RESEARCH ARTICLE

Orientation as a panacea for improving the Thermal Performance of a fully enclosed courtyard in a typical tropical climate

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Abstract
Globalization has resulted in pollution, carbon emissions, climate change, and an insufficient supply of natural resources. As a result, research is required to increase the thermal performance of buildings. In this regard, using a courtyard as a building component is one of the most sustainable ways to improve the building's thermal performance and microclimate. While utilizing the Envi-met program on the configurations chosen for the fully enclosed courtyard, this study investigated the effect of orientation on the fully enclosed courtyard's thermal performance. 1:1:1 and 1:2:1 are examples of this setup. The orientations considered in this example were N-S, E-W, NE-SW, and NW-SE. The air temperature, mean radiant temperature and physiological equivalent temperature were measured during simulations of two configurations of the fully enclosed courtyard. According to the research, the air temperature, mean radiant temperature and physiological equivalent temperature rises as the size of the courtyard grows. As a result, the air temperature in the 1:1:1 courtyard arrangement is lower than in the 1:2:1 courtyard design.

Keywords: Courtyard; Simulation; Orientation; Air temperature and Mean Radiant Temperature

Introduction

Globalization has been linked to environmental pollution, carbon emissions, climate change, rising energy demand, and a scarcity of natural resources, according to numerous research (Behrens et al., 2007; Rasul and Sharma, 2016; Wang et al., 2018). Over 30% of carbon emissions, which are the primary cause of climate change, are reflected in the thermal performance of buildings (Wang et al., 2018).
Therefore, it is necessary to conduct studies to improve the thermal performance of buildings. In this context courtyard as a building component is one of the sustainable strategies to checkmate the thermal performance and improve the microclimate of the building. The use of courtyards in buildings solves a variety of issues, including seclusion, comfort, and reduced energy consumption. The courtyard also provides natural ventilation, lighting, and thermal performance. According to Meir et al. (1995), using courtyard constructions as a microclimatic modifier has been considered for decades. The solution to the issue of thermal performance focused on finding effective passive strategies. The outcome of this step that the designers became more aware of traditional strategies that depend on non-mechanical methods, in order to improve the comfortable atmosphere. For an example in hot-dry and warm-humid zones cooling is a priority than heating, for this demand many elements support natural techniques applied in these buildings for many decades, such as courtyards, mashrabiyya, wind towers and ventilation tunnel (Allen G. Noble, 2007; Rajapaksha et al., 2003; Zain,2012). Rajapaksha et al., (2003) in their study focused on the cooling techniques around the building, they found that in warm-humid regions, vernacular design techniques involved elements in providing a cooling environment such as courtyard, building orientation, shading device, while in the United State of America, a ventilation tunnel is accessible in the region. In Middle Eastern countries mashrabiyya and ventilation through water elements used in a humid area, whereas in the tropics they used courtyard

For generations, the courtyard has served as a utilitarian and symbolic architectural element. The courtyard concept is employed in every part of the world. "A court open to the sky, especially one enclosed on all four sides," McKean (2006) defined courtyard. However, different scholars have varied meanings of the courtyard. According to Abass et al. (2016), a courtyard is a covered outdoor space that is open to the elements at its apex, but Zakaria and Kubota (2014) defined it as an open chamber into the skies that is bordered by buildings or rooms. Taleghani et al., (2014), on the other hand, describe the courtyard as an outdoor place that is virtually interior, exposed to the sky, in contact with the ground, yet surrounded by rooms. Yaşa and Ok (2014) defined courtyard as an open space surrounded by vertical components or structures. Berkovic et al. (2012) also refer to the courtyard as a part of a house that serves as an internal open space surrounded by pleasant rooms. Some words appear often in all meanings, including 'open, "space,' 'enclosed,' and 'wall. 'As a result, a courtyard can be defined in this context as an area within a building that is wholly or partially internal and exposed to the sky.

The use of courtyard in Malaysia dates back to the era of indigenous architecture. In this case, the traditional Malay home in Melaka (one of Malaysia's oldest cities) was modified by the influence of Chinese traditional architecture by incorporating enclosed courtyards (Makaremi et al., 2012; Ghaffarianhoseini et al., 2015). There is a strong interest in the usage of courtyard in many architecture structures in Malaysia nowadays, including residential, educational, and health care.

The orientation of outdoor spaces should be possible in such a way that adequate airflow is maintained, resulting in a cooling effect during the hot summer days. It's important to note the wind factor before conducting the orientation because too much wind can be uncomfortable in an outdoor setting. It is one of the most important aspects influencing the air temperature in an outdoor environment, necessitating extra research in addition to temperature studies. Another important aspect that is Influenced by spatial orientation is solar radiation exposure.

Literature review

Another key aspect that is influenced by space orientation is space exposure to solar radiation. Shading can improve thermal comfort levels; however, solar exposure levels degrade on the other side. For the transfer of temperature on surfaces and the accumulated solar energy assimilated in a certain period and space, the direction of space is far more important than the retained quantity. According to Ali-Toudert & Mayer (2006a), the temperature stress in E-W canyon was higher than in N-S canyon, resulting in improved thermal comfort. The shading coefficient expands in this way in NESW and NWSE orientations, resulting in improved comfort levels with little difference between the two. According to Haggag & Elmasry (2011), the SENW hub can receive cooling breezes and provide shading, reducing thermal loads in structures.

The orientation factor is not that successful concerning air temperature deviation when contrasted with W/H ratio of the space. Orientations that have high solar exposure require further spaces (Large H/W ratio) then again orientations that experience less exposure to solar radiation can have wider spaces (littler H/W ratios). The primary basis of orientation is the collaboration of built forms with respect to sun angle and prevailing wind direction. Despite the fact that there are conflicts between proficient prevalent wind orientation and solar orientation that must be considered in the site-by-site evaluation. Controlling the layout of the urban fabric in terms of roadways and plot shape also transmits appropriate orientation. As previously said, traditional short streets and reduced form design diminish sun exposure and increase shading impact, darkening the East and West exteriors of North-South oriented streets.

Muhaisen (2006) evaluated the effect of changing the orientation, following Muhaisen (2006)'s prior investigation of the geometrical courtyard form linked to environmental performance in various climatic zones. Because the internal walls are always vertical, the orientation of the single surfaces would change. As a result, some walls are always in the shadow while others are exposed to solar radiation, reducing the thermal performance. The experience of the greatest shaded area is influenced by climatic conditions and location. As a result, Muhaisen rotated the courtyard to study the influence of orientation. According to Muhaisen (2006), positioning the courtyard long axis between the North-South axis and the Northeast-Southwest axis determines effective courtyard performance throughout the year. According to the Muhaisen theory, the sun passes overhead for places around the equator, resulting in the east and west walls receiving the maximum solar radiation. Most modern buildings, according to Soflaei et al. (2016), were designed without enough attention for environmental implications. The courtyard is built to allow direction, dimensions, and proportion to serve as climatic modifiers, according to their research. Similarly, Al-Hafith et al. (2017) carried out an experimental investigation to evaluate the impact of orientation and geometry on shading; their findings show that geometry and orientation have a substantial impact on shading level. They proposed a regression equation for predicting the shade level of various courtyard shapes throughout the year.

In their study in Kuala Lumpur, Malaysia, Ghaffarianhoseini et al. (2015) found that the right location and orientation of courtyards could result in more wind and more shade throughout the day. As a result, it is an important aspect in improving outdoor thermal comfort. According to simulations, the courtyard facing north has somewhat better thermal performance, with a minimum air temperature of 27°C at 8:00 and a maximum air temperature of 32°C at 15:00. As a result, the purpose of this article is to determine the impact of orientation on the performance of a fully enclosed courtyard in a hot, humid climate.

Thermal performance of courtyard was analysed by Aldawoud (2008), Moonen et al. (2011), Muhaisen (2006), Muhaisen & Gadi (2006) and Safarzadeh & Bahadori (2005). Whereas vegetation effect was analysed in some studies:(Ghaffarianhoseini et al., 2015; Haggag et al., 2014; Mangone et al., 2014; Park et al., 2012; Shashua-Bar et al., 2011). Past studies were directed on the courtyard and their impacts, the majority of these studies were focused on hot-dry climate. Studies on courtyard building in the tropics are limited because the focus on buildings in Malaysia is based on terraced houses and high rise buildings.(Almhafdy et al., 2013;
Ghaffarianhoseini et al., 2015; Kubota et al., 2014, 2017; Rajapaksha et al., 2003;Tablada and Blocken, 2005; Zakaria and Kubota, 2014). Therefore, a gap in knowledge is identified, and there is a need to bridge the gap. This study intends to bridge the gap in knowledge.

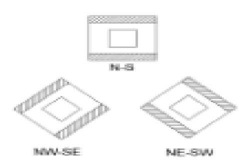
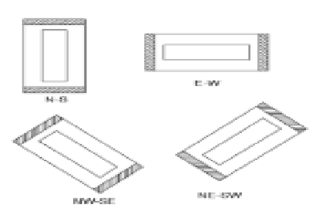
Methods and Material

The influence of orientation on a fully enclosed courtyard with a 15-meter-high wall in a hot humid climate is the topic of this research. The study's major parameters were identified as environmental microclimate characteristics such as air temperature, mean radiant temperature, and physiological equivalent temperature. It motivates a study into the effect of orientation on thermal performance in order to improve the completely enclosed courtyard microclimate, which influences the fully enclosed courtyard's indoor condition.

The week of the 11th to the 17th of July 2017 was chosen for checking and capturing meteorological data from the fully enclosed courtyard at Universiti Teknologi Malaysia's Raja Zarith Sofiah Library. To demonstrate the study, data from a typical sunny day on July 16, 2017 was chosen to be used as input for simulation and detail analysis. Numerical simulation is used to achieve the study goal. For the simulation, Yaşa and Ok (2014) proposed courtyard ratio models (Sadafi et al. 2011; Ghaffarianhoseini et al. 2015; Muhaisen 2006). The models are based on the courtyard from the case study. 1: 1: 1 was the assumed courtyard ratio (height: length: width). This courtyard ratio is 15m: 15m: 15m.

Table 1 shows the courtyard configurations A and B. The following is a full description of the simulation process: The surface covering for configuration A (15m x 15m x 15m) with a courtyard ratio of 1:1:1 (H: L: W) was 100 percent concrete. The North-South (N-S) direction, the Northeast-Southwest (NE-SW) orientation, and the Northwest-Southeast (NW-SE) orientation are the three orientations to examine in this context. In the instance of configuration B (15m x 30m x 15m), which has a courtyard ratio of 1:2:1 (H: L: W), the surface finish was 100 percent concrete, and it has four orientations in total: North-South (N-S), East West (E-W), Northeast – Southwest (NE-SW), and Northwest – Southeast (NW-SE).

Table 1: Table showing a detailed simulation test case

SN	Configuration	Dimension(m)	Courtyard ratio (H:L: W)	Surface covering	Orientation	Total simulation
1	A	15m x 15m x 15m	1:1:1	100% concrete		3
2	B	15m x 30 x 15m	1:2:1	100% concrete		4

Results and Discussion

One of the key variables in heat mitigation has been identified as orientation. The effect of orientation on the thermal performance of the courtyard has been studied extensively (Ghaffarianhoseini et al., 2015; Muhaisen, 2006). The effect of orientation on the thermal performance of fully enclosed courtyard designs is examined in this section.

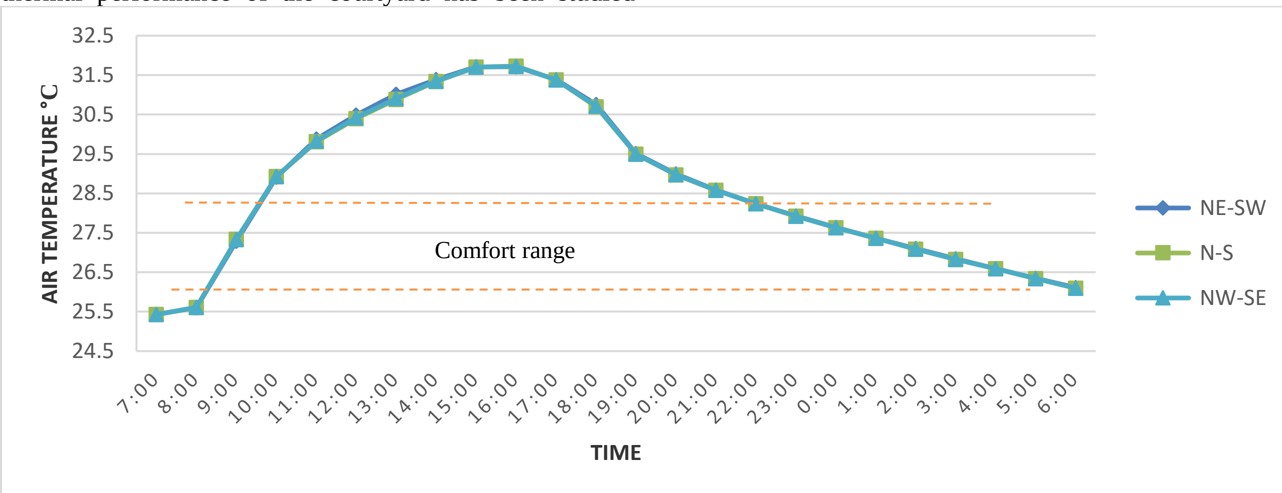


Figure 1: Variation in the air temperature of the courtyard ratio 1:1:1for different orientation.

The air temperature in this scenario ranges from 25.41°C to 31.73°C. The influence on air temperature begins at 07:00 and gradually increases until it reaches its peak at 16:00. As a result, the impact begins to fade gradually (around 19.00 hours) in the evening. A minimum air temperature of 25.43°C (07:00) and a maximum air temperature of 31.73°C were recorded in the N-S orientation (most extended length facing East).

This implies that the courtyard is hotter on the N-S orientation because a larger portion of the courtyard is exposed to sun radiation throughout the day.

The NE-SW orientation recorded a minimum of 25.41°C (in this case, the most extended length, is inclined at an angle of 45° and faces east direction), exposing a larger portion of the courtyard to solar radiation. However, the NW-SE orientation recorded the least through the courtyard, recording a minimum of 26.19°C and a maximum of 31.54°C, due to the fact that the NW-SE orientation is inclined at an angle of 45° and faces west direction, which is far.

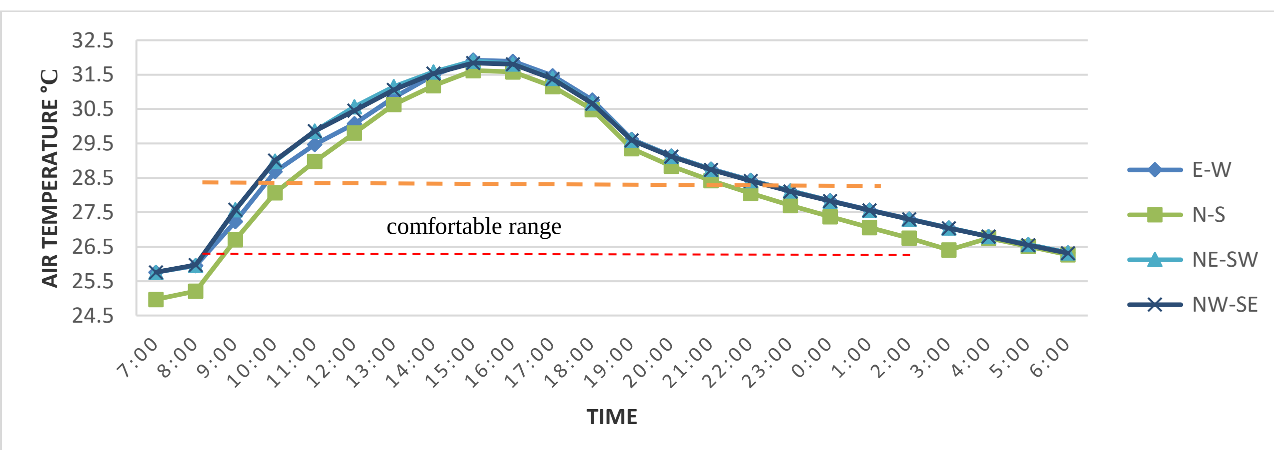


Figure 2: Variation in the air temperature of the courtyard ratio 1:2:1for different orientation

Figure 2 depicts the fluctuations in air temperature for the courtyard ratio 1:2:1 during the course of 24 hours. The temperature ranges from 25.76°C to 31.92°C in the air. Hourly temperatures begin to increase at 7:00 a.m. and peak between 13:00 and 17:00 a.m., with the greatest point at 15:00 p.m., after which the temperature begins to fall at 19:00 p.m. The courtyard with the E-W orientation (shorter side facing East, longest side facing North) recorded a minimum temperature of 25.7°C (at 07.00) and a maximum air temperature of 31.95°C (at 15:00), eventually the highest air temperature recorded, due to the courtyard space being exposed to solar radiation more than the other orientations.

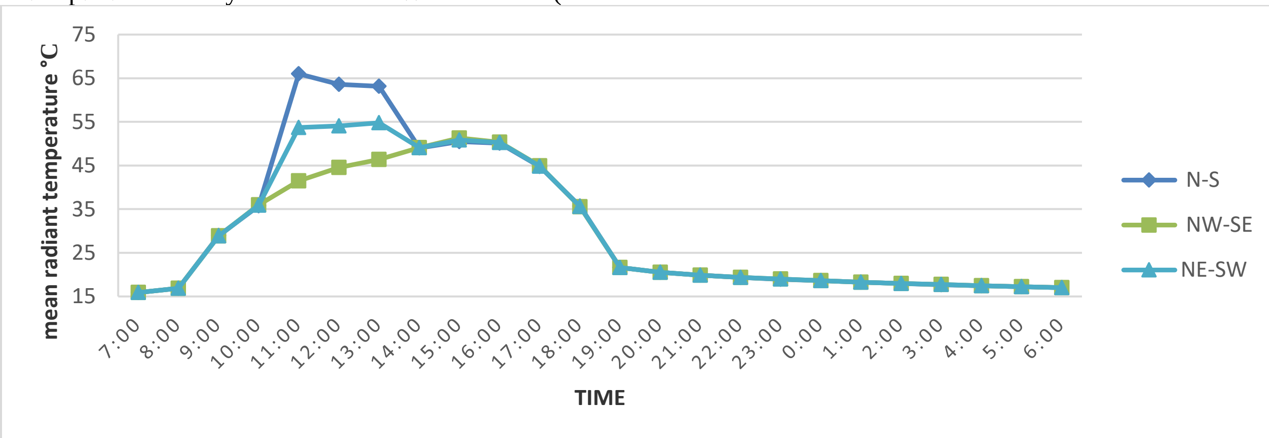


Figure 3: Variation in the mean radiant temperature of the courtyard ratio 1:1:1for different orientation.

Figure 3 depicts the hourly fluctuation in the mean radiant temperature of the courtyard ratio 1:1:1 over a 24-hour period. The average radiant temperature is between 15.90 and 66 degrees Celsius. Starting at 8:00 a.m., greater values of mean radiant temperature were recorded until it peaked at 10:00 a.m. to 13:00 a.m., and then moved farther from 13:00 a.m. to 15:00 a.m. Convection and radiant heat loss contribute to the mean radiant temperature. The behavior of the courtyard configuration 1:1:1 from 10:00 to 13:00, where NW – SE recorded a lower mean radiant temperature than N – S and NE – SW, was owing to the courtyard's shading effect, as shown in figure 3.0.

The radiant interaction affects mean radiant temperature. Figure 4.0 depicts the hourly variation of mean radiant temperature over a 24-hour period. The minimum and maximum mean radiant temperatures are 15.97°C and 72.96°C, respectively. Starting at 08.00, greater values of radiant were recorded till it reached its peak at 10.00 to 13.00, after which it shot up to its greatest from 13.00 to 15.00, owing to early daytime when the highest solar radiation was recorded, as well as the sun angle being at 90° at the peak hour. Due to the sun's low altitude, the mean radiative temperature begins to drop at 17.00. The minimum mean radiant temperature in the E-W orientation was 15.97°C, with a maximum of 72.96°C, while the minimum mean radiant temperature in the N-S orientation was 15.15°C, with a maximum of 72.96°C. While the minimum mean radiant temperature was 15.97°C and the maximum was 72.95°C in the NE-SW direction.

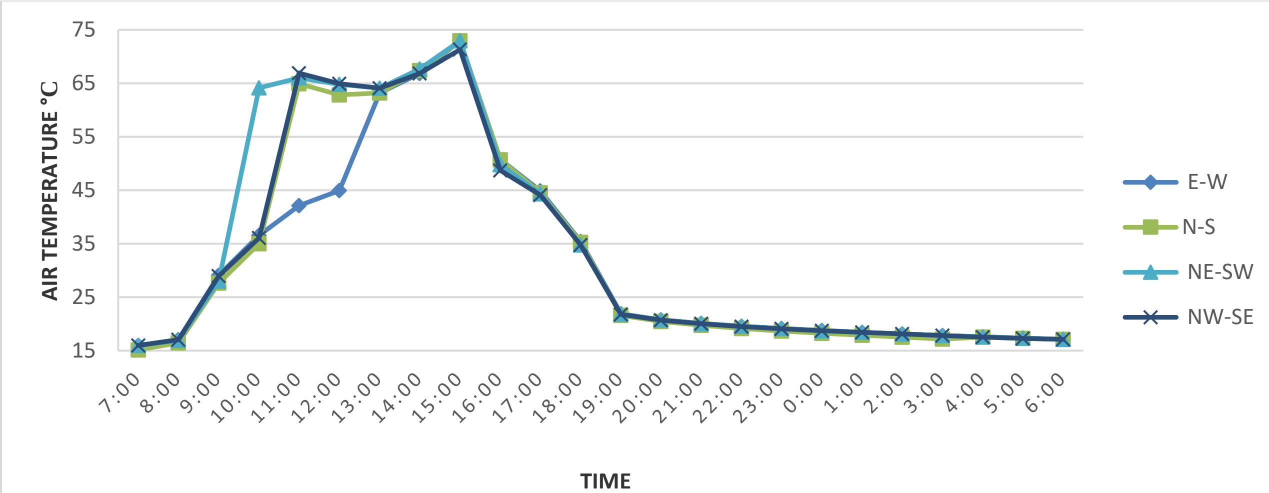


Figure 4: Variation in the mean radiant temperature of the courtyard ratio 1:2:1for different orientation

Figure 5.0 depicts the Physiological Equivalent Temperature's hourly changes (PET) of courtyard ratio 1:1:1. The PET has a temperature range of 20.10°C to 44.2°C. The higher estimates of Psychological Equivalent Temperature were observed starting at 08:00 and continuing until the crest around 10:00 to 13:00. This was due to the early morning hours, when the most incredible radiation was recorded, as well as the time when the sun angle hits 90. N – S orientation, meaning the most significant side is facing east, with a PET of 20.10, and a maximum of 44.2°C. Minimum PET of 20.10 and a maximum PET of 39.90°C in the NE–SW. NW – SE, on the other hand, had the lowest PET of 20.10°C and the highest of 39.00, meaning that it is the lowest of the other orientations. This is due to the NW – SE orientation, which causes the west direction to fail away from the east direction, as well as the shading.

Figure5 shows that from 10:00 to 14:00, the NW – SE orientation had a lower PET than the N – S and NE – SW orientations. The behaviour is due to the courtyard's shading effect.

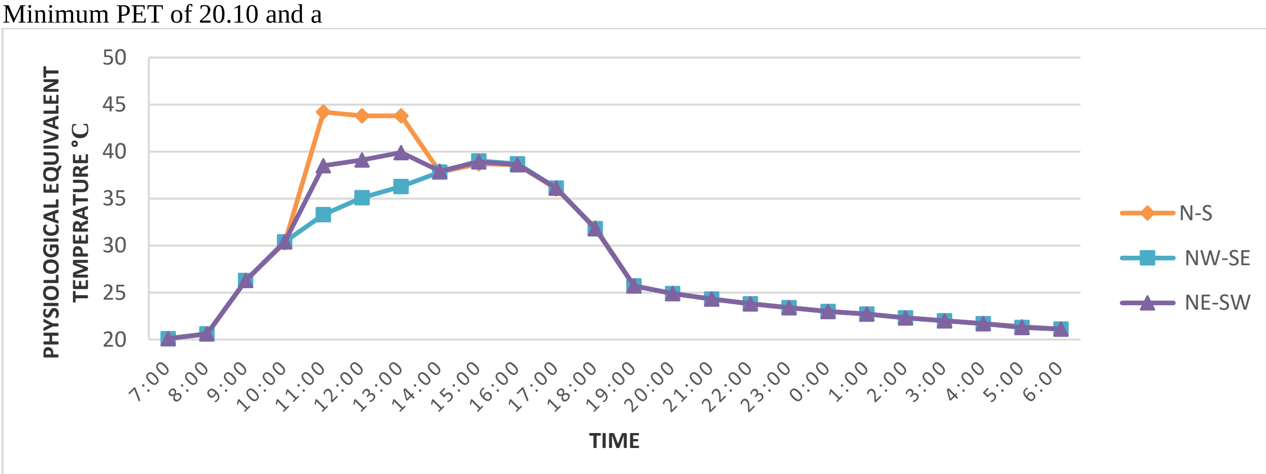


Figure 5: Variation in the physiological equivalent temperature of the courtyard ratio 1:1:1for different orientation.

The hourly change of physiological equivalent temperature can be shown in Figure 6. Temperatures in the physiological equivalent range from 20.5°C to 49.9°C. Starting at 08:00, increased levels of physiological equivalent temperature were recorded until it peaked between 10:00 and 13:00, with a rise between 13:00 and 15 hours. This was due to the fact that the first radiation was detected early in the day, during the peak hour of the sun angle, which is at 90 degrees. The N–S and E–W orientations both recorded the same minimum and maximum physiological equivalent temperatures of 20.50°C and 49.40°C, respectively, whereas the NE–SW orientation recorded a minimum PET of 20.50°C and a maximum of 49.30°C. Following that, the NW-SE orientation had a minimum PET of 20.50°C and a maximum of 48.40°C. This indicates that NW-SE performed better thermally since it had the lowest PET, as indicated in Table 4.3. The physiological equivalent temperature of a specific outdoor or indoor environment is equivalent to the air temperature where the indoor setting is typical (v = 0.1m/s, water pressure = 12hpa, and Mrt = air temperature), the human body's heat balance is maintained, and core and skin temperatures are equal to those under the condition being assessed. This is relevant in this study because the tenant of the totally enclosed courtyard will be able to compare the effects of the complicated thermal conditions outside with his or her own internal experience.

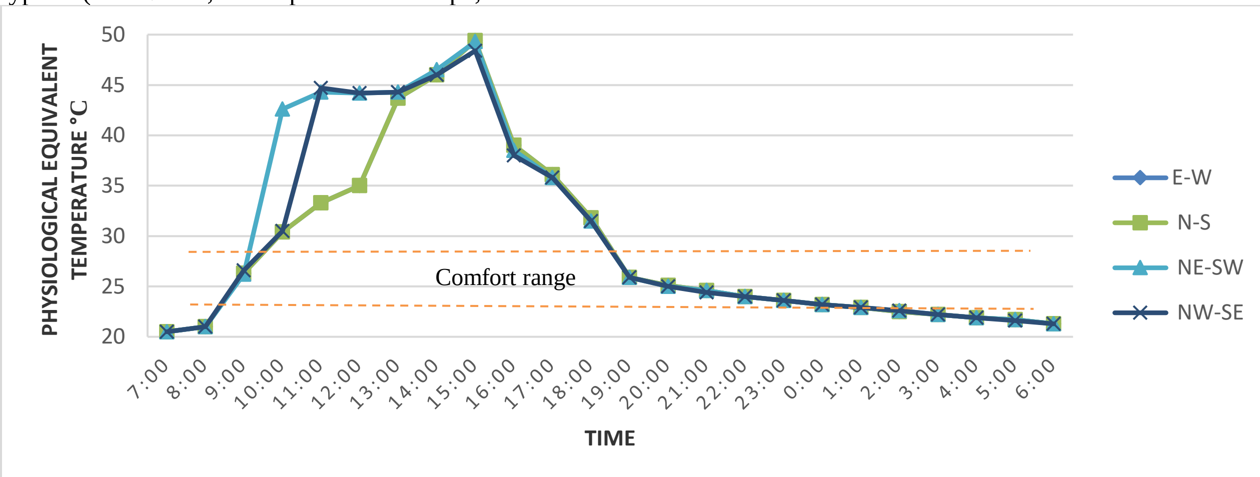


Figure 6: Variation in the physiological equivalent temperature of the courtyard ratio 1:2:1for different orientation.

The effect of courtyard orientation on thermal performance has not been thoroughly investigated. The purpose of this research is to see how the orientation of courtyards affects their thermal performance. The research was founded on the assumption that the courtyard's orientation has both positive and negative effects on its thermal performance. As a result, in this context, courtyard arrangements configuration with a height of 15 meters were studied. Manipulate the configurations with a fixed length of 15 meters in various orientations to improve the courtyard microclimate. The study looked at how different orientations affect the courtyard microclimate, such as shadowing and sun angle.

The air temperature, mean radiant temperature, and physiological equivalent temperature increased as the size of the courtyard configuration increased, according to the analysis. This suggests that as the courtyard is exposed to more solar radiation, the shading level of the courtyard diminishes. Inferring that the greater the thermal performance, the smaller the courtyard configuration.

According to the research, the courtyard configuration 1:1:1 has the optimum performance in terms of air temperature in all orientations. This is because the courtyard configuration 1:1:1 is the smallest and receives the most shade from the walls that surround the courtyard perimeter. In comparison to other courtyard arrangements, this reduces solar radiation exposure, lowering air temperature. In terms of mean radiant temperature, courtyard configuration 1:1:1 performed best in NE – SW and NW- SE orientations, whereas courtyard configuration 1:2:1 performed best in N – S and E – W orientations (Mrt). This is due to the fact that as the sun's angle varies, the mean radiant temperature changes as well. The courtyard 1:1:1 was found to be the most effective in reducing Mrt, with Mrt reduced by 11.20°C for NE – SW direction and 14.7°C for NW – SE orientation. Similarly, for N – S and E – W orientations, the 1:2:1 design performed best, with Mrt lowered by 0.81°C. This is about the sun's angle.

The study also discovered that as the ambient temperature rises, the physiological equivalent temperature (PET) rises as well. PET is the air temperature at which a person's heat budget in an indoor context is balanced with their skin temperature in an outside environment. The simulation approach revealed that mean radiant temperature, rather than air temperature, influenced the variance of the thermal index PET, demonstrating that air temperature is insufficient for evaluating thermal performance in a fully enclosed courtyard. Due to shading from the walls and self-shading of the totally enclosed courtyard, PET values for protection from direct sun radiation have decreased. This result is consistent with Ali-Toudert and Mayer's research (2006) and Muhaisen (2006).

Conclusion

The influence of orientation on the courtyard's thermal performance was validated using the Envi-met software on the fully enclosed courtyard configuration chosen for this study. 1:1:1 and 1:2:1 are examples of this setup. The orientations considered in this example were N-S, E-W, NE-SW, and NW-SE. The air temperature, mean radiant temperature and physiological equivalent temperature was measured during simulations of two configurations of the totally enclosed courtyard.

According to the research, the air temperature, mean radiant temperature and physiological equivalent temperature rises as the size of the courtyard grows. So et al. (2017) and Taleghani et al. (2014) both validated that the 1:1:1 courtyard configuration had a lower air temperature than the 1:2:1 courtyard configuration.

The configuration 1:1:1, and1:2:1, reveals that E- W orientation recorded the highest air temperature, mean radiant temperature and physiological equivalent temperature. While the NW-SE orientation had lowest air temperature, mean radiant temperature, and physiological equivalent temperature. The courtyard configuration 1:1:1 performed better in NE – SW and NW – SE with a reduction in PET by 4.3°C, while courtyard configuration 1:2:2 performed better in N – S and E – W orientation with a reduction in PET by 0.2°C and 0.3°C respectively.

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