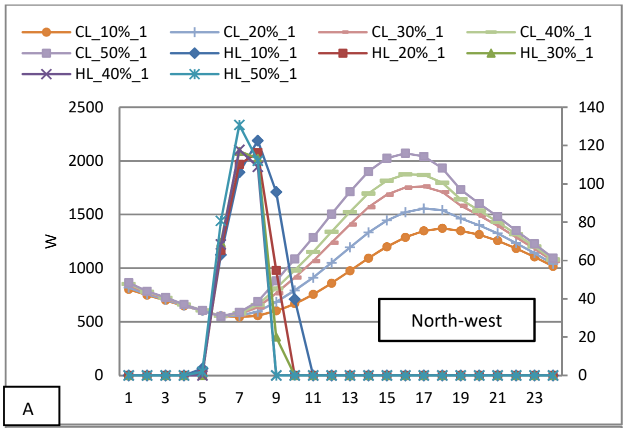
Fig. 1 Views of the examined buildings, where (A) is the CY design shape and (B) is the thermal mass and thermal insulation design shape

TABLE I
PROPERTIES OF ALL MODELS EXAMINED

	Layers	**Width (mm)**	**Conductivity (W/mK)**	**Total U value (W/m².°C)**
		Properties of CY building		
External wall	Block	200	999.9	**3.1**
Internal wall	Block	100	175.9	**4.4**
Ground	Concrete	200	0.87	**1.42**
	Crashed brick aggregate	75.0	0.55	
Roof	Acoustic Panel	15	0.056	**1.6**
	Concrete	200	1.13	
	Asphalt	3.0	0.42	
		Properties of thermal insulation building		
External wall	Brick	100	1.33	**0.294**
	Polystyrene expanded	100	0.033	
	Brick	100	1.33	
Internal wall	Block	100	175.9	**4.4**
Ground	Polystyrene expanded	50	0.04	**0.316**
	Screed concrete	50	1.28	
	Concrete	150	0.87	
	Crashed brick aggregate	75	0.55	
	Soil	1000	0.7	
Roof	Acoustic Panel	15	0.056	**0.274**
	Concrete	100	1.13	
	Polystyrene expanded	125	0.43	
	Asphalt	3.0	0.43	
		Properties of thermal mass building		
External wall	Concrete	400	0.2	**0.46**
Internal wall	Block	100	175.9	**4.40**
Ground	Concrete	200	0.87	**1.42**
	Crashed brick aggregate	75.0	0.55	
Roof	Acoustic Panel	15	0.056	**1.6**
	Concrete	200	1.13	
	Asphalt	3.0	0.42	

Glazing properties in all models

	Type of glazing	Width mm	Solar reflectance	Solar absorptance	Solar transmittance	Emissivity	Total U value (W/m2K)
Glazing	Single	10.00	0.070	0.115	0.7	0.845	5.53



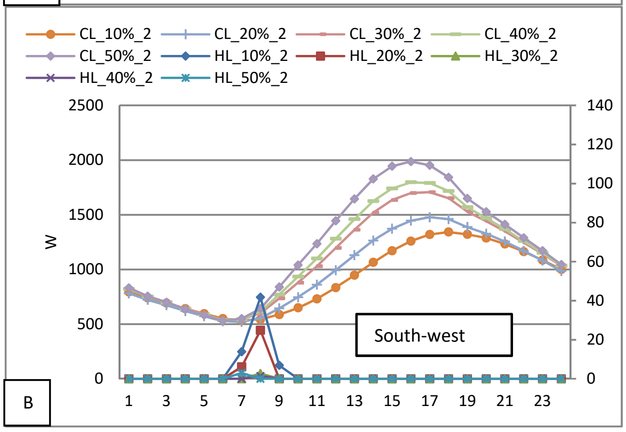
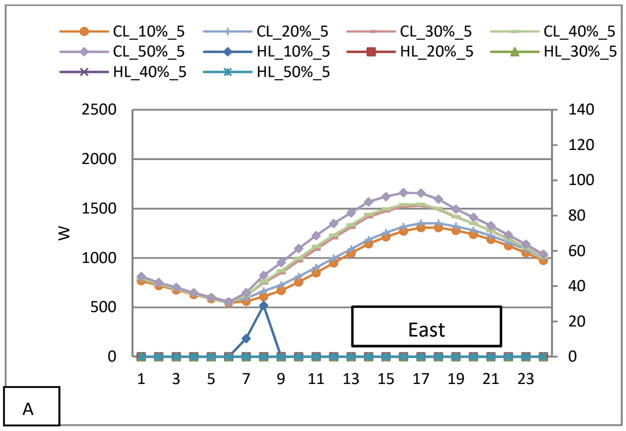


Fig. 2 Heating and Cooling Loads of various glazing to wall ratio in zones 1 (A), and 2 (B)



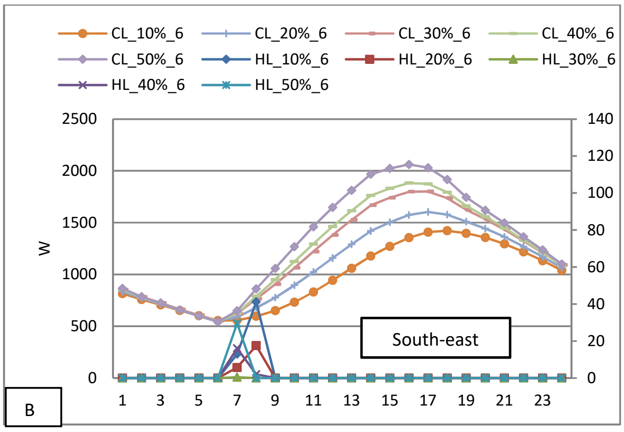
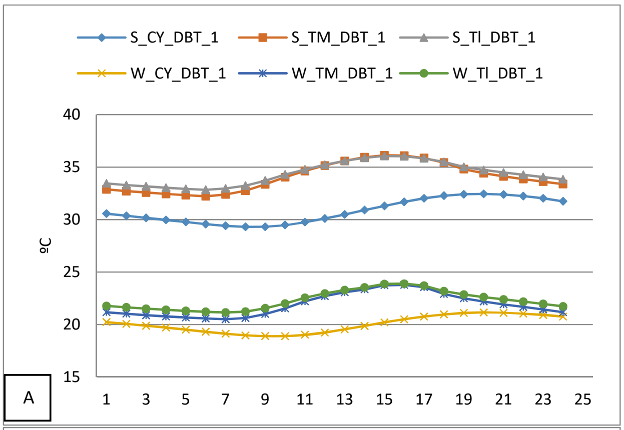


Fig. 3 Heating and Cooling Loads of various glazing to wall ratio in zones 5 (A), and 6 (B)



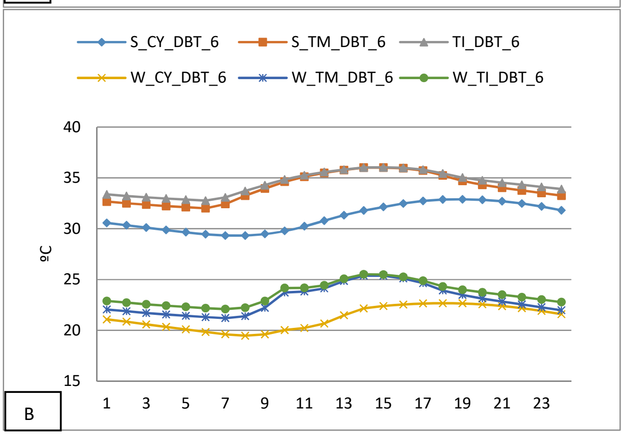


Fig. 4 IAT of various building fabrication of zones 1 (A), 6 (B) in both summer and winter

III. Results and Discussion

With respect to the influence of glazing to wall ratio in the city of Riyadh, it can be noted that each direction has performed differently. The main leverage was the access of direct solar gain. In the north-west facing classroom, it was noted that it has worst zone in comparison to the others. This is due to the limited access of sunlight in north orientation in winter, and high access in the west after 12 o'clock noon in summer (Fig. 1). On the other hand, the south-west has a similar cooling load, but considerably lower heating in winter. This is attributed to high solar gain in the southern facing zone. The south-facing zone has the lowest amount of energy loads. Since north-facing zones are not considered in this research, this finding seems to be reasonable. These findings support the outcomes revealed by [21]. The impact of cooling with respect to glazing to wall ratio was more constant than the impact on heating.

The discussion mentioned above shows that glazing to wall ratio is recommended to be 10% and no more than 30% in any direction in hot and dry climates. Alwetaishi [21] shared a similar view as well. Moreover, it is possible to achieve zero carbon building in this region in winter with no reliance on energy loads if most of the building faces south, west and east. Regarding the most appropriate passive technique which can be used in hot and dry climates, results revealed in Fig. 3 indicate that using CY is more beneficial than modifying building fabrication such as thermal mass and thermal insulation. This is justifiable due to blocking external building envelope from direct sunlight.

IV. Conclusion

The work has investigated the influence of various passive techniques which can improve the performance of buildings in the hot and arid climate with reference to the city of Riyadh. Usage of thermal mass, thermal insulation, CY and glazing to wall ratio were investigated. One of the most common findings of this research is that glazing to wall ratio is recommended to be 10% and no more than 30% in any direction in hot and dry climates. Furthermore, it is possible to achieve nearly zero carbon building in hot and dry region in winter with no reliance on energy loads if most of the building faces south, west and east. Moreover, using CY is more beneficial than modifying construction of building envelope.

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] 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.
[3] Meir IA, et al. On microclimate behaviour of two semi-enclosed attached courtyards in hot and dry regions. Building and Environment. 1995: 30 (4) 563-572 http://dx.doi.org/10.1016/0360-1323(95)00018-2
[4] Cadima PSP. Transitional spaces: the potential outdoor of semioutdoor spaces a means of environmental control with special reference to Portugal. PhD thesis. The Open University, 2000.
[5] 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.
[6] 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.
[7] Abdulbasit, A., Ibrahim, N., Ahmed, S., Yahya, J. Courtyard design variants and microclimate performance. 101 (2013): 170-180.
[8] 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.
[9] Muhaisen, A. Shading performance of polygonal courtyard form. 41 (2006): 1731-1741.
[10] Al-Hafith, O., Satish, B., Bradbury, S., Wide, P. The impact of courtyard parameters on its shading level: An experimental study in Badhdad, Iraq. 9th International Conference on Sustainability in Energy and Buildings, SEB-17, 5-7 July 2017, Chania, Crete, Greece, 134 (2017) 99-109.
[11] Nasrollahi, Z., Hatami, M., Khastar, S., Taleghani, M. Numerical evaluation of thermal comfort in traditional courtyards to develop new microclimate design in a hot and dry climate. Journal of Sustainable Cities and Society, 35 (2017) 449-467.
[12] Roberto, F., Walter, M., Marc, A., Nathan, M. (2011) 'Capacitive effect on the heat transfer through building glazing systems' Journal of Applied Energy 88 4310–431.
[13] Lollinia, B., Fasanob, M. (2006) 'Optimisation of opaque components of the building envelope. Energy, economic and environmental issues' Journal of Building and Environment 41, 1001–1013.
[14] Kolaitis, D., Malliotakis,, E., Kontogeorgos,, D. (2013) 'Comparative assessment of internal and external thermal insulation systems for energy efficient retrofitting of residential buildings' Journal of Energy and Buildings 64, 123–131.
[15] Hanifi, B., Mustafa, E., Mustafa, D., Orhan, A., Mehmet, K. (2014) 'An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres' Journal of Construction and Building Materials 51, 24–33.
[16] Jinghua, Y., Changzhi, Y., Liwei, T., Dan, L. (2009) 'A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China' Journal of Applied Energy 86, 2520–2529.
[17] Ji, R., Zhang, Z., Liu, J., Qu, S. simulating the effects of anchors on the thermal performance of building insulation systems. Journal of Energy and Buildings 140 (2017) 501-507.
[18] Ashok, K., Suman, B. (2013) 'Experimental evaluation of insulation materials for walls and roofs and their impact on indoor thermal comfort under composite climate' Journal of Building and Environment 59, 635-643.
[19] Asan, H., (1998) 'Effects of Wall' s insulation thickness and position on time lag and decrement factor' Journal of Energy and Buildings 28, 299-305.
[20] Meral, O. (2013) 'Determination of optimum insulation thickness based on cooling transmission load for building walls in a hot climate' Journal of Energy Conversion and Management 66, 106–114.
[21] Alwetaishi, M. Impact of glazing to wall ratio in various climatic regions: A case study. Journal of King Saud University – Engineering Sciences (2017), http://dx.doi.org/10.1016/j.jksues.2017.03.001.