Proceedings of 3rd Conference: ***People and Buildings*** held at Westminster University, School of Architecture and the Built Environment, London, UK, 20th September 2013. Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Solar Performance of Courtyard and Atrium Buildings with Different Forms and in Different Latitudes

Ahmed Qadir Ahmed[1] and Mohamed B Gadi[2]

1 Student, MSc course Renewable Energy and Architecture, Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham, UK, architalar@yahoo.com;
2 Associate Professor, Department of Architecture and Built Environment, Faculty of Engineering, The University of Nottingham, UK, mohamed.gadi@nottingham.ac.uk.

Abstract
This paper presents a study of the effects of building form on the received solar irradiance by courtyards and atria in different latitudes. Ecotect program is used to model and simulate certain courtyard and atrium building forms. The four main orientations (south, west, north and east) were considered in the simulations and results were obtained separately for each orientation. Weather data in four different cities on four different latitudes (0°, 20°, 40° and 60°) were used in the simulations. The results show that the effects of building form on solar performance of courtyard and atrium vary according to orientation and latitude. In high latitudes, the amount of received solar radiation increases significantly when the tilt angle of the roof increases especially in south orientation and in winter; whereas, this increment is not considered in low latitudes.

Keywords: Courtyard, Atrium, Solar performance, Tilted roof, Different latitudes

1 Introduction
Environmental aspects and especially energy efficient forms of buildings have been concentrated on in contemporary architecture as an architectural attempt to reduce the environmental impacts and energy consumption. So, recently, certain studies have been done regarding climatic responsive building forms to determine the most energy conscious forms of buildings. Courtyard building, which is used widely during thousands of year, is one of the traditional forms on which many studies have been done. Another form is atrium building, which can be considered as an improved courtyard building in modern architecture. There are also certain studies concerning energy performance of atrium (Taleghani et al, 2012, Medi, 2010 and Bagneid, 2006).

According to the Oxford Dictionary, courtyard is “an unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or large house”. Taleghani et al. (2012) considered the courtyard as a ‘transitional space’ where the outdoor and indoor climate can be moderated through passive climate controls. It can protect the building from harsh conditions of weather in different seasons and climates. Moreover, it can be a good source for solar heat gain as well as daylighting in buildings with deep plans. In addition to the environmental purposes, it can be used for daily activities such as in houses and schools (Heidari, 2000). In terms of the atrium, it is defined by Oxford Dictionary as “a central hall in a modern building, typically rising through several stories and having a glazed roof”. Moreover, Samant (2011) and Taleghani et al. (2012) state that an atrium can be made by covering a courtyard by glass roof. As it a glazed enclosure, it protects the adjoining walls between the atrium and building from harshness of weather conditions. So, it can enhance the daylighting of the building. In addition, it can be a proper strategy to promote solar heat gain and providing preheated ventilation to the adjacent building. However, overheating may occur in summer. It can be reduced by using proper shading devices (Baker et al, 2005 and Hug, 2003).

2 Methodology

In this study, Ecotect software, which is one of the five major programs taught in the MSc course in Renewable Energy and Architecture (*www.nottingham.ac.uk/~lazmbg/MScREA/*), is used for modelling the investigated forms of courtyard and atrium buildings which are shown in figure 1. The forms are rectangular and central courtyard and atrium buildings with tilted roofs with different tilt angles (β) towards the buildings’ long sides. The various tilt angles are 0°, 10°, 20°, 30° and 40°. The only difference between the courtyard and atrium forms is that the atrium is covered by glass roof. The glass roof is a single glazed with 0.94 solar heat gain coefficient and its transmittance is equal to 0.753.

The investigation of the forms is undertaken in four different latitudes on the northern hemisphere. On each considered latitude, the weather data of a city is selected, which almost represents the weather data of the regions along that latitude. The cities and latitudes are Nairobi (0°), Mexico City (20°N), Madrid (40°N) and Saint Petersburg (60°N). The used weather data in the simulations has the data of clear sky solar radiation. This is to neglect the effects of changing the cloudiness along the latitudes. Furthermore, the investigation is undertaken in four main orientations which are south, west, north and east. In each orientation, the roof is tilted towards that direction. In addition, 21st June (summer solstice) and 21st December (winter solstice) are selected in which the simulations are undertaken.

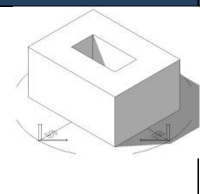
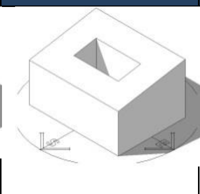
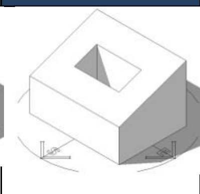
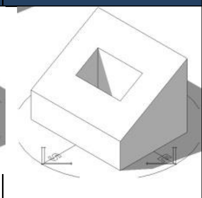
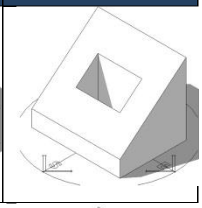
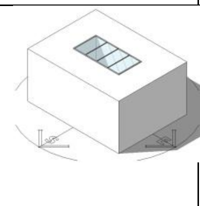
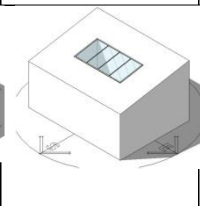
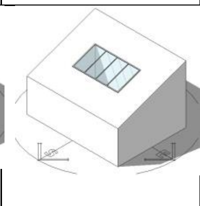
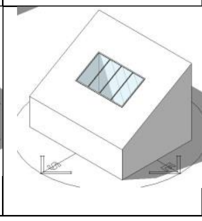
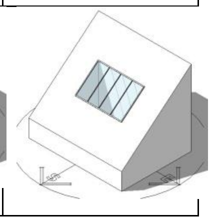
Building Types	Tilt angle of the building roof				
	0°	10°	20°	30°	40°
Courtyard Building Forms					
Atrium Building Forms					

Figure 1. The investigated courtyard and atrium building forms

3 Results and discussion

The results of courtyard and atrium simulations are obtained in daily-averaged hourly received irradiation (W/m^2) and daily-averaged hourly solar gain (W/m^2) respectively. This is to avoid the effects of changing the day length in various latitudes as well as changing the area of the internal walls in different forms. The results of simulations of both courtyard and atrium forms are separately discussed in the following subsections.

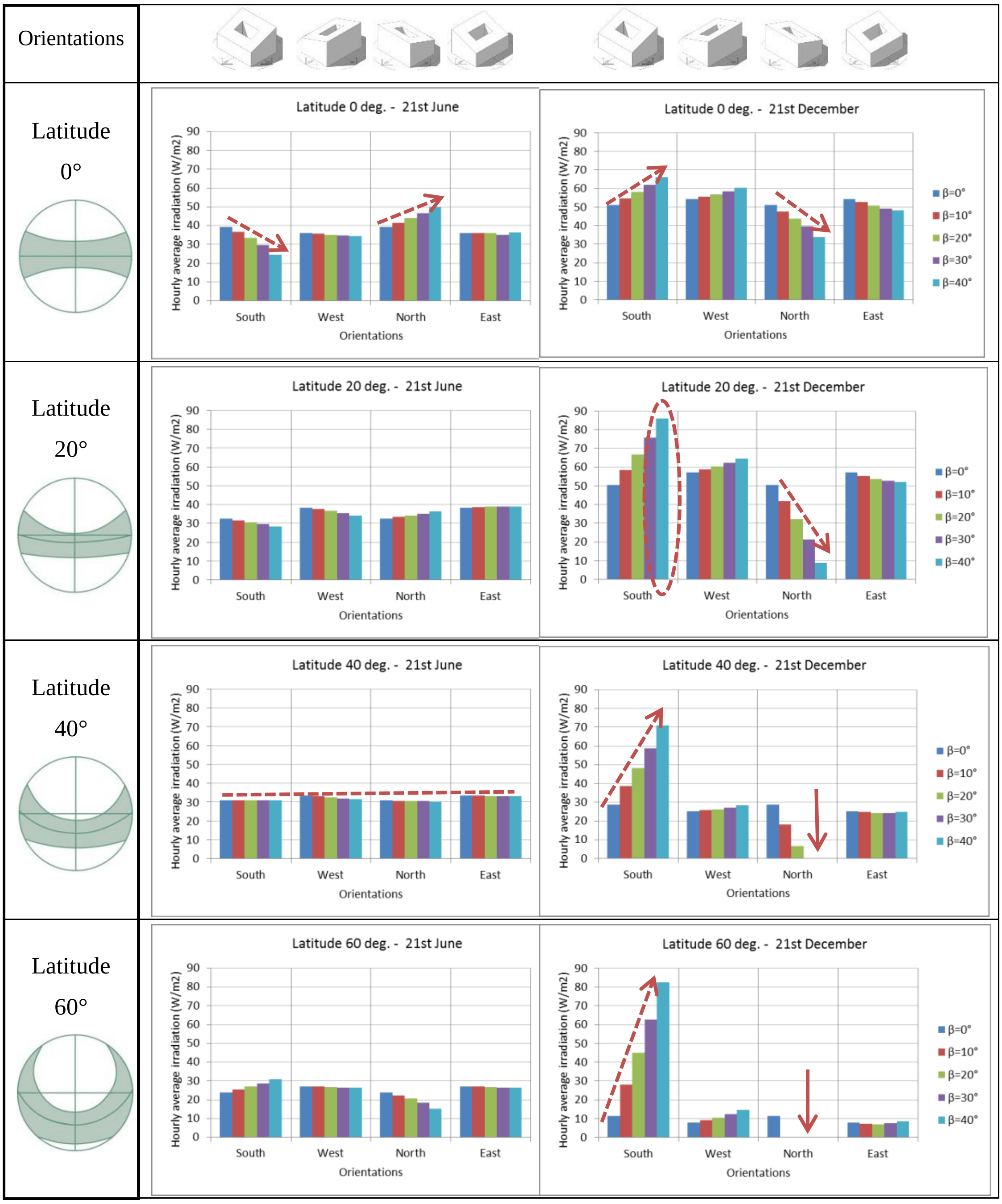


Figure **2.** Effects of changing slope of the building's roof on the received irradiation by the courtyard walls in different orientations and latitudes

3.1 Simulation results of courtyard building forms

The Figure 2 shows the effects of changing slope of the building's roof on the received irradiation by the courtyard walls in different orientations and latitudes. Moreover, the sun path diagrams in considered latitudes are presented. In terms of the results in equator (zero degrees latitude), where the sun is more perpendicular and its intensity is considerably high compared to that in high latitudes, the amount of received irradiation is considerable in all cases. On 21st June, increasing the tilt angle of the roof towards the west and east orientations would have no important effects.

Whereas, it causes steady decreases and increase in south and north orientations respectively. This is due to that the sun moves through the northern half of the sky, as shown in the related sun path diagram. On 21st December in the same latitude, increasing β value leads to rising received irradiation in south and west orientations as well as decreasing received irradiation in north and east orientations. This is also because of that the sun moves through the southern half of the sky.

With regard to the 20 degrees latitude, effects of changing the tilt angle of the roof are more considerable in winter compared to those in summer, as shown the same figure. On 21st June, increasing the β value causes gradual decrease in the results in south and west orientations as well as gradual increase in north and east orientations. This is due to that the solar radiation is more perpendicular during a long period of the daytime. On 21st December, significant increase and decrease in the received irradiation occur in south and north orientations respectively. It reaches about 85W/m^2 in south orientation when the roof's tilt angle is equal to 40°; whereas, the received irradiation falls down to around 9W/m^2 in north orientation and in the same tilt angle.

In 40 degrees latitude and on 21st June, changing the tilt angle of the building's roof would have no important effects on the received irradiation by the courtyard walls in all orientations. This is may be due to that the sun moves through both halves of the sky. On 21st December, significant increase and decrease in the results occur in south and north orientations respectively when the β value increases. The received irradiation falls down to 0 W/m^2 in north orientation and tilt angle equal to 40°.

Regarding the 60 degrees latitude and on 21st June, increasing the tilt angle of the courtyard building's roof causes gradual increase and decrease in both south and north orientations respectively. On 21st December, a significant increase occurs when the β value increases. It is due to that the sun moves through the southern half of the sky with very low altitude angles.

3.2 Simulation results of atrium building forms

The Figure 3 presents the effects of changing the tilt angle of an atrium building's roof on the solar gain in the atrium in different orientations and latitudes. Moreover, the sun path diagrams in considered latitudes are shown. It can be seen that generally the received irradiation by the internal atrium walls is less than received irradiation by the courtyard walls. This is because of that a part of the solar radiation is absorbed and reflected by the skylight of the atrium when enters through the glass roof. Furthermore, the trends of the results variations are almost the same in different cases.

In zero degrees latitude (equator) and on the 21st June, increasing the tilt angle of the roof causes a decline in the results in south orientation as well as it causes rises in other orientations. However, the changes in the solar gain are more considerable in both south and north orientations. On 21st December, the trends of the results variations are opposite in both south and north orientations. This is due to changing the sun path from the northern half of the sky to the southern half.

Concerning the 20 degrees latitude and on 21st June, a gradual decrease occurs only in south orientation when the β value increases; whereas, it leads increases in the solar gain in other orientations. On 21st December, the maximum solar gain is recorded at approximately 32W/m^2 when the roof is tilted towards the south with 40° tilt angle.

In 40 degrees latitude and on 21st June, the trends of the results variations due to the changing the tilt angle of the roofs are almost the same in various orientations. This is because of that the sun moves in both halves of the sky during the daytime. At any value of the tilt angle, the greater the β value, the greater the solar gain in the atrium. On 21st December, a significant increase occurs only in south orientation which is due to that the sun moves in the south half of the sky.

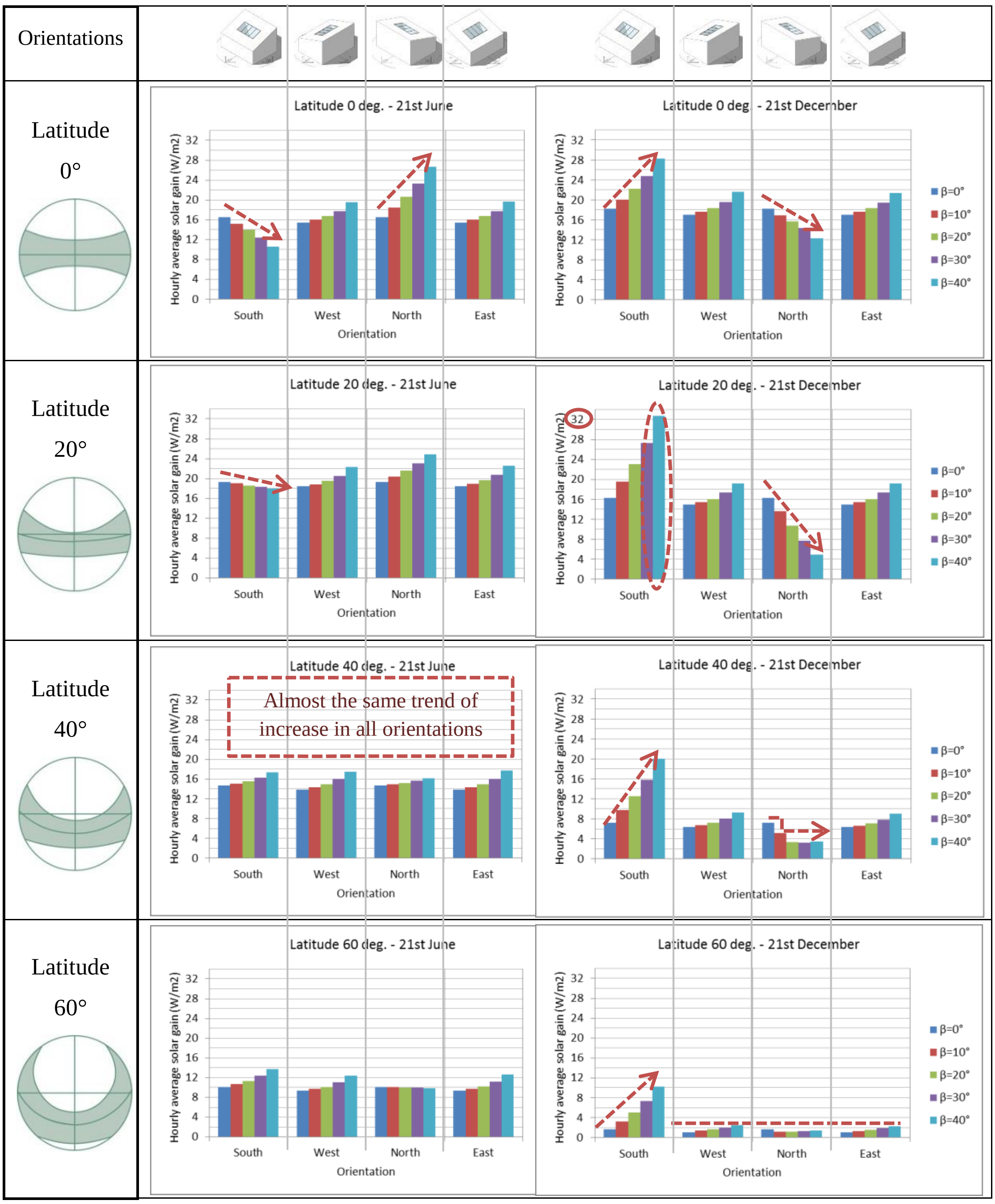


Figure **3**. Effects of changing slope of the building's roof on the received irradiation by the internal surfaces of the atrium in different orientations and latitudes

With regard to the 60 degrees latitude and on 21st June, increasing the slope of the roof leads to gradual increases in the solar gain in all orientations except in north one in which no significant changes occur. On 21st December and in south orientation, at any value of tilt angle of the roof, the greater the β value, the greater the solar gain in the atrium. Moreover, the solar gain in other orientations is not considerable because the sun moves through only a short route in the southern half of the sky.

4. Conclusion

The conclusion which has been drawn from the study shows that the effects of changing the tilt angle of the courtyard and atrium buildings' roof on their solar performance vary in different latitudes and orientations. The effects are more considerable when the roof is tilted towards the south in north hemisphere especially in winter and in high latitudes, where the air temperature is low compared to low latitudes. So, increasing the tilt angle of the roof can be a proper strategy to enhance the solar performance of courtyard and atrium buildings.

The optimum tilt angle of the roof should be considered in different latitudes. In equator, where the air temperature is considerably high all year round, the optimum tilt angle is that which causes minimum received irradiation by courtyard and atrium internal walls. In both 20 and 40 degrees latitude, where the summer is hot or warm and winter is cold, the optimum tilt angle is that leads to minimum received irradiation in summer and maximum in winter. In addition, in 60 degrees latitude, where the air temperature is cold throughout the year, the optimum tilt angle of the roof can be that causes maximum received irradiation during the whole year.

References

Baker, N. and Steemers, K. (2005) *Energy and Environment in Architecture: A Technical Design Guide*. London: Taylor & Francis e-Library

Bagneid, A. (2006) *The Creation of a Courtyard Microclimate Thermal Model for the Analysis of Courtyard Houses*. PhD dissertation. Texas: Texas A&M University

Heidari, S. (2000) *Thermal Comfort in Iranian Courtyard Housing.* PhD thesis. Sheffield: University of Sheffield

Hung, W. Y. (2003) 'Architectural Aspects of Atrium'. *International Journal on Engineering Performance-Based Fire Codes* 5(4), pp 131-137

Medi, H. (2010) *Field Study on Passive Performance of Atrium Offices* [online]. '1st International Graduate Research Symposium on the Built Environment'. held 15-16 October 2010 at Middle East Technical University (METU). Available from <http://www.academia.edu/368277/Field_Study_on_Passive_Performance_of_Atrium_Offices_> [25 May 2013]

Taleghani, M., Tenpierik, M., and Dobbelsteen, A. (2012) 'Environmental Impact of Courtyards: a Review and Comparison of Residential Courtyard Buildings in Different Climates'. *Journal of Green Building* 7(2), pp 113-136

Samant, S. (2011) *A Parametric Investigation of the Influence of Atrium Facades on the Daylight Performance of Atrium Buildings*. PhD Thesis. Nottingham: University of Nottingham