Vegetation as a Strategy to Improve the Thermal Performance of Fully Enclosed Courtyard in Tropical Climate

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Abstract: Many studies have shown that globalization has caused environmental pollution, carbon emission, climate change, increasing energy demand and inadequate natural resources. The application of passive design, which is part of sustainability, needs to give more attention in buildings. However, courtyard as a passive design strategy, use as a microclimate modifier is adopted in this study. Field measurement and Numerical Simulations using Envi-met V4.3 and Rayman Pro software were used as a methods to conduct this study. Three courtyard strategies, A (6m x 6m x 6m), B (15m x 7.5m x 7.5) and C (15m x 15m x 15), in the proportion of concrete, grass and trees were proposed to study their effect on the energy consumption and the thermal comfort by measuring the air temperature, mean radiant temperature and physiological equivalent temperature factors. . The results demonstrate that the courtyard strategy C that has the combination of trees and grass performed better with a reduction in air temperature of 0.9°C, 9.93°C reduction in Mean Radiant Temperature (Tmrt) and 19.40°C reduction in Physiological Equivalent Temperature (PET). The best strategy is the combination of grass and trees in reference to courtyard strategy C (15m x 15m x 15). Strategy C, shows the ability to perform better with vegetation compared to the other two courtyard strategy A (6m x 6m x 6m) and B (15m x 7.5m x 7.5m) which their impacts is not significant because the courtyard in strategy A and B are self-shaded and does not require vegetation to improve its performances. Therefore the study recommended that courtyard with large size can use vegetation as one of the strategy to improve the thermal performance.

Keywords: Courtyard strategy, Tropical climate, Thermal comfort, Mean Radiant Temperature, Physiological Equivalent Temperature, Air Temperature

Introduction

Many studies have shown that globalization has caused environmental pollution, carbon emission, climate change, increasing energy demand and inadequate natural resources. Passive design strategies applied to the building. However, courtyard as a passive strategy, use as a microclimate modifier in building envelope. Usually defined as a space within a building that is open to the sky. In general, the size and design of courtyard have a great influence on its performance. (Almhafdy *et al.*, 2013) The courtyard is basically, divided into two: Enclosed and Semi-enclosed courtyard. The performance of the courtyard can be optimized by considering the building shape and the heat gains control strategies. (Kim *et al.*, 2012)

There appears to be a mutual conviction that courtyards can act as climatic modifiers, and thus generate a pleasurable outdoor space as well as upset the nearby built-up mass (Meir, 2000). Nevertheless, the development of the internal courtyard is related with public and efficient aspects, such as solitude and safety in a private open space or day lighting and ventilation for the immediate indoor spaces, relatively than with the subject of microclimatic control (Meir *et al.*, 1995)

The solar energy expected by the courtyard exteriors is considered to be the main factor affecting its thermal performance (Muhaisen and Gadi, 2006). Numerous studies have revealed that the proportions (L/W, H/W) of a courtyard significantly modify the number of solar heat gains and the exposed and sheltered surfaces (Muhaisen, 2006), (Trenkle, 1988).

Psychological Equivalent Temperature PET is a temperature element index measured in degree Celsius (°C), creating its clarification logically to people without a great deal of understanding about meteorology. PET-based on the Munich Energy-Balance Model for Individuals (MEMI) (Hoppe, 1984). Defined as the air temperature at which atypical indoor sceneries, the human energy budget sustained by the skin temperature, core temperature, and sweat rate equivalent to those under the condition to measure. PET is predominantly appropriate for outdoor thermal comfort investigation in that it translates the assessment of a complex outdoor climate situation to a simple indoor setting on physiologically equivalent base, which can easily assume and inferred. PET has extensively applied in the areas with numerous climate condition. PET can assess using free software packages Rayman, which has used in an urban built-up area with intricate shading designs and created a correct prediction of the thermal environment.(Ali-Toudert and Mayer, 2006), (Höppe, 1999), (Johansson, 2006), (Thorsson *et al.*, 2014), (Matzarakis *et al.*, 1999)(Mayer and Höppe, 1987),

2.0 Literature Review

It is essential to note that the quantity of solar radiation inside the courtyard affected by the dispersed and redirected radiation as well as the uninterrupted solar radiation. (Trenkle, 1988), notes that the courtyard performances as a radiation trap as the nearby walls redirect the solar radiation according to their albedo.
The proportions of the courtyard have also an influence on its microclimate, as seems from a study that piloted in India. The study equated a variety of traditional courtyard houses with diverse courtyard sizes. It was established that as the size of the courtyard increases, the performance of the courtyard inclined to decrease (Taleghani *et al.*, 2012), (So *et al.*, 2017).
Shading of courtyards can deliberate in two ways: the first - self-shading of the courtyard by the neighboring walls, and the second - shading the courtyard's space by an added shading means. Concerning the first, (Muhaisen, 2006) studied the influence of self-shading by the surrounding built-up space on courtyards with diverse sizes. They used thermal simulation software to forecast the yearly essential cooling and heating loads in two circumstances: with solar shading deliberated and deprived of solar shading deliberated. It indicated that the shading effects more considerably on increasing the necessary heating load in winter than on decreasing the cooling load in summer. This translates that the susceptibility of heating load to the gained solar radiation is more than that of cooling load to shaded areas. Therefore, in their opinion, it is more serious to acquire solar radiation in winter than to obtain it in summer. A study piloted in Tucson, Arizona, examined major variances between surface temperatures for shaded and non-shaded walls. It revealed that heavy shading reduced solar heat gain on windows and impervious features. For example: at 08:00 surface temperature difference between shaded and non-shaded eastern wall was as high as 24°C (Scott *et al.*, 1999). The influence of shading the courtyard has dissimilar results in summer and in winter. (Muhaisen, 2006), indicated that the shading influence on increasing the required heating load in winter can be more important than on reducing the cooling load in summer. Thus, it might be more dangerous in some places to attain solar radiation in winter than barring it in summer.
Shading the courtyard by additional shading strategies can increase thermal conditions during summer, as was shown by (Al-Hemiddi and Megren Al-Saud, 2001). In a study on the influence of a ventilated internal courtyard on the thermal performance of a house an investigational house observed in six stages; each stage represented an altered ventilation approach (opening of an inner or outer window through the day or night, removing the courtyard's protection at night, a swimming pool with or without water). One of the altering features within the courtyard was a white cotton tent covering the courtyard's space and the swimming pool. The shading by the cover decreases the everyday temperatures. Nevertheless, eliminating the cover at night reduced the courtyard air temperature and the water temperature through the night. Therefore, the finest performance was while the cover was detached at night and ventilation amongst the outdoors and the courtyard was tolerable during the night only. Removing the cover at night permits long wave radiation to release from the courtyard's planes to the clear sky and night. This illustration that changeable shading devices, which avoid solar heating through the hot hours and permits long-wave emittance during the cool hours, can result in better thermal conditions inside the courtyard.
Planting is one of the primary approaches to advance the urban microclimate in which courtyard is inclusive (Jauregui, 1990): (Wong *et al.*, 2007); (Chen and Wong, 2006). Vegetation can be characterised as any plants or growing plants. Vegetation can be assessed as one of the operative methods at both huge and minor scale

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

where such natural constituents an ‘oasis impart’ thus decrease urban warming (Akbari, 2002).
The usage of vegetation in courtyard spaces has the main role of the microclimate created within it. Vegetation can use for shading the courtyard space by shading trees, or for decreasing the surface temperatures of the ground area or sidewalls. The cooling influence of shade trees in streets and attached courtyards in Tel-Aviv was evaluated by (Shashua-Bar *et al.*, 2004) by using experimental in-situ measurement and by evolving a systematic “Green CTTC (Cluster Thermal Time Constant) model”. The cooling influence of trees (in both measurements and simulations) defined as the discrepancy between the air temperature at the site (with shade trees) and a position point nearby (without trees). The cooling influence of trees in the two courtyards measured at 15:00 in July 1996 fluctuated between -2.47°C in the initial courtyard and -3.26°C in the subsequent. The cooling influence of trees established to depend on the tree shade exposure and on the group geometry. The effect is decreased by making deeper the group and by depressing the albedo of the nearby walls. The influence of landscape design of historical Islamic courtyards considered by Attia (2006), using quantities and shade study of four courtyards in Cairo and in Granada, Spain. The courtyards had diverse landscape approach of water bodies, vegetation and shade trees. Nevertheless, in all the courtyard landscape design used to recompense for the absence of shade in the hot summer months. The temperatures measured inside the courtyards were lesser by 2°C-8°C compared to the temperatures outdoor the courtyards, dependent on the quantity of vegetation, water and shade they encompassed. It appears that landscape design might help to increase the micro-climate in courtyards. Thus, courtyards might act as cool air tank to enhance the microclimate of the adjoining built-up mass. In the tropical climate (Ghaffarianhoseini *et al.*, 2015) suggested the use of vegetation as a strategy to mitigate the microclimate of the courtyard, but the studies are few compared to others strategies. Therefore, the aim of these studies is to evaluate the impact of vegetation, as a strategy to improve the thermal performance of courtyard buildings in a tropical climate.

2.0 Methods

The methodology involves in this study is divided into two part. The first part involves field measurements and the second part, numerical simulations.
2.1 Field Measurements in Malacca and Universiti Teknologi Malaysia (UTM)
The field measurements conducted between 15/10/2014 to 22/10/2014, in a two-story Chinese shophouse located within the shophouse in Malacca, Malaysia (2.2^{0}N and 102^{0}E). While in Universiti Teknologi Malaysia the climate documentation is done in a four-story new library complex, Raja Zarith Sofiah Library (1.33^{0}N and 103.39^{0}E) between the 11/7/2017 to 18/7/2017 as illustrated in figure 1

Figure 1: Figure showing the location of the two measurements points. (Source: Google map. Extracted on 18/8/17).

Data logger placed at the center of the courtyard in the case of the Chinese shop house at the height of 1.5 meters and a data logger placed at the entrance verandah of the shop house. While the case of the Library complex at Universiti Teknologi Malaysia, the data loggers placed at 3 different points, at the same height of 1.5 meters above the ground level. There exist six trees of the height of 15 meters each. All the data loggers calibrated before the experiment conducted to guarantee the accuracy. Consequently, they hobo were protected

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

from direct sunshine, and set at 10min interval to measure the air temperature and relative humidity. Apart from this, a HOBO weather station placed 500 meters from the measurement points at the height of 2 meters and clear from all obstructions.

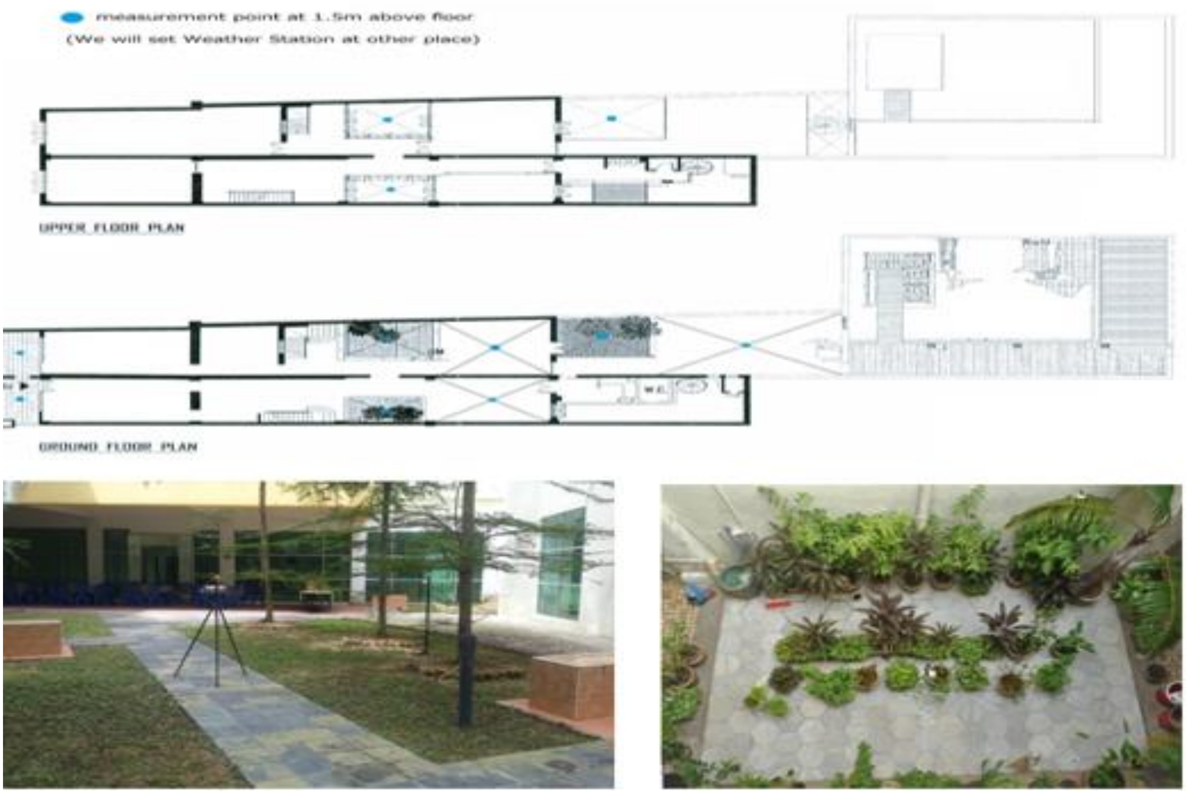

Figure 2: pictures showing the position of the data loggers in the two courtyards.

After the measurement, a day was chosen to run the validation simulation this day was the 16th July 2017 for the Library complex Universiti Teknologi Malaysia and 16/10/2014 was selected for the shophouse, because the day has a partly clear sky, no rain, high solar radiation, and highest air temperature was recorded.

Validation of the Envi-met model has become relevant and necessary in order to configure the performance of the software. Many scholars worked on the validation of the Envi-met software such as; (Salata *et al.*, 2016), (Ghaffarianhoseini, et al. 2015),(Ahmed *et al.*, 2014). However, well laid down evaluation method, as well as standard, is lacking. Study opined that model evaluation should be accompanied using statically analysis by comparing the measured(O) model output in agreement with the predicted(P) data and should have a level of confidence(Sivacoumar and Thanasekaran, 1999)

The use of r and r^2 as used frequently for correlation has been deliberated extensively. Statistical significance of such values is unsuitable specifically when used in comparing predicted (P) and measured (O) variables. However, (Willmott, 1982), suggested that root means square error, RMSE, or mean absolute error, MAE, systematic and unsystematic root mean square error and index of agreement, d, are important. (Yahia and Johansson, 2014) demonstrates the importance of root mean square error, RMSE, (systematic and unsystematic) and index of agreement, d, for predicting model performance, however (Nash and Sutcliffe, 1970), advocated another coefficient, E, which is dimensionless, variables that compare models. This coefficient is a better goodness-of-fit model compares to R^2. (Daren Harmel and Smith, 2007), affirmed the use of the following as indicators: E the Nash-Sutcliffe coefficient of efficiency, d-degree of the agreement, RMSE.

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

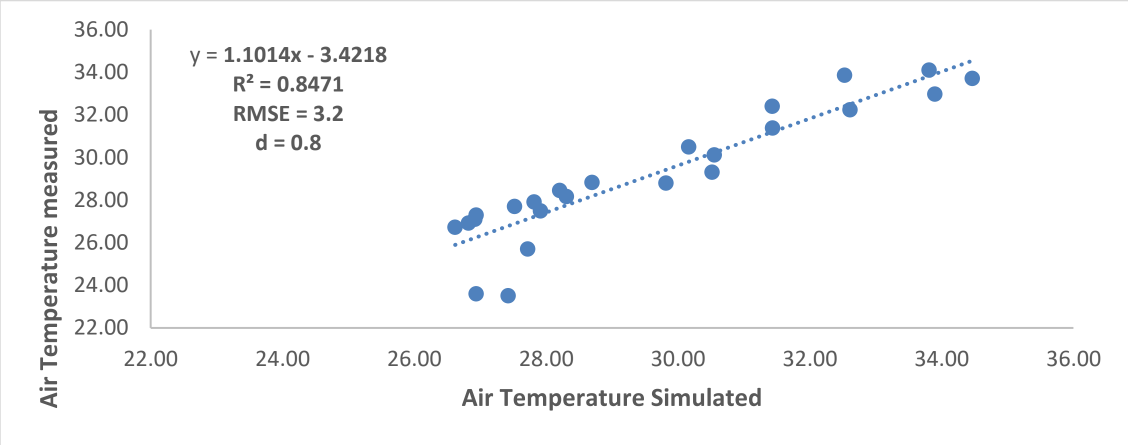

Figure 3: Correlation diagram showing the relationship between the simulated and the measured air temperature of the Chinese shophouse.

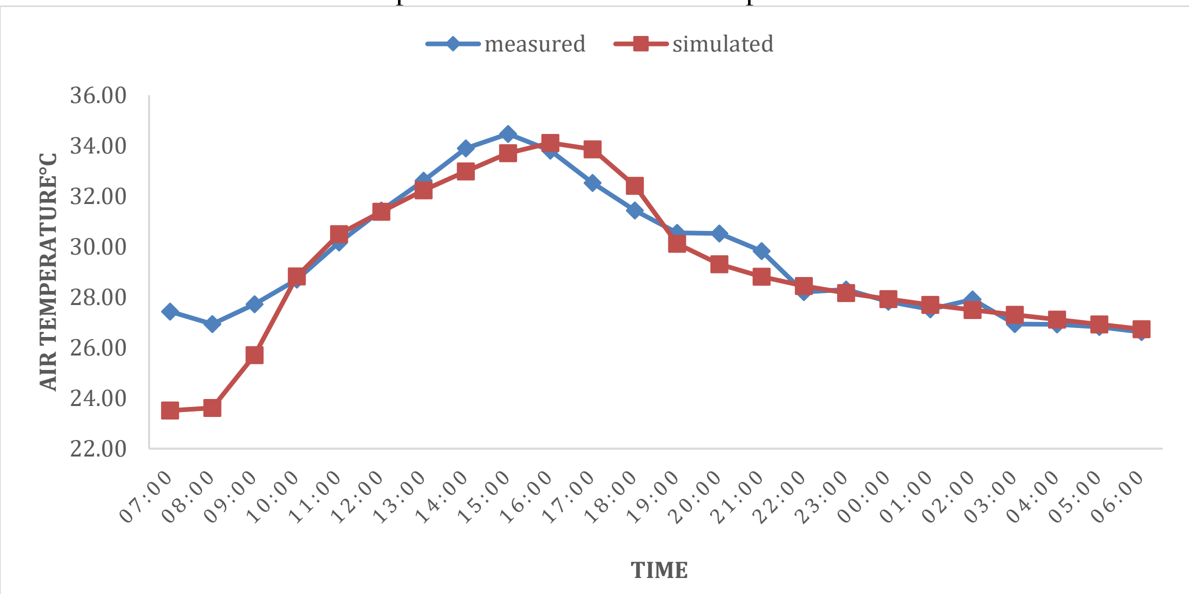

Figure 4: Graph showing the relationship between predicted and measured data.

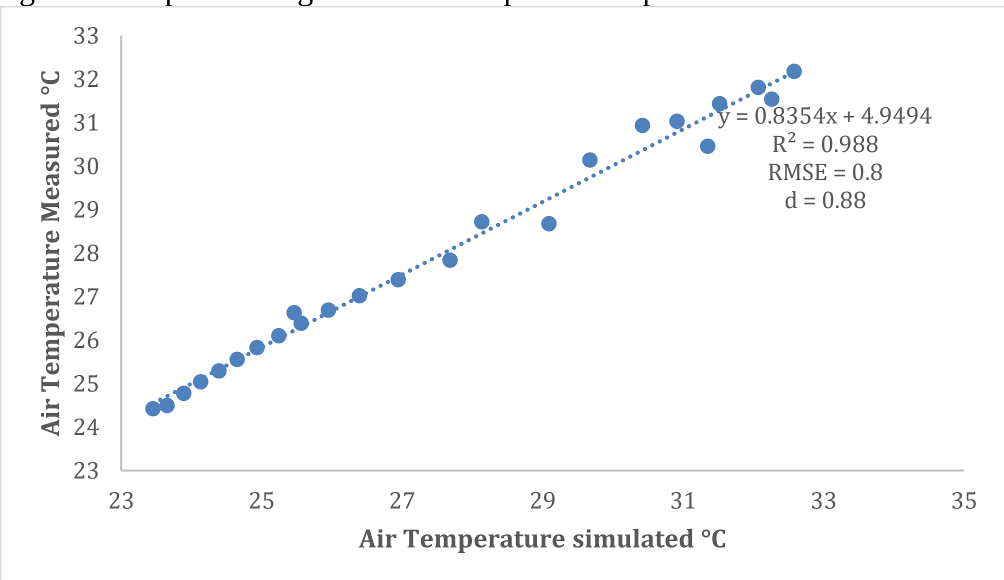

Figure 5: Correlation diagram showing the relationship between the simulated and the measured air temperature of the Chinese shophouse.

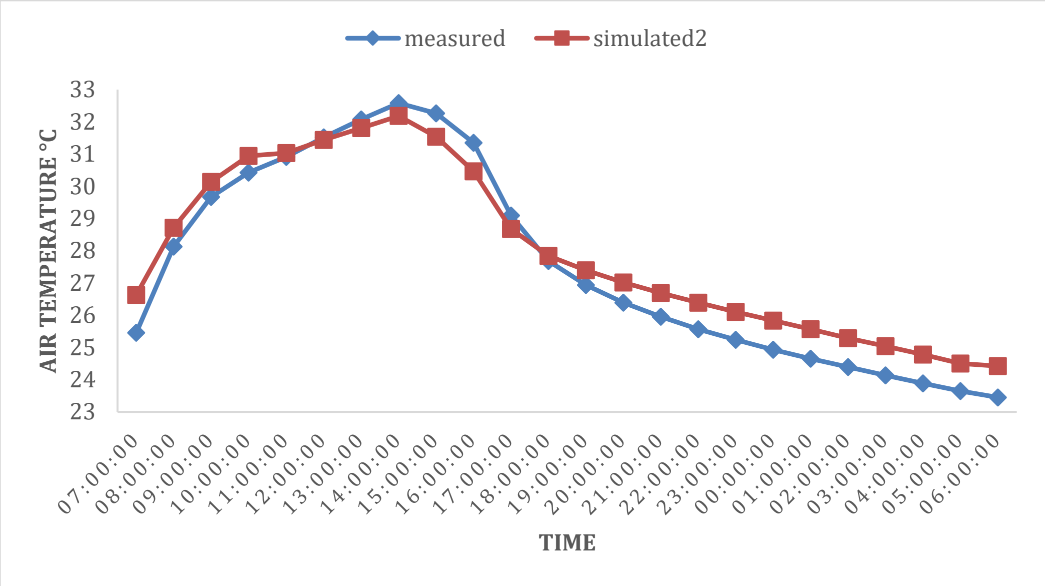

Figure 5: Graph showing the relationship between predicted and measured data of the library complex.

The outcome of the validation shows that the correlation R^2, in the two model has a value that is approximate to one, which indicates that the models are fit. The figures are 0.98 in the case of the library complex and 0.87 in the case of the Chinese shophouse. The index of agreement d, recorded a value of 0.88 in the case of the library complex and 0.80 in the case of the Chinese shophouse, indicating that the model performance is stable. The values of the Root Mean Square Error (RMSE) translate that the errors in the models minimal. Generally, the validation of the model shows that it is fit for the simulation, and the accuracy of the results assured.

2.20 Simulation Experiment.

The importance of the process is to develop the courtyard models, which then used for the simulation experiment. For this, a courtyard ratio used, defined as the relationship between the height, length and the width of the courtyard.

Envi-met software is widely used in many types of research that have to do with the climate, including thermal comfort and microclimate. The software is free and practical, and there is reliability in its results. Envi-met V4.2 was utilised for the simulation in this study. Envi-met is proficient in manipulative the air temperature and the surface temperature.

It is capable to calculate the outdoor thermal comfort indices such as Mean Radiant Temperature (Tmrt) and psychological Equivalent Temperature (PET) in each perpendicular grid point of the layout of the built-up environment. The software equations were elucidated by (Ali-Toudert and Mayer, 2006) and the solar radiations equations articulated in (Bruse and Fleer, 1998), (Huttner and Bruse, 2009).

Three Strategies clearly define the process to run the simulations. These strategies as shown in Table 1 below.

Strategy	Dimension (H x Lx W)	Courtyard ratio(HxLx W)	%Concrete	%Grass	%Tree	Total simulations
A	6mx6mx6m	1:1:1	100%	100%	75%	3
B	15mx7.5x7.5	2:1:1	100%	100%	75%	3
C	15mx15mx15m	1:1:1	100%	100%	75%	3

Table 1: Table showing the strategy to employ in running the simulations

In each of the strategy three simulations, totalling nine-simulation process conducted this strategy period. This is done in order to justify the fact that vegetation affects the courtyard ratio and to what extent the courtyard need vegetation.

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

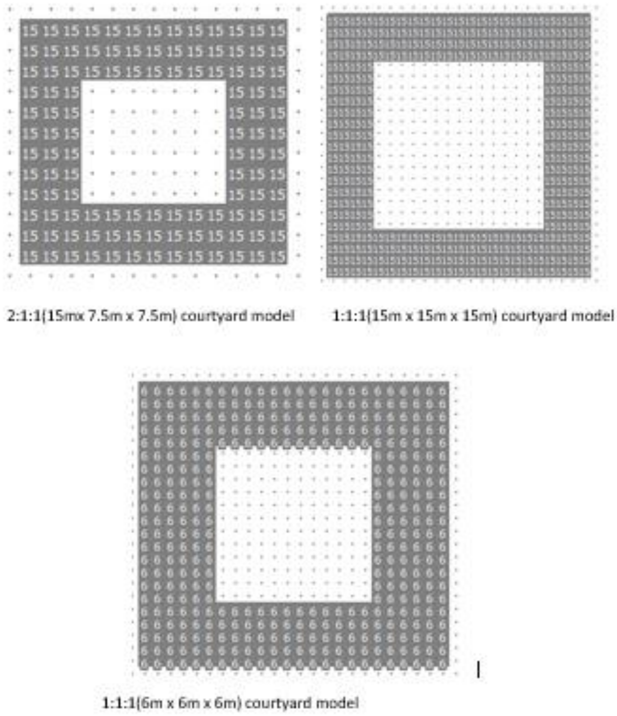

Figure 6: Plans showing the three courtyard configurations

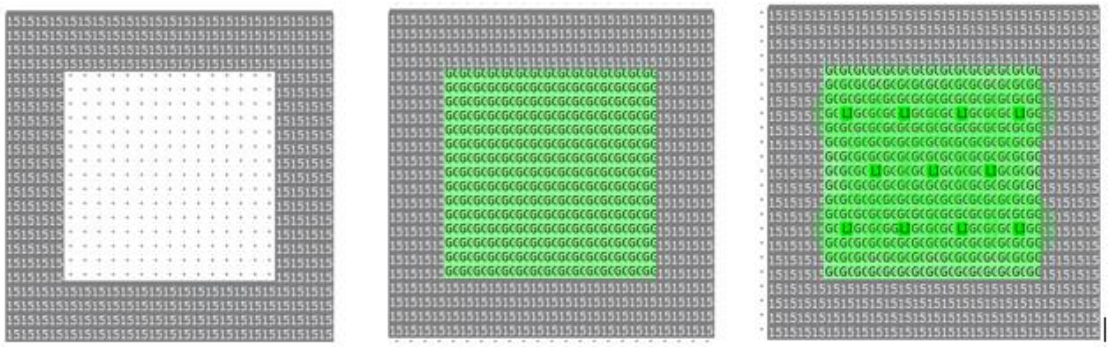

Figure7: plan of typical courtyard model showing the vegetation pattern.

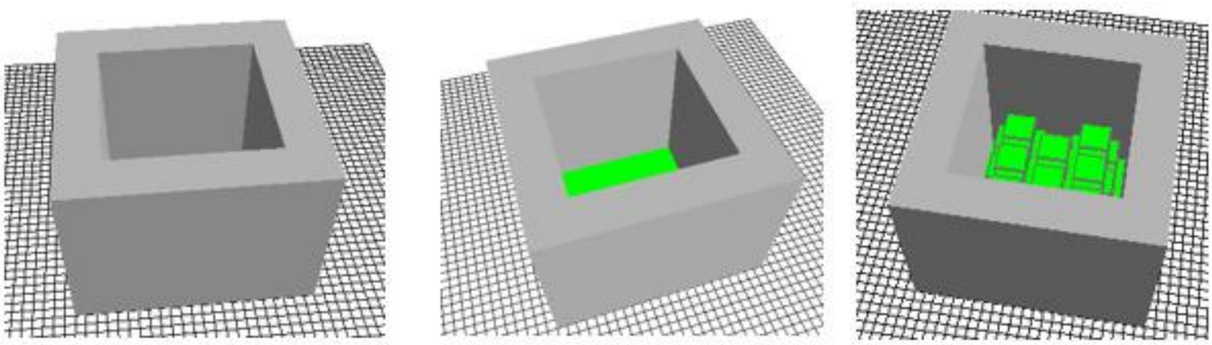

Figure 8: The typical courtyard models in 3- dimension.

3.0 Results and Discussion

The aim of this research is to evaluate the impact of vegetation as a strategy to improve the performance of courtyard building in a tropical climate. The variables that measured in this context are:

(i) Air temperature

ISSN NO: 2771-8840
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(ii) Mean Radiant Temperature (MRT)
(iii) Psychological Equivalent Temperature (PET)

3.1 Air Temperature

The distribution of air within the courtyard in the three strategies (A, B.C). The results show that strategy A (figure 9) the air temperature is at its peak at 16:00hrs and translate to 31.98°C in the courtyard laid with concrete. When 100% grass laid the air temperature drop by 0.03°C. It is observed that 0.12°C when a combination of 75% tree and grass laid within the courtyard. While strategy B(figure 10), the air temperature reaches its maximum at 16:00hrs translating to 31.94°C with concrete laid.100% grass observed a temperature difference of 0.02°C, and when 75% trees in combination with grass laid, a temperature difference of 0.11°C observed. However, strategy C (figure 11) recorded a maximum air temperature at16:00hrs translating to 31.94°C with concrete laid. When laid with 100% grass temperature difference of 0.21°C observed. While 75% trees in combination with grass laid temperature, a difference of 0.90°C observed. This shows that strategy C performs better than strategy A and B in the context of air temperature.

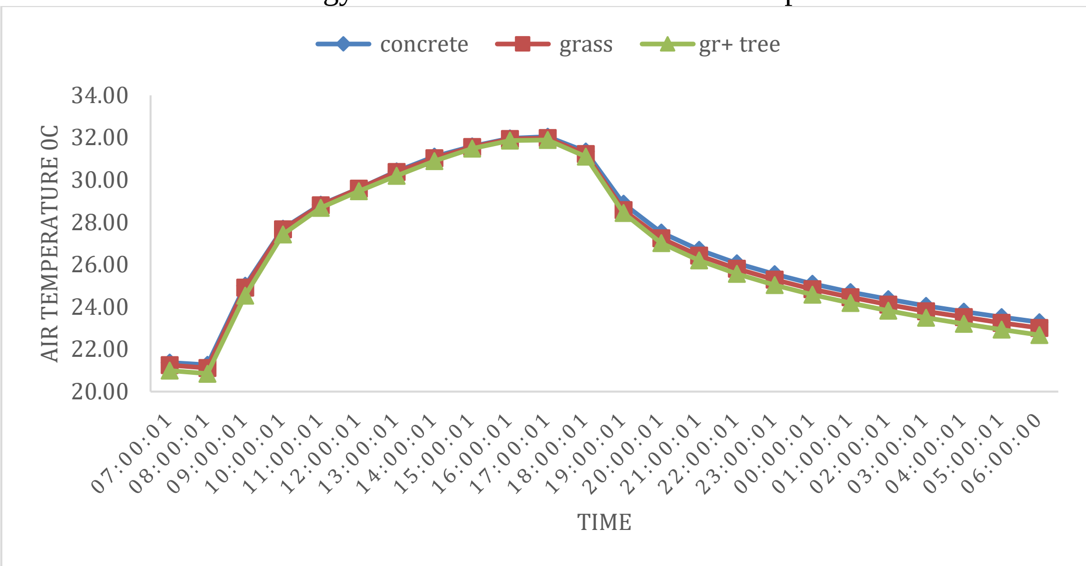

Figure 9: Curves showing the air temperature distribution within the strategy A (6m x 6m x 6m)

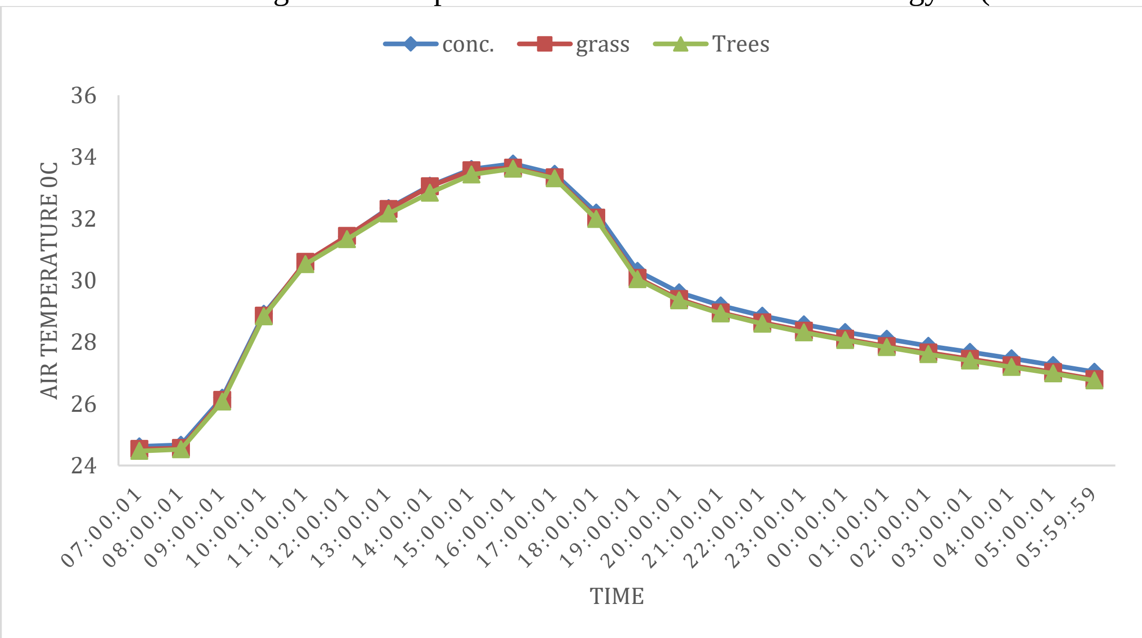

Figure 10: Curves showing the air temperature distribution within strategy B (15m x 7.5m x 7.5m) of the Chinese shophouse model

ISSN NO: 2771-8840
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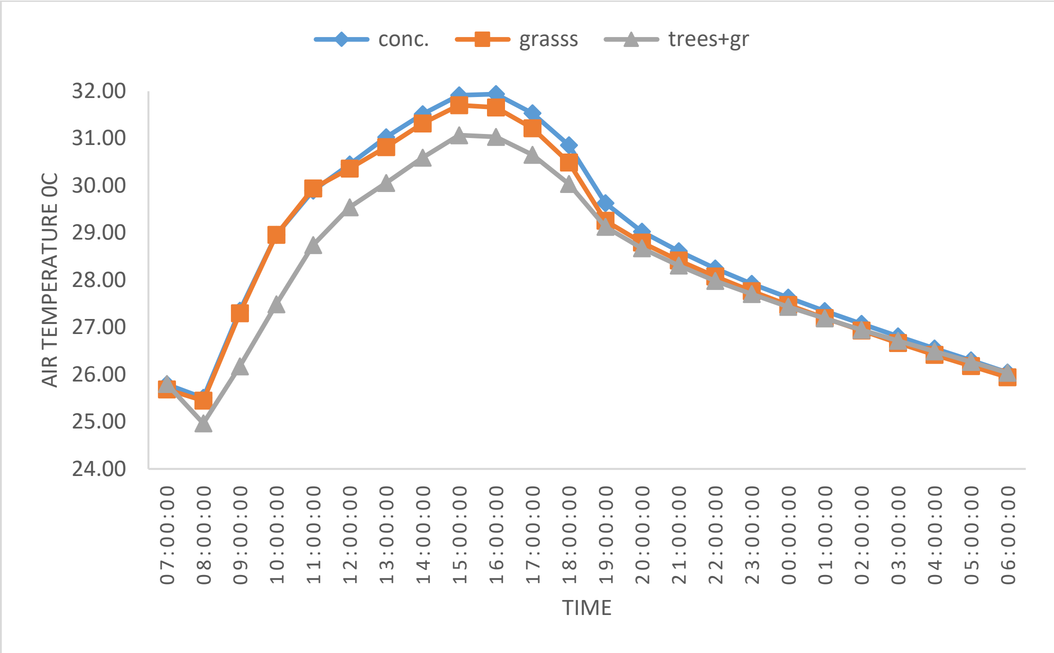

Figure 11: Curves showing the air temperature distribution within the strategy (15m x 15m x 15m)

3.2 Mean Radiant Temperature

The distribution of the Mean Radiant Temperature within the courtyard as in the figures below. The strategy C perform better as it the strategy that has trees. Figures below show the details.

In strategy, A (figure 12) maximum Mean Radiant Temperature (Tmrt) recorded at 16:00hrs translated to 47.77°C. A reduction of 1.0°C observed when laid with 100% grass. When 75% trees in combination with grass a further reduction of 3.41°C observed. Meanwhile, strategy B (figure 13), recorded its maximum Tmrt at16:00hrs with 47.70°C. When 100%grass laid 1.2°C Tmrt difference observed. Consequently, 3.40°C Tmrt difference observed when 75% tree with grass laid within the courtyard. However, strategy C (figure 14) observed its maximum Tmrt at 15:00hrs with a Tmrt of 51.36°C. When 100% grass laid within the courtyard a reduction of 2.75°C observed. 9.93°C Tmrt reduction observed when the courtyard laid with 75% trees in combination with grass. This shows that strategy C perform better than strategy A and B in the context of Mean Radiant Temperature.

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

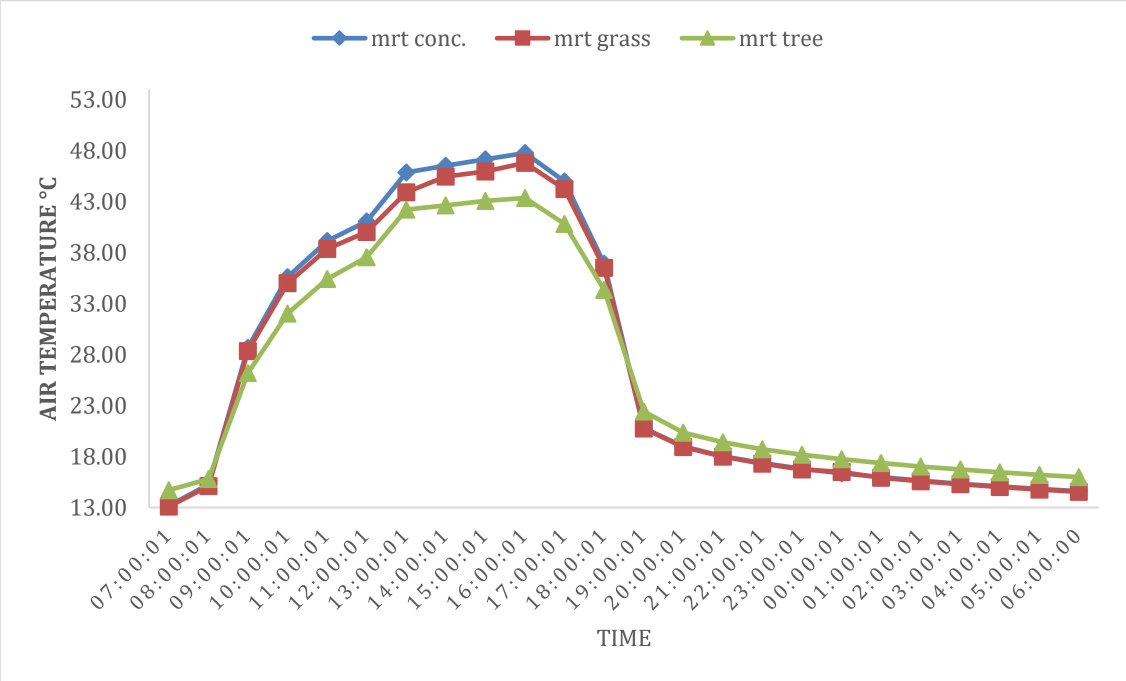

Figure 12: Curves showing the relationship of the mean radiant temperature of strategy a (6m x 6m x 6m)

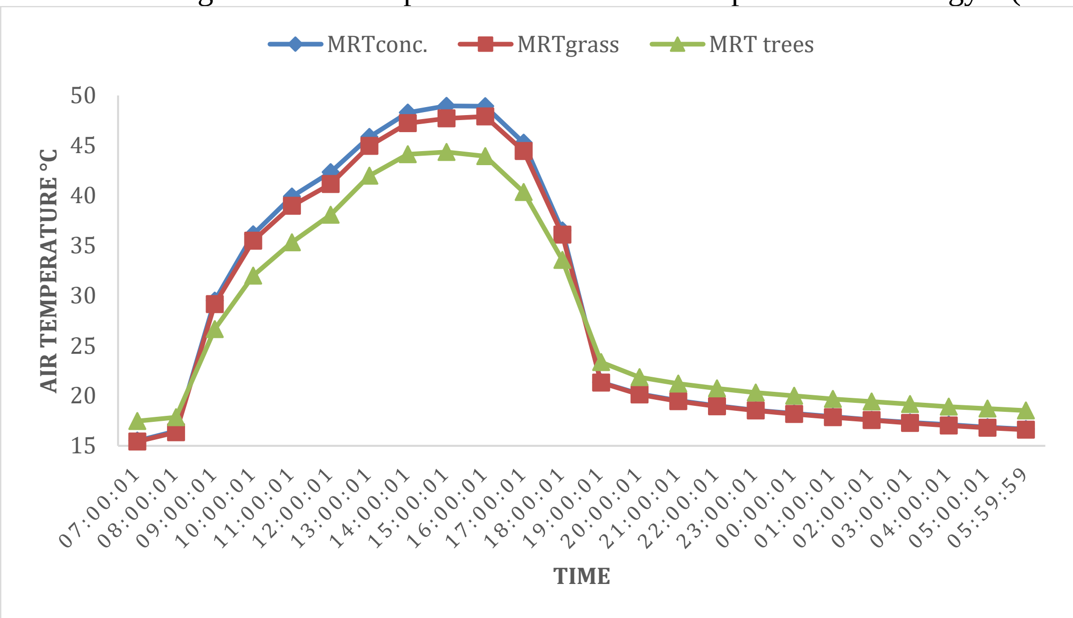

Figure 13: Curves showing the relationship of the mean radiant temperature of strategy B (15m x 7.5m x 7.5m)

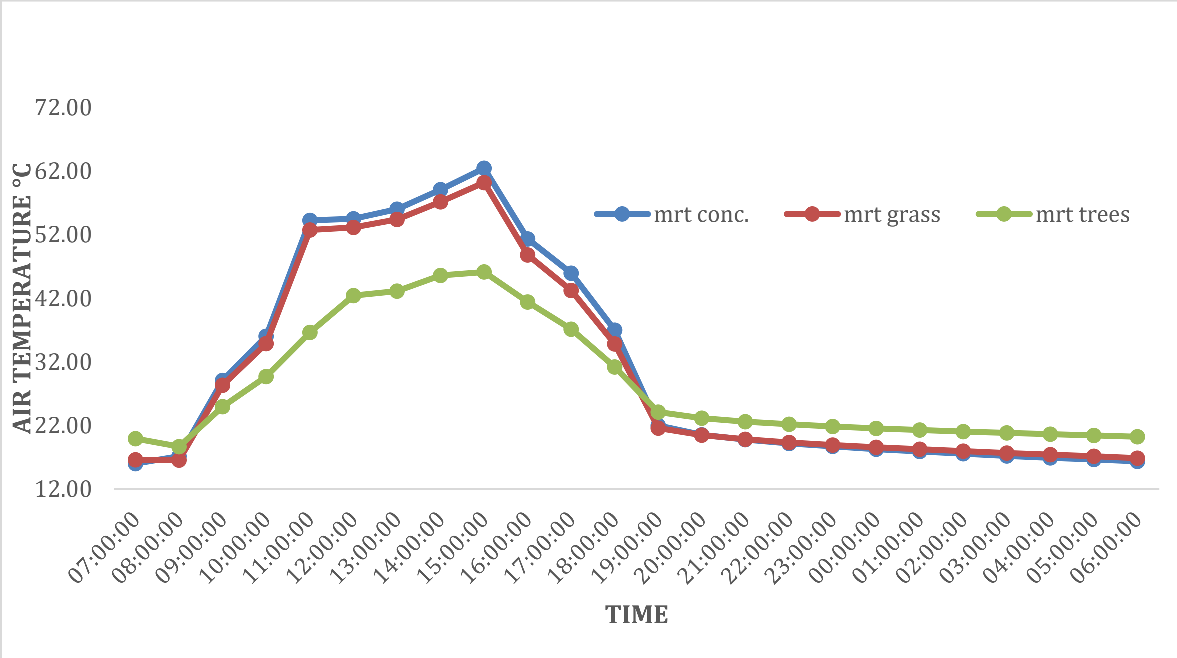

Figure 14: Curves showing the relationship of the mean radiant temperature of strategy C (15m x 15m x 15m)

Physiological Equivalent Temperature (PET)

Physiological Equivalent Temperature, PET, defined as the air temperature at which an ideal indoor setting(without wind and solar radiation) the heat budget of the human is balanced with the same core and skin temperature as under the complex outdoor conditions. This evidently shown in the figures below:

The physiological Equivalent Temperature (PET) of 37.90°C observed at the critical time of 15:00hrs laid with concrete. Laying 100% grass recorded a reduction in PET of 1.5°C in strategy A (figure 15). Further, reduction of 1.90°C of PET is recorded when 75% trees in combination with grass are laid. Meanwhile, the PET in strategy B recorded a maximum of 37.85°C laid with concrete. When 100% grass laid, a reduction of 1.6°C observed. Furthermore, a reduction of 2.00°C observed when 75% trees in combination with grass laid. However, PET in the case of strategy C recorded 52.4°C as its maximum at 11:00hrs laid with concrete. A PET reduction of 16.40°C recorded when 100% grass laid within the courtyard. Consequently, when 75% trees in combination with grass laid. PET reduction of 19.40°C. This demonstrates that the PET of strategy C performs better than strategy A and B as the case may be.

ISSN NO: 2771-8840
Date of Publication: 17-03-2022

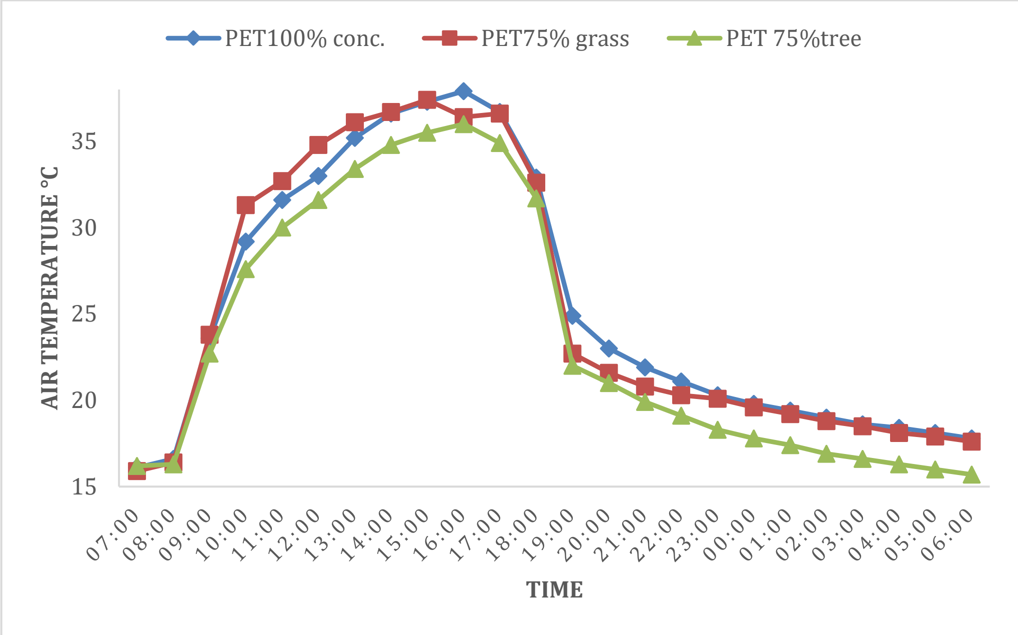

Figure 15: Curves showing the relationship of the Physiological equivalent temperature of strategy A (6m x 6m x 6m)

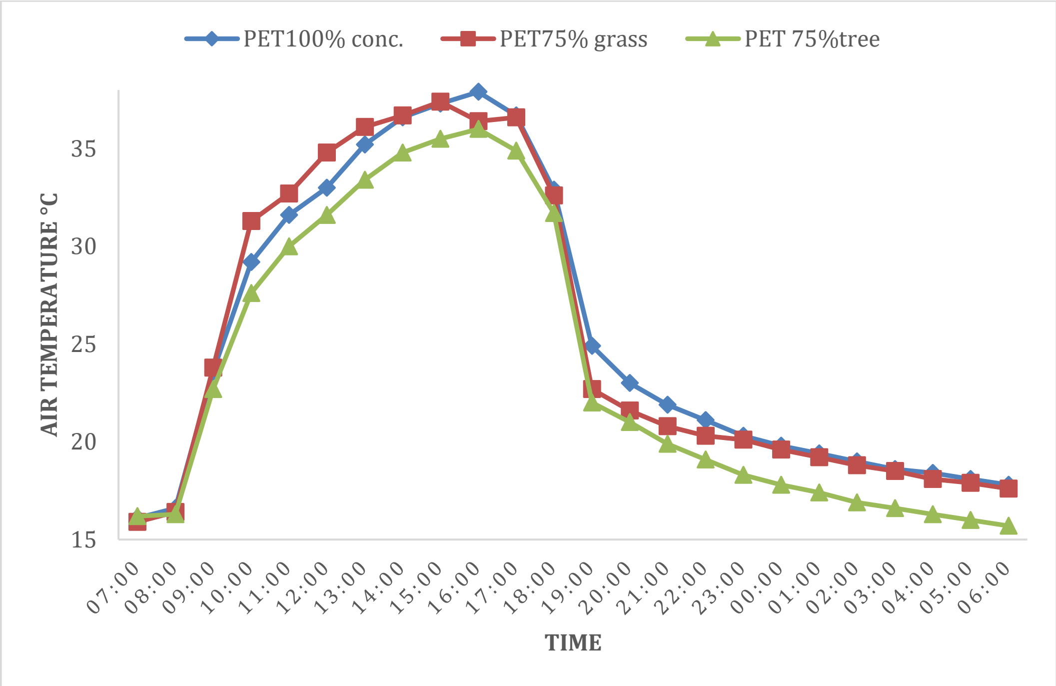

Figure 15: Curves showing the relationship of the Physiological equivalent temperature of strategy B (15m x 7.5m x 7.5m)

ISSN NO: 2771-8840
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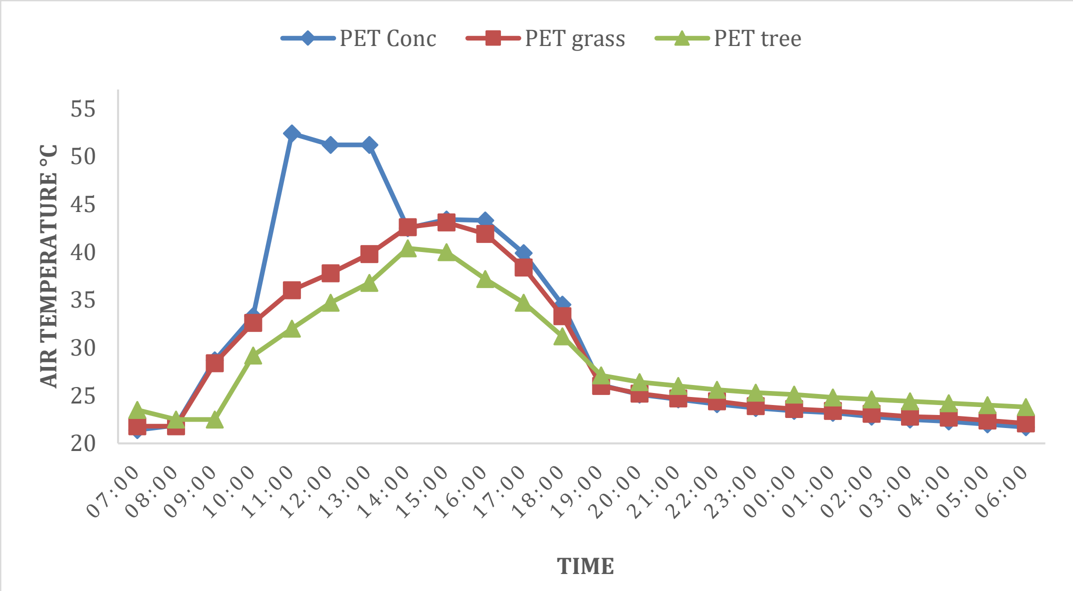

Figure 15: Curves showing the relationship of the Physiological equivalent temperature of strategy C (15m x 15m x 15m)

The reason why there is a significant difference in the air temperature distribution within the courtyard was, the shading the trees provide thereby blocking the solar radiation from reaching the ground to heat it up. Another reason is that of evapotranspiration, a process where the leaves transpire by releasing water vapour on the surface of the leaves and then evaporate into the air thereby cooling the air.

The courtyard ratio in strategy A and B has no significant difference in their air temperature, though vegetation laid. This is because the courtyard is self-shaded and so the effect of vegetation will not affect the air temperature much. Therefore, this kind of courtyard ratio doesn't need vegetation as a strategy to improve the thermal performance. The impact of the vegetation on the courtyard of the shophouse and that of the library building courtyard was the shophouse is self-shaded and so the impact of vegetation is not pronounced while the size of library building courtyard is bigger and so the self-shading is less compared to the shophouse thus is exposed to solar radiation. Because of that, the shading of the tree prevents the solar radiation from heating the internal courtyard surfaces and the effect of evapotranspiration from the leaves surfaces and therefore cooling the courtyard.

4.0 Conclusion

The research evaluates the impact of vegetation as a strategy to improve the performance of courtyards in Tropical climate. Three strategies namely strategy A (6m x 6m x 6m), B (15m x 7.5m x 7.5m), C (15m x 15m x 15m), identify and select for Simulations conducted under three different proportion of concrete, grass and trees. The results demonstrate that the courtyard strategy C perform well than the other two strategies, and also all the thermal indices measured (Air Temperature, Mean Radiant Temperature, and Physiological Equivalent Temperature)

There is a reduction of 0.9°C of the Air Temperature, 9.93°C of Mean Radiant Temperature and 19.40°C of Physiological Equivalent Temperature.

Strategy A (6m x 6m x 6m) and B (15m x 7.5m x 7.5m) do not need vegetation to improve their thermal performances as the results shown there is no distinct difference this is because the two courtyards are self-shaded. However, strategy C (15m x 15m x 15m) requires vegetation to improve the thermal performances of the courtyard as indicated in the result this is because of the courtyard area is exposed to solar radiation throughout the day. Therefore the study recommended that courtyard with large size can use vegetation as one of the strategies to improve the thermal performance.

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ISSN NO: 2771-8840
Date of Publication: 17-03-2022

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