©2017 International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies.

TuEngr Group

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

Impact of Courtyard and Narrow Streets on Thermal Comfort of Traditional Buildings in Mukalla City

Rasha Saeed Baangood [a*] and Ahmad Sanusi Hassan [a]

[a] *School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Penang, MALAYSIA*

ARTICLEINFO

Article history:
Received 23 August 2010
Received in revised form
23 September 2010
Accepted 26 September 2010
Available online
26 September 2010

Keywords:
Courtyard houses, Natural ventilation, Urban layout, Air temperature, shading.

ABSTRACT

The traditional buildings, especially in Mukalla city used local materials that characterized with thermal comfort and natural ventilation, while the urban layout has a compact layout with dense buildings that provides shade. This study is conducted to identify the advantage of using a courtyard with narrow streets in urban layout and its impact to thermal comfort to the traditional buildings. The study applied ECOTECT® and DesignBuilder® as simulation software at several building orientations and onsite experiment using anemometer to measure the air temperature of the building, courtyard and narrow street. This aimed to produce the proper orientation, which explains that the courtyard has more effects than narrow street as a result of its shading percentage. The study found that narrow street and outside courtyard are able to provide lower air temperature due to good shading percentage. However, they give small changes in natural ventilation. But it is important to increase the wind velocity make breezing way for it between courtyard and narrow street.

1. Introduction

The outside courtyard, the narrow streets and the building form as well as the site orientation create an impact to the urban layout for vernacular architecture in Mukalla city. The study focuses on the site orientation which stands as the most important parameter to find out the direct solar radiation amount which absorbed by the building walls.

2. Literature Review

Recently many studies have tackled the courtyard and its influence on the environment. Muhaisen study (2006) explores some matters of shading and different climatic regions. In it, he

*Corresponding author (R.S. Baangood). E-mail: rashabaangood@gmail.com.

reported that the condition of internal shading in courtyard depends on the altitude of location, form, proportions and the condition of the climate that available on location (Muhaisen, 2006). Drawing on the same issue, Muhaisen and Gadi (2006) conducted another study in which they explored the considerable influence of the proportions of the courtyard need for heating and cooling(Muhaisen & Gadi, 2006). Al-Dawoud (2008), explained the better energy performance that normally can get into the building's open courtyard especially in hot-humid and dry climates (Aldawoud, 2008).

Orientation does have great impact on buildings. Its effects on indoor thermal comfort by control the way of usual wind direction and the amount of solar radiation that received for the building (Abraham et al., 1996; Al-Obaidi & Woods, 2006; Szokolay, 2008).

The present urban layout and traditional architecture are connected with theories and equations that explain methods and strategies used in the design. Accordingly, the current study aspires to explain the strategy of the design.

2.1 Mukalla City

The city of Al-Mukalla is located in the coastal region, at an altitude of 14° 5′ north and a longitude of 49° 20′ east, and it enjoys a pretty Yemeni-like climate, very similar to other coastal towns in Hadhramout.

2.1.1 Temperature

In the summer, the day temperature reaches 32 °C and while relative humidity might increase to more than 80%. Average values of monthly air temperatures from 2010 to 2013 are plotted in Figure 1.

Table 1: Average Temperature during 2010 – 2013 (Celsius).

Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
24.0	26.0	28.0	26.0	30.0	32.0	32.0	30.0	32.0	28.0	28.0	29.0

Source: Archives of weather at the airport (Al Rayan) Mukalla

2.1.2 Wind

Wind speed functions as parameter, though unstable, to control thermal comfort. Generally, the wind direction is dictated by temperature differences during daytime and nighttime. The prevailing wind directions in Mukalla is southeast and north with speeds of between 5 to 8 m/s. Table 2 below shows how the wind in Mukalla blows the southeast direction all over the year.

2.2 Outside Courtyard

The courtyard has got different shapes to allow more ventilation and therefore help in reducing the outer air temperature. The most once used in Mukalla city are rectangular courtyard, so the self-shading of the courtyard works on reducing the need for cooling by an average about 4% (Muhaisen & Gadi, 2006).

As a comparison between warm-humid and hot-arid climate, the urban structure is compact, crowd and it becomes open to enhance the air movement between buildings (Edwards, 2006).

Table 2: Wind Speed (m/s) and Directions in Al-Mukalla City

Wind	**2010**		**2011**		**2012**	
Month	Wind Speed (m/s)	Direction	Wind Speed (m/s)	Direction	Wind Speed (m/s)	Direction
Jan	6.8	NW	6.3	E	6	N
Feb	5.9	N	5.7	SE	6.5	SE
Mar	5.5	SE	6.0	NW	6.1	N
Apr	5.6	SE	6.8	E	6.2	SE
May	6.4	SE	6.4	SE	6.3	SE
Jun	7.5	N	6.9	SE	8.2	SE
Jul	7.6	S	7.8	E-NE	7.6	E
Aug	7.9	NE-E	8.1	N-NE	7.5	SE
Sep	6.7	E	7.0	S	7.3	E
Oct	5.5	E-SE	5.7	SE	5.8	N
Nov	5.4	NW	6.2	SE	5.7	N
Dec	5.9	NW	6.6	N	5.9	N
Mean	6.4	…	6.6	…	6.6	…

Source: Civil Aviation & Meteorology Authority-Yemen

2.3 Parameters

The surrounding building and the climatic properties of the outside courtyard depend on the length, height and width proportion. So that, Koch Nielson recommended to using the x to 3x as courtyard width, where x is equal to width, and 3x is equal to the courtyard height (Koch-Nielsen, 2013).

Edward noted that, the proportions of width to length ratios that most commonly used: 1:1.8 and 1:3.6, based mainly on the path of the sun (Edwards, 2006). While Wadah (2006, p. 156) showed that the courtyard area to the build area ratio must be ranged between 1.5 to 2.7, and that to avoid the environmental effect to be too large or too small. However, according to (Reynolds, 2002) should be enough with minimally 25% of the plot to make sky open and using the following to describe the affection of two main parameter factors on courtyard:

a. Aspect Ratio (AR): explain the openness to sky degree, which concentrate on the biggest aspect ratio and that makes the courtyard exposed. Therefore, to provide good daylight that factor had been considered in architectural designing and calculated with the following equation:

$$\text{Aspect Ratio} = \frac{(\text{area of courtyard}'\text{s floor})(\text{m})^2}{(\text{average height of walls})(m)^2} \qquad (1)$$

b. The Solar Shadow Index (SSI): that compatible with exposure to winter sun (Reynolds, 2002). It is concentrated on the maximum solar shadow index and the deep wall that formed the courtyard and reduce the winter sun that could be reached to the south wall or floor.

$$\text{Solar Shadow Index} = \frac{\text{South wall height (m)}}{\text{North}-\text{South floor width (m)}} \qquad (2)$$

Continuously, the aspect ratio will be high when the courtyard is shallow and wide, which as similar as sun collector, while in low aspect ratio the courtyard be deep and narrow as similar as sun protector.

2.4 Corridors and Shading

That could be described as a contact between closed spaces of the building and opened spaces, where it would be provided an area with outdoor pressure zone to transfer indoor environment through detailed design that integrated with passive elements of building (Siew et al., 2011).

2.5 Effects of Outdoor Spaces on the Building Performance

The integration between natural ventilation and the orientation of the building would become a challenge, especially for the designers and need to study the effect of wind and its direction in addition to the area of building that exposed to the wind and all that to obtain the optimum effect of ventilation on buildings (Cardinale et al., 2003). The site details and its feasibility should be studied to ensure the strategy of cooling that could be applied (Anselm, 2006), (Omer, 2008).

2.6 Thermal Comfort

To design a suitable passive system, Yemenis need to recognize the thermal comfort expectations (Sayigh & Marafia, 1998). Thermal comfort, it is argued, depends on the people's thoughts and attitudes towards the environment. Comfort normally happen when the body of temperature is being held during a narrow range, low moisture in the skin and reduce the effort of the physiological regulation. Macpherson (1962) explains the factors that affect on the sensation of thermal. These physical variables include:

1. Air temperature
2. Air velocity
3. Relative humidity
4. Mean radiant of temperature

(Personal variables):

5. The insulation of cloth.

De Dear & Brager (2001) noted that the standards and models of thermals comforts could be applied to all types of buildings, ventilation and climate region. Thermal comfort is also considered as a parameter key for productive workplace and provide a healthy environment (Taylor et al., 2008) and (Wagner et al., 2007).

3. Research Design

The case study of research takes residential area in Mukalla city that located along the west coast in latitude (14.33) north of the equator with Longitude (49.13) east of Greenwich at the coastline of Hadhramout governorate, with hot climate in summer and moderate in winter. The research design has an experiment divided into the following stages:

3.1 Onsite measurement

After measuring the outside courtyard and narrow street, then measure the residential building spaces to determine the number and style of openings, doors and windows in one room. Also measure the velocity of airflow indoor the building with one meter as height from the floor level at the middle and near the window.

The survey was conducted from the 1st to 15 of July in 2014 for 15 days consecutively. The reason is that this period time one of the hottest of the year according to the average of 5 years meteorological data from the nearest station of the weather. There are three types of climatic factors were measured indoor and outdoor which are air temperature, wind speed and direction. The device which was used is the **Anemometer**. The indoor measurements of the temperature and movement of air were taken in the middle of all spaces at the high of 1.2m from the floor level, while outdoors at the high of 1.8 m from ground level (Krüger & Givoni, 2008).

3.2 Simulation

The simulation makes model for building to compare between the results and measure the percentage of error before taking it to next stage. Use ECOTECT® and DesignBuilder® to establish the model and make sure of the result. While the data used was driven from the experiment which was hourly-measured from 1st July to 15 July in 2014 from 6:00 am to 12:00 pm for air temperature and wind velocity, as base line data to construct virtual environment with simulation weather data and compare between them to minimize the differences. And by use DesignBuilder® change the independent variables to recognize the relationship between courtyard, narrow street and get the proper orientation with low air temperature value.

3.3 Changes in independent variables

3.3.1 The relation between the outside courtyard and the Narrow Street

To find out the effect of outside courtyard and the narrow street on air temperature and to identify the optimal ratio, there is a great need to illustrate a case study with its surroundings. The analysis of existing location started on 1st July with concentration on air temperature, shading and sun movement, which is the same time of starting the practical experiment on the case study.

The effect of outer courtyard and the narrow street on air temperature and its relation was measured by simulation software. Then, the aspect ratio has been changed to be equal 0.2, 0.5, and 0.7, and the best aspect ratio has chosen according to Muhaisen (2006) research. Finally, the results of air temperature and shading percentage have been compared with the results of aspect ratio.

3.3.2 Effect of orientation

It is impact on the air temperature of indoor building could be fined to identify the optimal orientation, consider all the building models but concentrate on the room 1 as it has windows were facing one direction more than other rooms which have windows facing three directions. First, the real existing orientation was analysed. Then, the model was rotated site in steps of 270° especially the long façade to investigate the effect of different orientations starting from 0° and 270° North-South and East-West respectively (Figure 1).

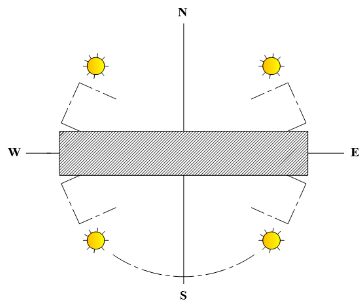


Figure 1: Model rotate

After that, calculate the differences between orientations in air temperature and natural ventilation and then make a comparison between 0 and 270 orientations.

4. Result of the Analysis

4.1 The effect of orientation on temperature

The effect of orientation between 0 and 270 degree causes small changes to the building temperature with only 2°C. The building temperature at 0 degree is higher than 270 degrees, reaching its maximum increase at 16:00 with 1°C as shown in Figure 2.

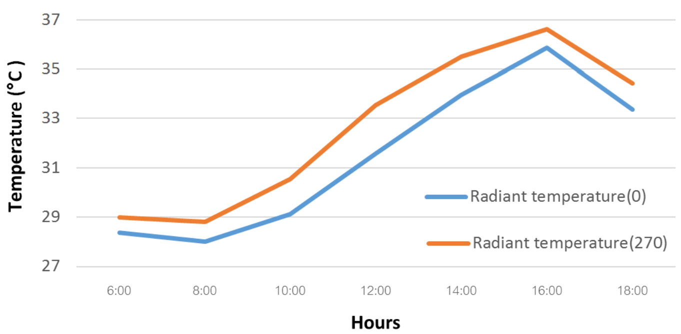
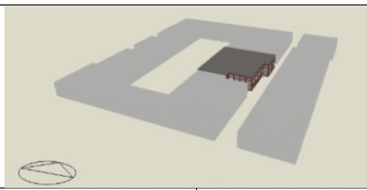
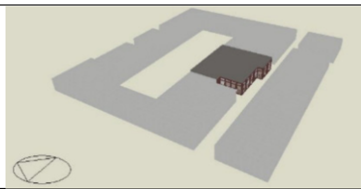


Figure 2: Difference between orientations.

As the whole site had been rotated from 0 to 270 degree, Table 1 shows that the temperature had increased gradually to approximately 2°C from 10:00 am to 12:00 pm, while the natural ventilation had changed at the 0 degree with 0.01 m/s from 10:00 am to 12:00 pm compared with 270 degree.

Table 3: Differences in orientation.

Orientation	0		270		
Zone					1
Air Temperature (°C)	30.5	33.2	31.5	34.9	---
Radiant Temperature (°C)	29.1	31.58	30.75	32.87	---
Natural ventilation (m/s)	0.68	0.69	0.68	0.68	---
Time	10:00 am – 12:00 pm		10:00 am – 12:00 pm		2H.

4.2 Outside Courtyard and Narrow Street

The changes between R3 and R2 aspect ratio of outside courtyard and narrow street in air temperature decreased at 8:00 am and reached 33°C in outside courtyard and 33.12°C in narrow street, and increased at 10:00 am and reached 34.22°C and 35.03°C, respectively, while reached its maximum at 12:00 pm. Also, the changes in R1 aspect ratio of outside courtyard and narrow street decreased at 10:00 am and reached 32.41°C and 33.22°C, respectively while reached its maximum at 10:00 am as shown in Figure 3.

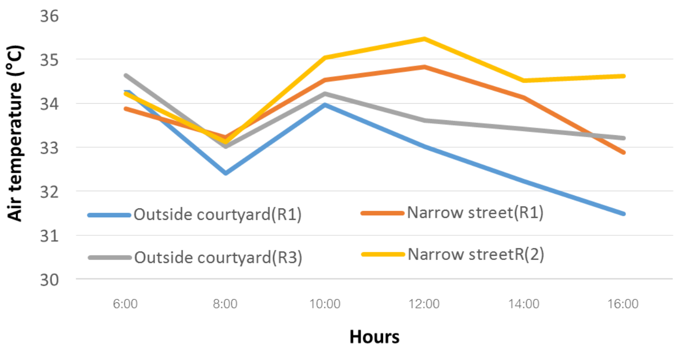


Figure 3: The air temperature of outside courtyard and narrow street (North-South).

It should be noted that the original case study has come up with decreased results in air temperature compared with outside courtyard and the narrow street where the changing aspect ratio less than 1°C in air temperature. Also, the shade percentage has increased in the outside courtyard compared with the narrow street, as shown in Table 2.

Then change the orientation to the west-east (270) and repeat the same aspect ratio. The changes appeared in used R2 on the narrow street when the comparison between two orientations in the decrease at 16:00 reached to 2F as shown in Figure 4. While the shading percentage decrease in the narrow street compare with the North-South orientation to 0.03% as shown in Table 3.

Table 4: Difference between outside courtyard, narrow street aspect ratio.

	Outside Courtyard			Narrow street			Hours
Aspect Ratio(R1*)	R1			R1			
Aspect Ratio (R2**)	---			R2			
Aspect Ratio (R3***)	R3			---			
Air Temperature	34.13	34.22	33.61	35.03	35.46	34.51	
Air temperature (R1*)	33.96	33.38	33.02	34.52	33.88	34.82	
Shade Percentage (R2**&R3***) , (R1*)	28 -50 %			25 %			
Time	10:00 AM – 12:00PM			10:00 AM – 12:00PM			2 H.

*R1=0.2, **R2=0.5, ***R3=0.7

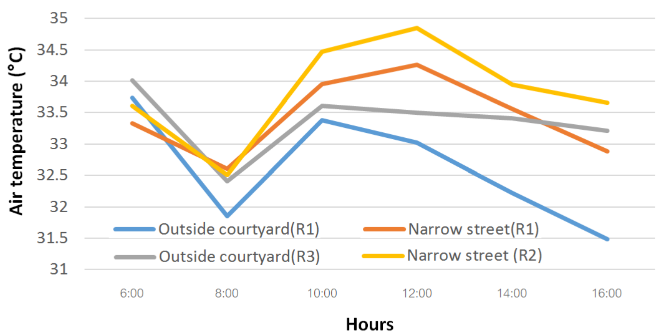


Figure 4: Air temperature of outside courtyard and narrow street (West-East)

Table 5: Difference between outside courtyard, narrow street aspect ratio (East-West)

	Outside Courtyard			Narrow street			Hours
Aspect Ratio(R1*)	R3			R2			
Air Temperature	33.61	33.55	33.5	34.47	34.75	34.85	
Shade Percentage	50 %			24.47 %			
Time	10:00 AM – 12:00PM			10:00 AM – 12:00PM			2 H.

**R2=0.5, ***R3=0.7

5. Discussion

The orientation between 0 to 270 degrees have affective results even with radiant temperature that use mean of the heat transferred from surrounding walls compared with air temperature that use the average of air surrounding temperature. While the orientation between 90 to 180 degrees neglected as a result of high values of air temperature and uncomfortable environment that produced direct sun for more than 4 hours.

The First aspect ratio (R1= 0.2) has used the minimum width comparing to height and that makes the outer courtyard deep such as narrow street, but the outer courtyard width is higher than the original narrow street. While in the second and third aspect ratio (R2 = 0.5 & R3= 0.7) were near to the equations of Koch with the effection.

The simulation software helps to know the proper aspect ratio especially when using more than two aspect ratio R1, R2 and R3 to obtain the optimum one that suitable with the climate and allow to increase the shaded area as shown in Table 4.

The effect of the rectangular outside courtyard aspect ratio that ranged (0.5 to 0.7) appeared in choosing its heights and storeys and increasing in the shading percentage. So, the height difference from one storey to three storeys was tested and showed high result in the shading with the height of level floors as shown in Table 5.

Table 6: Aspect ratio to shading percentage of courtyard and narrow street

Location	Optimum ratio	Shade percentage
Outside courtyard	R2=0.5	28%
	R3=0.7	50%
Narrow street	R1=0.2	25%

Table 7: Minimum shading percentage

Number of storeys	Minimum shading percentage
1 = 3 M	18%
3 =10 M	28%

While the shading percentage of the area in the courtyard especially in the summer could be increased by making it deeper, where it was determined the optimum ratio according to the equality for heating and cooling energy requirements.

As shown in Figure 5 the outside courtyard has two orientations north-south and east-west and all of them were monitored for 15 days from hot summer period with concentrate on the relative humidity, air temperature, shading percentage and the wind direction and ventilation. Whereas, the buildings surrounding the courtyard characterized with no openings contact between courtyard and narrow street from first to second floor and just variation in heights of buildings which prevent wind speed and breezing.

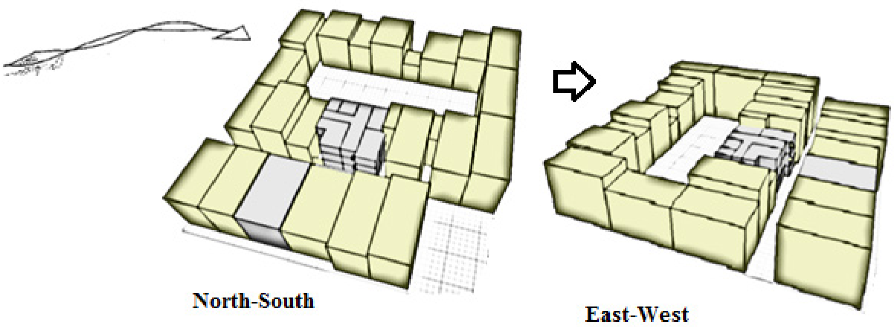


Figure 5: North-south and east-west courtyard and wind direction

After monitoring the percentage of internal shading for both of north-south and east-west courtyard, it was noted an increase in the direct radiation of the sun that faced from the morning to late afternoon the east-west courtyard and narrow street, compare with north-south one as shown in Figures 6 and 7. However, it is observed that even though the high effect of the courtyard, narrow street and orientation on decreasing the thermal behaviour of the building, but still there is an overheating especially in the summer daytime and that because of the radiation that trapped inside the building envelope and the shortage in the ventilation.

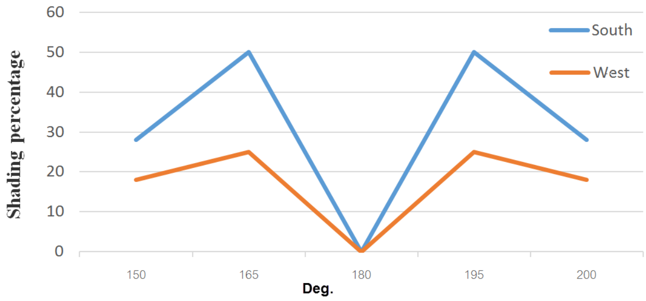


Figure 6: The courtyard shading in west and south orientation

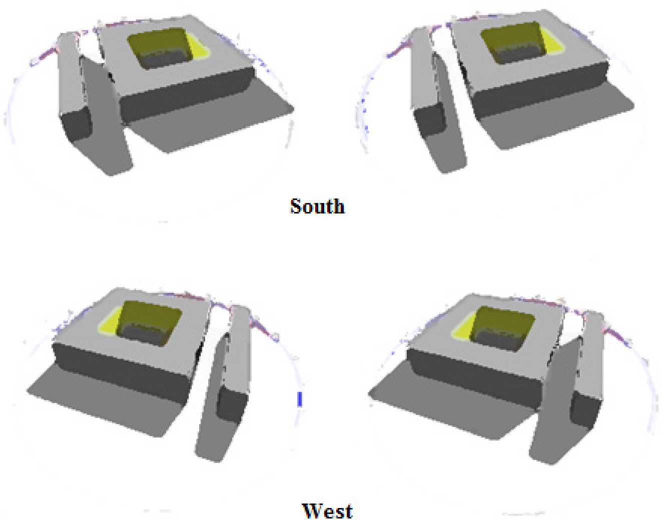


Figure 7: Area to shade total percentage

6. Conclusion

The urban context in Mukalla city have their characteristics in passive design, especially in the east side. Also, the space for building construction is found to be small with vertical extension while the remaining used for narrow street and outside courtyard to control the air temperature and shading percentage by increase wind velocity outside courtyard and narrow street which are integrated into the building's structure. But as a result of no direct openings in the first and second floor of the building envelope that contact between courtyard and narrow street, get increased wind speed with 0.68-0.69 m/s. The outside courtyard and the narrow street provided little changes in natural ventilation and kept the temperature harmonized especially in the increase and decrease points, compared with the south-north orientation. So that the north-south orientation was the perfect orientation compared with the east-west orientation in providing better natural ventilation. Also, the orientation of the building was affected by the direction of prevailing winds which control the natural ventilation and air temperature.

7. References

Abraham, L. E., Agnello, S., Ashkin, S., Bernheim, A., Bisel, C., Burke, W., . . . Gottfried, D. (1996). Sustainable Building Technical Manual: Green Building Design, Construction, and Operations. In: Estados Unidos: Public Technology, Inc.

Al-Obaidi, M. A. A. H., & Woods, P. (2006). Investigations on effect of the orientation on thermal comfort in terraced housing in Malaysia. International Journal of Low-Carbon Technologies, 1(2), 167-176.

Aldawoud, A. (2008). Thermal performance of courtyard buildings. Energy and Buildings, 40(5), 906-910.

Anselm, A. J. (2006). Building with nature (ecological principles in building design). Journal of Applied Sciences, 6(4), 958-963.

Cardinale, N., Micucci, M., & Ruggiero, F. (2003). Analysis of energy saving using natural ventilation in a traditional Italian building. Energy and Buildings, 35(2), 153-159.

de Dear, R., & Brager, G. S. (2001). The adaptive model of thermal comfort and energy conservation in the built environment. International Journal of Biometeorology, 45(2), 100-108.

Edwards, B. (2006). Courtyard housing: past, present and future: Taylor & Francis.

Koch-Nielsen, H. (2013). Stay cool: A design guide for the built environment in hot climates: Routledge.

Krüger, E., & Givoni, B. (2008). Thermal monitoring and indoor temperature predictions in a passive solar building in an arid environment. Building and Environment, 43(11), 1792-1804.

Muhaisen, A. S. (2006). Shading simulation of the courtyard form in different climatic regions. Building and Environment, 41(12), 1731-1741.

Muhaisen, A. S., & Gadi, M. B. (2006). Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. Building and Environment, 41(3), 245-253.

Omer, A. M. (2008). Green energies and the environment. Renewable and Sustainable Energy Reviews, 12(7), 1789-1821.

Reynolds, J. (2002). Courtyards: aesthetic, social, and thermal delight: John Wiley & Sons.

Sayigh, A., & Marafia, A. H. (1998). —Thermal comfort and the development of bioclimatic concept in building design. Renewable and Sustainable Energy Reviews, 2(1), 3-24.

Siew, C., Che-Ani, A., Tawil, N., Abdullah, N., & Mohd-Tahir, M. (2011). Classification of natural ventilation strategies in optimizing energy consumption in Malaysian office buildings. Procedia Engineering, 20, 363-371.

Szokolay, S. V. (2008). Introduction to architectural science: the basis of sustainable design: Routledge.

Taylor, P., Fuller, R., & Luther, M. (2008). Energy use and thermal comfort in a rammed earth office building. Energy and buildings, 40(5), 793-800.

Wagner, A., Gossauer, E., Moosmann, C., Gropp, T., & Leonhart, R. (2007). Thermal comfort and workplace occupant satisfaction—Results of field studies in German low energy office buildings. Energy and buildings, 39(7), 758-769.

Rasha Saeed Baangood is a PhD candidate in Architecture Programme, at Housing Building and Planning, University of Sains Malaysia (USM). She is a lecturer in Architectural Department, Faculty of Engineering at Aden University. She obtained Bachelor of Architectural Engineering in Aden University, Aden, Yemen. And awarded master in Architectural Engineering. Her research focus on computer simulation, natural ventilation, thermal comfort and onsite experiment. At the university, she teaches theoretical and practical courses related to urban design, interior design and working design.

Professor Dr. Ahmad Sanusi bin Hassan teaches in Architecture Programme at the School of Housing, Building and Planning, University Sains Malaysia (USM). He obtained Bachelor and Master of Architecture from the University of Houston, Texas, USA. He was awarded a PhD degree from the University of Nottingham, United Kingdom. He was promoted to Associate Professor and later Full Professor. His research focuses on computer simulation on daylighting and thermal comforts, architectural history and theory, and housing in urban design. He is one of the nine regional writers involved in the preparation of Guideline: Agenda 21 for Sustainable Construction in Developing Countries: A Discussion Document, which was launched at The Earth/World Summit, Johannesburg in September 2002. At the university, he lectures in architecture courses related to urban design, studio, history, Computer Aided Design (CAD), and computer movie animation. He has integrated all these specialisations into his research, teaching, consultation and publications. He had designed several architectural projects such as mosque, USM guest house and a proposal for low-cost houses for fishermen community.

Note: The original work of this article was reviewed, accepted, and orally presented at the 3rd International Conference-Workshop on Sustainable Architecture and Urban Design (ICWSAUD 2017), a joint conference with the 3rd International Conference on Engineering, Innovation and Technology (ICEIT 2017), held at Royale Ballroom at the Royale Chulan Penang Hotel, Malaysia, during 13-15th November 2017.