Environmental Design Requirements for Courtyard Buildings in Hot-Dry Climate

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ABSTRACT

The main goal of this study is to review the environmental design requirements for courtyard buildings in the hot-dry climatic region. The study aims at bringing to understanding the design requirements for shading and ventilation performances of the courtyard. The study was conducted by making an analogy with respect to courtyard buildings in the hot-humid climatic zones. The study shows that, for optimum shading performance in the courtyard, its shape, orientation, and sky view factor are the most important environmental design requirements for courtyard in the hot-dry climatic zone. For ventilation performance, the use of night ventilation could improve the interior thermal situation in the hot-dry region, but in hot-humid zone, however, some scholars opine that air flow through courtyards is vital to comfort, whereas others state that ventilation is needless because it would allow hot air into buildings. This study concludesthat the courtyard shape, orientation, and sky view factor are the major environmental design requirements in the hot-dry climatic zone, but their appropriateness is still unknown and need to be studied in future simulation studies.

Keywords: *Courtyard, hot-dry climate, environmental design, shading, ventilation*

INTRODUCTION

Mitigating the challenge of global warming and carbon dioxide emission caused by energy consumption in buildings in the entire world and most especially in the developing countries like the African countries (Nigeria) inclusive, has remain on top among the numerous challenges in this twenty first century, and the application of courtyard as a Passive and Low Energy Architecture (PLEA) design strategy may be one among the most suitable approaches (Abass, Ismail and Solla, 2016). According to Koch-Nielsen (2002) a courtyard house is defined as that which has an interior area opened to the atmosphere. Almhafdy, Ibrahim, Ahmad and Yahya (2013a) emphasise that courtyard in buildings had been in practice during the Neolithic civilization and was broadly familiar in China and Morocco. Courtyard majors in providing protection against the increased climatic conditions and eco-friendly purposes such as normal lighting, shading and ventilation (Hyde, 2000). Climatic conditions are the major determinant factor for courtyard shape. For example, the form of the courtyard changes from the colder regions to warm regions (Knapp, 1999). A perfect example is China where the colder region –the northern part, has courtyards with small

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ISSN: 2141-2731

depth in other to enhance solar radiation, but the warmer regions – the southern part, uses deeper courtyard form to avoid solar heat gain (Koch-Nielsen, 2002).

According to Hyde (2000), the design of courtyard is very important in improving thermal performance especially when the appropriate size is known. He emphasised that there are three basic courtyard typologies; namely: fully enclosed courtyard, semi-enclosed courtyard and semi-open courtyard. These courtyard typologies are suitable for different functions, for instance, a long building will require a fully enclosed courtyard. Also, the eco-friendly behaviour of courtyards can be enhanced by nature of the building form and the heat improvement strategies (Hyde, 2000). Therefore, one can run to conclusion that, the relationship between the building, the courtyard design and the local climatic conditions would be directly proportional to its environmental performance.

The preceding works on courtyard buildings are still inadequate, but few of them looked at the eco-friendly functions of courtyards like, Jamaludin, Hussein, Mohd Ariffin and Keumala (2014); Almhafdy, Ibrahim, Ahmad and Yahya (2013b); Almhafdy, Ibrahim, Ahmad and Yahya (2013a); Gou, Li, Zhao, Nik and Scartezzini (2015); Jamaludin, Hanita, Mohamad and Syed (2014); Ahmed and Mohamed (2006); Berkovic, Yezioro and Bitan (2012); and Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015). Also, studies on the impact of courtyard shape on internal environmental behaviour, such as; Muhaisen (2006); Canton, Ganem, Barea and Llano (2014); Ok, Yasa and Özgunler (2008); Ratti and Raydan (2003). In addition, studies on ventilation impact of the courtyards include: Taleb and Sharples, (2011); Al-Masri and Abu-Hijleh (2012); Tablada, Blocken, Carmeliet and Troyer (2005). Other scholars like; Gou *et al.*, (2015); Al-hemiddi and Al-saud (2001); Yan and Santos (2009); Canton, Ganem, Barea and Llano (2014) and Akande (2010) suggested the courtyard as a passive design strategy.

Most of the studies mentioned were carried out in hot-humid climatic regions and temperate climatic regions, and only few focused on environmental requirements for courtyard buildings in hot-dry climatic regions. Therefore, this study reviews on environmental design requirements for courtyards buildings in hot-dry climatic region by making analogy between courtyards in hot-humid climatic region and those in the hot-dry climatic regions. This study has provided the background for future prospects in design thoughts for courtyard buildings.

Environmental Design Requirements for Courtyards in Hot Climates

Shading and ventilation are the most significant eco-friendly design thoughts for courtyards in buildings, especially in the hot regions. The impact of shading in courtyards is commonly influenced by the building orientations, height, and their exposure to the sky (Meir, Pearlmutter and Etzion, 1995) see, fig2, 3and 4. But the impact of ventilation by courtyards is largely based on the outside wind situation or the inside temperature variance for the stack effects (Koch-Nielsen, 2002; Givoni, 1994).

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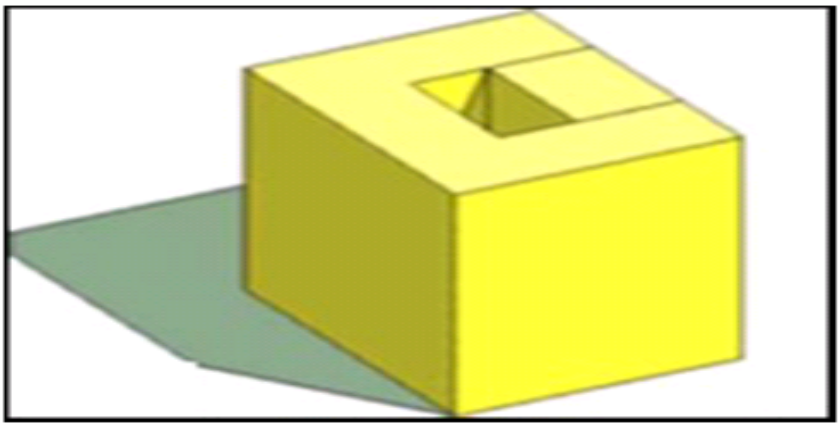

Fig.1: Shading generated by building form.
Source: Jamaludin, Hanita, Mohamad and Syed (2014)

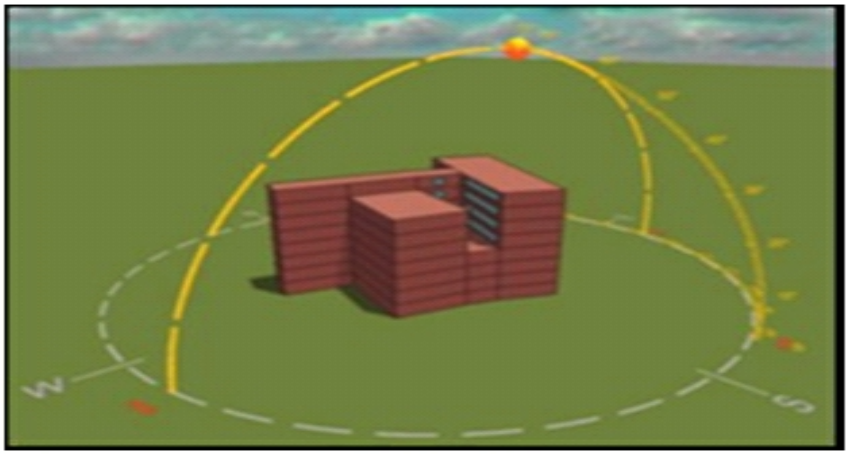

Fig.2: Shading generated by building orientation.
Source: Jamaludin, Hanita, Mohamad and Syed (2014)

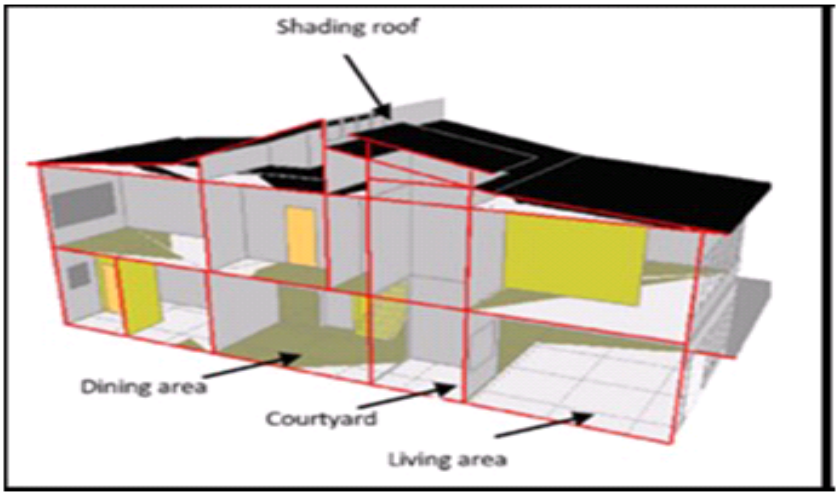

Fig.3: Shading generated by courtyard roof
Source: Jamaludin, Hanita, Mohamad and Syed (2014)

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Courtyard Shading and Ventilation

In the hot climatic zones, the main significant design strategy for courtyards in buildings is believed to be shading and ventilation strategies. Shading strategy of courtyards is generally based on the orientation of the structure, its elevation, and the degree of its open contact to the heavens (Meir, Pearlmutter and Etzion, 1995). Also, the courtyard form is another factor (Jamaludin, Hussein, Mohd Ariffin and Keumala, 2014). Its suitability is hinged on the climatic situation, in China for instance, the form of courtyard reduces as one travels from the northern to the southern part of China, that is, as the temperature goes down from the north to the south (Knapp, 1999). In sketching the courtyard, its size is significant if shading is required (Hyde, 2000). Jamaludin, Hanita, Mohamad and Syed (2014) has concord that courtyard can better eco-friendly performance if its shape and heat gain/loss ability is not ignored.

But the ventilation strategy on the courtyard primarily is based on the open-air breeze conditions or the inside hotness variations due to the stack effects (Koch-Nielsen, 2002; Givoni, 1994). The amount of assimilation of radiant heat on the structure and courtyard space may lead to a rise in the degree of air hotness in the immediate areas (Muhaisen, 2006). Consequently, shading could be essential to lessen the amount of direct radiant heat gain (Hyde, 2000). Shading methods that are usually employed for courtyard houses include: Shading produced by house shape, Shading produced by house orientation, Shading produced by courtyard roof, and vegetation (Muhaisen, 2006; Almhafdy, Ibrahim, Ahmad and Yahya, 2013a; Berkovic, Yezioro and Bitan 2012; Tabesh and Sertyesilisik, 2015). Almost all the studies conducted in hot-dry climates reveal that a courtyard orientation is one of the best strategies for shading effects. For instance, Meir, Pearlmutter and Etzion (1995) studied two courtyards in Israel through direct measurements. Still, Ghaffarianhoseini, Berardi and Ghaffarianhoseini (2015) carried out a simulation investigation in courtyard in the same region. They concluded that, North to South direction of a rectangular courtyard, possibly, will attain the uppermost shading result.

On the contrary, investigations on comparison of the two zones (hot-humid and hot-dry) on shading strategy by orientation of the building, for instance Muhaisen (2006) in a shading simulations study, considering the two climatic situations that is, hot-dry and hot-humid concluded that in hot-humid situation, the mainly appropriate direction of courtyards is the north-east to south-west direction. On the other hand, based on an investigation by Almhafdy, Ibrahim, Ahmad and Yahya (2013b), orientation strategy possibly will merely trim down for about 2% for the atmospheric hotness of courtyards in hot-humid situations. The courtyard direction for hot-humid situation is recommended to be based on the direction of breeze (Koch-Nielsen, 2002; Jamaludin, Hussein, Mohd Ariffin and Keumala, 2014; Givoni, 1994). It then means that, the result of radiant heat in a hot-dry situation has superior as weigh against in hot-humid situations. But on the contrary, in the hot-humid region, manipulating the degree of sky exposure is the best option for obtaining effective shading in courtyard buildings. Because of the high concentration of radiant heat in hot-dry region, the shading result by building orientation possibly will provide a key

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defence ahead of taking into consideration the use of other additional approaches (Akande, 2010). The amount of contact of courtyard to the radiant heat mostly causes a rise in temperature for the courtyard area in hot-humid region. Consequently, the shading obtained by the amount of direct contact with the courtyard or the direct shading device in the courtyard is more significant than shading obtained through building orientation.

For buildings in the hot humid regions, Shading obtained by determining the level of the courtyard roof exposure is more important in proffering improved interior thermal environment for buildings. An appropriate design thought of the courtyard roof exposure could present advantageous shading results and permit the flow of ventilation. The amount of courtyard roof exposure can be calculated by using the sky view factor (Muhaisen and Gabi, 2006).

Analogy of Courtyard Shading in Hot-Dry and Hot Humid Climates

It is a very clear fact that shading in courtyard is mainly achieved through its shape and orientation, most especially in hot-dry climatic regions (Jamaludin, Hanita, Mohamad, and Syed, 2014). It is due to the fact that in a hot-dry region, the radiant heat is to a great extent stronger than that of the sky emission. However, the hot-humid region, has mist content in the atmosphere at a higher degree and consequently, the radiant heat is for the most part diffused in the atmosphere (Koch-Nielsen, 2002). So, the atmospheric emissions, which move towards all ways, mostly have an effect on the heat gain in the courtyard. Therefore, it is expected that courtyard shape and its orientation are not too significant for shading and cooling in the hot-humid regions. As a result, for the hot-humid regions, the degree of exposure to the atmosphere has to be the most significant factor for obtaining shading in courtyard. In reality, considering the level of atmospheric exposure gives the impression to be much better than a completely enclosed courtyard (Jamaludin, Hussein, Mohd Ariffin and Keumala, 2014). This is due to its dual function of creating shade and opportunity through the courtyard roof for allowing gentle breeze circulations in the courtyard.

One of the processes to calculate the amount of exposure in courtyard is through the use of a sky view factor. Almhafdy, Ibrahim, Ahmad and Yahya (2013a) examine the cooling impacts of courtyards in conventional Chinese shop building in Malaysia and made known that a connection exist among sky view factor and air temperatures calculated in courtyards.

In the hot-dry region, the major design strategy is consideration for shading impacts rather than ventilation (Jamaludin, Hussein, Mohd Ariffin and Keumala, 2014). Courtyard are universally common in conventional buildings in this zone and are known for giving shade, and their design strategy for ventilation by evaporative cooling is considered suitable in both hot-humid and hot-dry climates.

Ventilation Effects

The impact of stack and wind is considered to be the significant factors for ventilation in courtyards (Ok, Yasa and Özgunler, 2008). According to Knoch-Nielson (2002), the warmed wind grows up and liquidates in the heavens throughout the daytime and the thick

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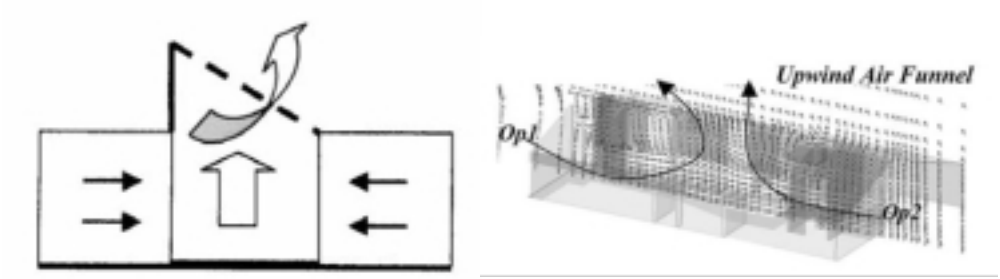
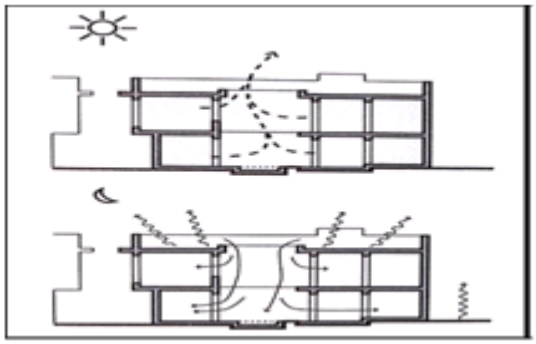
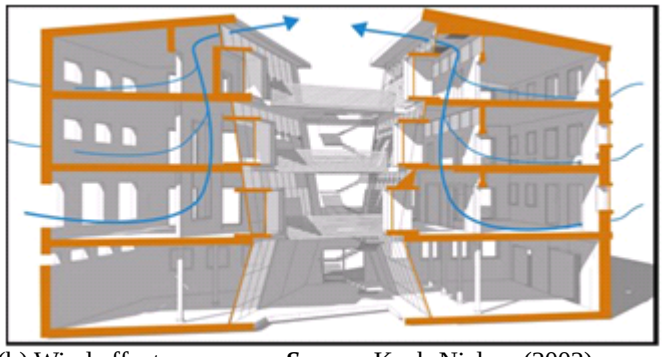
cool outside air descends into the courtyard throughout the night time as the result of stack effect. The nature of pressure will also determine the wind effect in the courtyard (Meir, Pearlmutter and Etzion, 1995). Yu and Su, (2015)opine that a constructive pressure enable the air to flow into the courtyard but the destructive pressure causes air suction externally from the courtyard, see figs 4 and 5.



Upward air flow caused by cross-ventilation in (a) Wind tunnel study on courtyard model (b) CFD study on detached courtyard house in Sri Lanka.
Source: Sharples and Bensalem, 2001; Rajapaksha, Nagai and Okumiya, 2003.



(a) Stack effects during daytime and night-time ventilation. ***Source:*** Koch-Nielsen (2002)



(b) Wind effects ***Source:*** Koch-Nielsen (2002)

Uninterrupted ventilated condition is vital in a hot-humid climatic region, where it could eliminate heat from the building for attaining comfort (Koch-Nielsen, 2002). Building design is supposed to encourage thoroughgoing air movement with little inner hindrance. The traditional wooden house is one of the examples, which has a raised timber floor with

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multiple window openings on the building's façade to achieve the necessary cross ventilation condition. However, the approach is different to the ventilation methodology for the hot-dry region. In the hot-dry climatic zone, the outside wind during the day is dry and warm with gusty air. Consequently, buildings in this zone are recommended to be designed with fewer fenestrations on the outside wall or shut during the daylight (Kabre, 2010). In numerous circumstances, evening ventilation is considerably more appropriate with their climatic situation (Cook, 1996; Givoni, 1994). Table 1 reveals several contributions of literature on ventilation means by courtyards in hot-dry climatic zone.

Table 1: Ventilation means by courtyards in hot-humid climates

Ventilation strategy	Effect	Sources
Landscape strategy by efficient water use	(1) Compared to a non-vegetated exposed courtyard, which on average reached a maximum air temperature of 34ºC in mid-afternoon, a similar courtyard treated with shade trees and grass yielded a daytime temperature depression of up to 2.5K (2) Improved interior comfort when courtyard acts as air funnel.	Shashua-Bar, Pearlmutter and Erell (2009)
Analogy of deep and street canyon	(1) The deep canyon was considerably cooler than the shallow one. (2) The shallow canyon conceived more heat in winter. (3) The study concluded that, in hot dry zone a compact built-up design with deep canyons is better.	Yu and Su s h a l l o w (2015)
Evapo-reflective roof beneath a water pool	The maximum interior air temperature could further be dropped by letting ventilation of the structure in the nightfall.	Ben Cheikh and Bouchair (2004)
Galleries and horizontal shading	The influence of wind under the studied shapes was limited and considerably lesser than the shade influence.	Sigalit *et al.* 2012
Simulation studies	The results show that the courtyard provides high competence in providing cool interior air by cross-ventilation.	Ok, Yasa and Özgunler (2008)

Eco-Friendly Thoughts for Courtyard in Hot-Dry Climate

The shading impact of a courtyard is principally influenced by its form and orientation, mainly in the case of hot-dry climates (Meir, Pearlmutter and Etzion, 1995). This is due to the fact that, in a dry environment, the direct solar radiation is much higher than that of sky radiation. But indivergence to a hot-humid environment, the molecules of water in the air is higher and consequently, the solar radiation is mostly diffused in the airborne (Koch-Nielsen, 2002). So, the sky radiation coming from different routes largely influenced the heat achievement in the courtyard area. It is expected that the form and orientation of a courtyard are less important in the eco-friendly design thoughts for hot-humid climates.

In terms of the ventilation eco-friendly design thought, adjusting the sky disclosure seems to be much more correct rather than a completely covered courtyard. This is due to

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the fact that, apart from providing shade to the courtyard, this strategy generates a route on the courtyard roof permitting the air flow inside the courtyard space. Thus, the courtyard space performs a dual function of shading and at the same time air flow throughout the daylight or night-time. The methodology for measuring the level of courtyard exposure is by the sky view factor. In a study carried out by Kubota, Toe, and Ossen (2014), the cooling impact of courtyards in traditional Chinese shop households in Malaysia was studied and revealed that a connection between sky view factor and air temperatures measured in the courtyards exist. In Figure 8, the connection is that gotten from the four courtyards is an illustration. The chart reveals that, a reduction in the sky view factor is directly proportional reduction in the air temperature in the courtyard. Though, it is understood that more examples are essential to elucidate this point.

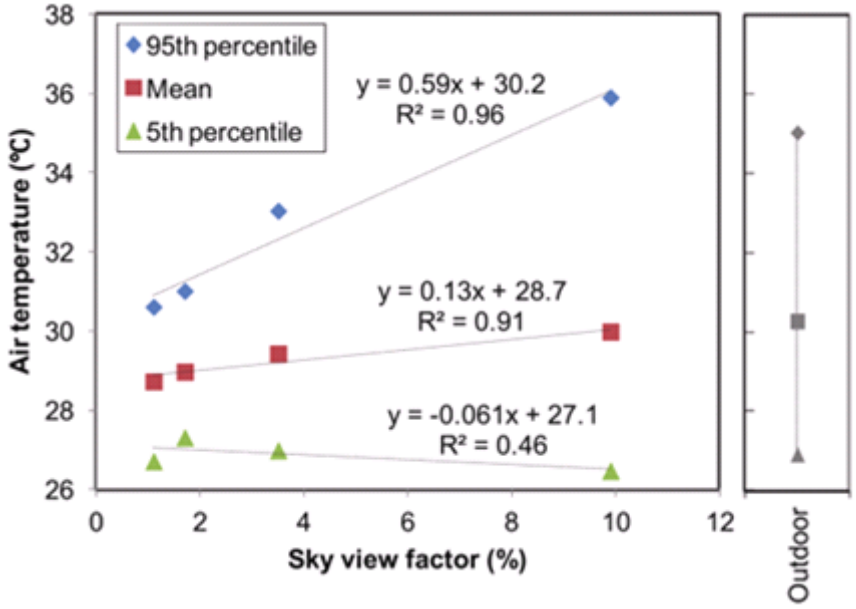

Fig. 8: The connection that gotten from the four courtyards
Source: Koch-Nielsen (2002)

However, in hot-dry climatic zone, the most significant design eco-friendly thought is not ventilation but shading effects. Courtyards are usually seen in old-style buildings in this zone for providing shade to the surrounded area, whereas for the ventilation approaches, night ventilation or an evaporative cooling is more applicable. The high temperature ranges amid daytime and night-time offers benefits in this climate.

CONCLUSION

This study is a review from on the environmental design requirements for courtyard buildings in hot-dry climates. The study primarily focuses on the shading and ventilation impact of the courtyard. The study reveals that climatic circumstances do affect shading and ventilation strategies for courtyard building. From the study, it is dedued that Courtyard form and

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orientation are considered to be the main priority for shading in buildings in hot-dry climates. But for the hot-humid climatic zone, the thought of shading impact by adjusting the sky exposure or courtyard roofs is expected to be more suitable. Therefore, the shading impact by the sky exposure could be less important as compared to the form and orientation.

In hot-dry climatic zone, the use of night ventilation could maintain the interior thermal situation in an appropriate level. But, for hot-humid climatic zone, appropriate ventilation approaches are still debateable. Some scholars underlined that unremitting ventilation with rising air flows through courtyards is central to offer comfort to interior situations, whereas others state that daylight ventilation is needless because it would allow hot air into buildings. Finally, more studies concerning the environmental design requirements for courtyard buildings in hot-dry climatic zone is needed. In addition, simulations studies to permit prediction of the appropriate courtyard dimensions and proportions for effective environmental performance is recommended.

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ISSN: 2141-2731