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Effects of Vegetation Covers for Outdoor Thermal Improvement: A Case Study at Abubakar Tafawa Balewa University, Bauchi, Nigeria

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ABSTRACT

Frequent increases in temperature and related consequences have been the trending phenomenon for over ten decades, with a general rise of about 0.74^{0}C. This study evaluates the effects of different percentage covers of tree canopies for outdoor thermal improvement of campus areas in Bauchi, Nigeria. Firstly, the study involves on-site measurement of existing features on the site and the climatic conditions. Secondly, performing simulation for evaluation of the plant-surface-atmosphere interactions with Envi-met Version 4.4.2. The vegetation effects were evaluated for outdoor air temperature and mean radiant temperature (MRT) reduction. It is found that the maximum air temperature reduction of 3.38^{0}C and 24.240C of MRT were achieved with up to 45% tree canopy coverage. The mean air temperature and MRT reduction of 0.63^{0}C and 4.80^{0}C were respectively achieved with the same percentage coverage of the canopies. However, it was found that the thermal reduction effects of vegetation do not apply to every hour of the day. In essence, proper planning and implementation of campus

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outdoor spaces is the key factor in improving its thermal conditions. Thus, adhering to the practical recommendations bring a significant improvement in ameliorating the rise in atmospheric temperature on campus outdoors.

Keywords: Air temperature, campus outdoor, envi-met simulation, hot-and-dry climate, mean radiant temperature, urban climate

INTRODUCTION

A rise in temperature and its related consequences have been the trending phenomenon because of its rapid increase than in previous decades (Brysse et al., 2013; Morakinyo et al., 2016). Between 1906 and 2005 indicates a general rise of 0.74^{0}C with up to 0.13^{0}C increase in some decades (Frédéric et al., 2008). Correspondingly, an increase in global atmospheric temperature to 0.74^{0}C in the past 100 years has been reported by Intergovernmental Panel on Climate Change (Morgan, 2006). Moreover, it has been projected that the global mean atmospheric temperature will increase by 0.3 to 4.8^{0}C by the year 2100, depending on the context parameters and its specific emissions scenario (Centre for Science and Environment, 2018). In urban areas, frequent anthropogenic activities increase the effects of greenhouse in the atmosphere. Consequently, the increase in the greenhouse effect leads to a rise in temperature (Shahzad, 2015). Apart from the increase in the greenhouse effect in the atmosphere, Urban Heat Island manifests in most urban environments, which leads to the rise in atmospheric temperature. The rise in temperature due to the Urban Heat Island in cities deteriorates its microclimates, decreases energy efficiency, and increases the thermal condition of outdoor spaces (Lai et al., 2019).

A study conducted by Hassan et al. (2017) reveals that there were increasing temperature trends from 1982-2014 in most parts of the cities in northern Nigeria with a value of 0.03^{0}C to 0.05^{0}C per decade. Air temperature and MRT are the most common parameters used to assess indoor and outdoor thermal conditions (Al-Mohsen et al., 2020; Lucchi et al., 2017; Yıldırım, 2020). An increase in these two climatic parameters tends to worsen the thermal conditions of a microclimate. Air temperature (Adunola, 2014) and the MRT remain the dominant climatic parameters affecting the outdoor thermal state in the hot and dry regions (Soydan, 2020), especially in Nigeria. In Nigeria, the hot and dry region possesses the highest degree of air temperature and MRT. In the area, the air temperature rises to 42^{0}C in late May of each year. The excessive rise in the temperature emanates from less vegetation in the region that can provide shades over surfaces against direct solar radiation. The vegetated areas are mostly replaced with hard surfaces that absorb more heat and light (Hami et al., 2019; Hertel & Schlink, 2019). This phenomenon frequently happens in urban areas of Nigeria, especially during construction processes.

Shading in urban outdoor environments has been identified as an essential aspect in modifying microclimatic conditions and enhancing thermal comfort, particularly in hot regions (Peeters et al., 2020). Many open and semi-open spaces in university campuses are not adequately planned to respond to microclimate conditions. These aspects hinder university students from having campuses with thermally comfortable outdoor environments (Ghaffarianhoseini et al., 2019). Including vegetation in the planning and implementation of campus outdoor spaces will ameliorate the rise in outdoor temperature. Equally, it improves the well-being and learning capacity of students. Thus, vegetation is one of the fundamental concepts for enhancing the thermal condition of urban microclimates (Morakinyo & Lam, 2016). It plays a significant role in influencing the urban microclimate thermal conditions (Tong et al., 2017; Wong et al., 2007; Wong et al., 2010). There are three aspects to consider in reducing outdoor air temperature and MRT: designing the outdoor spaces, vegetation planning, and implementation (Hami et al., 2019; Yahia et al., 2018; Yahia & Johansson, 2014). The cooling effect of vegetation extends beyond its green area (Lu et al., 2017). The extension depends on the vegetation density and its percentage cover. Generally, foliage has a vital influential role in outdoor and indoor thermal condition improvement (Tong et al., 2017). Tree canopy, in particular, helps in the provision of shade against direct solar radiation. Furthermore, evapotranspiration by leaves is important in reducing the intensity of heat (Dhakal, 2002).

Researchers in passive architecture and urban planning have been trying tremendously in improving outdoor thermal environments in urban centres. They suggested practical solutions to achieve the mitigating effects. Such as increasing the green areas (Aboulnaga & Mostafa, 2020), proper natural ventilation (Al-Mohsen et al., 2020), provision of shades from natural and built forms (Abaas, 2020; Peeters et al., 2020), and minimization for the use of surfaces that enhance the increase of longwave radiations. However, studies are still needed to add to the body of knowledge regarding improving our microclimates. Authorities and scholars around the globe put less emphasis on climate conditions and thermal improvement of microclimates at regional and urban scales (Dhakal, 2002). Furthermore, most studies on thermal improvement were indoors; few were conducted on the outdoor spaces. Hence, the fewer conducted in urban areas were centred on improving parks, street canyons, office environments, and residential neighbourhoods rather than academic environments. Equally, the research emphasis was less on hot and dry climates than other parts of the globe.

This study investigates the effects of tree canopy coverage in the outdoor thermal environment of a university campus in the city centre of Bauchi. The ENVI-met 3-dimensional non-hydrostatic simulation model was employed to evaluate the outdoor thermal environment. It is widely used to improve urban spaces in various climatic zones and within diverse urban structures (Chatzinikolaou et al., 2018; Perini et al., 2017). The study investigated the reducing effects of tree canopy cover on the intensity of the outdoor climatic conditions in a campus setting. It equally hypothesized the significant positive effects of tree canopy cover in reducing the intensity of outdoor air temperature and the MRT in the context of urban centres within hot and dry climates (Davtalab et al., 2020).

MATERIALS AND METHOD

The research work was carried out in two stages consecutively to evaluate the effects of different vegetation cover on air temperature and MRT reduction. The stages were field measurement survey and the Envi-met computer simulation.

Study Site

The study was conducted at the Abubakar Tafawa Balewa University in Bauchi town of Northern Nigeria (Figures 1 & 2). The location is categorized as a hot and dry Savanna climate, with less grass and sparse trees. The university has a student enrolment of 14,492 for the 2016/2017 academic session (Office of the University Registrar, 2018). The mean daily maximum temperature of Bauchi town ranges from 27.0^{O}C to 29.0^{O}C between July and August. While 37.6^{O}C in March and April (Sylvester & Abdulquadir, 2015). The mean daily minimum temperature ranges from 22.0^{O}C in December and January to about 24.7^{O}C in April and May. The mean maximum air temperature of Bauchi was higher than the mean maximum air temperature of the country (Eludoyin et al., 2014). The sunshine hours range from 5.1 hours to 8.9 hours. October to February was recorded as the longest sunshine hours in the city of Bauchi. Humidity ranges from 12% in February to about 98% in August. The months for the rainy season are May to September, with the annual precipitation ranges from 600mm to 1300mm (Akande & Adebamowo, 2010). Currently, vegetation covers 9% of the total land area of the study site.

Field Measurements

On-site air temperature data were collected from the study site for twenty-one days, from the 10th to 31st August 2018. The selected study period was to obtain changes in air temperature. HOBO UX100-011 data loggers were placed at the height of 1.5m above the ground (Evola et al., 2017) to capture the climate parameter at the pedestrian level (Ghaffarianhoseini et al., 2019). Ten days of pretest measurement were conducted for the climatic condition parameter before the actual site measurement. The pretest measurement took place from the 1st to 10th day of August 2018. It was carried out to ensure the functionality and reliability of the data loggers. All the data loggers were set at 8:00hrs on the first day. Receptor points were selected for the on-site measurements (Figure 2b) as; i. location without vegetation (T_aNV), ii. location with grasses only (T_aGR), iii. location with trees only (T_aTR), and

Figure 1. The location Bauchi, Nigeria *(https://www.mapsofworld.com/nigeria/maps/nigeria-location-map.jpg)*

Figure 2. (a) The study area, (b) study area with the four receptors on the measurement points as TaNV (location without vegetation), TaGR (location with grasses only), TaTR (location with trees only), and TaTG (location with both trees and grass) (Google map imagery).

iv. location with both trees and grass (T_aTG). The four different receptors were placed to capture all the possible different vegetation scenarios on the site. Both the actual and the pretest measurements were carried out on the same measurement points.

Figure 3 presents the mean daily air temperature changes for the four measurement points, measured against the primary "y" axis. While the line charts depict the daily maximum and daily minimum changes. They were measured against the secondary "y" axis. The measurement shows that the scenario without vegetation has the highest degree of outdoor air temperature to about 38.6^{0}C on the second day. The combination of trees and grass has the lowest maximum outdoor air temperature of about 35^{0}C on a corresponding day. The decrease of air temperature in the latter scenario was from the effects of the existing vegetation on the campus. The shading and evapotranspiration rates significantly influenced the air temperature. Exposure of surfaces to direct solar radiation leads to increased air temperature in the scenario 0% vegetation.

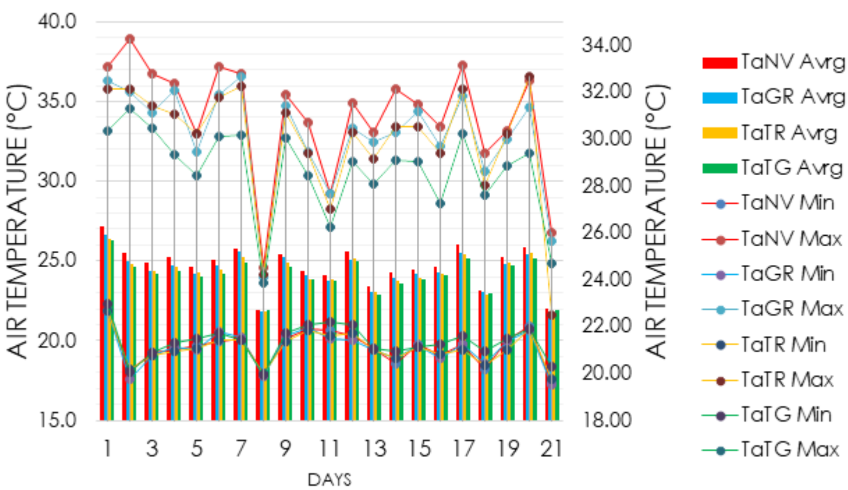


Figure 3. Mean daily changes for the existing air temperature for the 21 measurement days

Envi-met Simulation

Envi-met Version 4.4.2 computer simulation was employed in this study for the simulation of the modelled environment. In the same vein, while performing the simulations, the Envi-met evaluated the heat flux, evaporation, and transpiration flowing from the trees to the atmosphere (Salata et al., 2016). ENVI-met was developed to simulate the relation of surfaces, vegetation, and airflow for local microclimatic conditions. It also evaluates the effects of solar irradiance, humidity, and heat storage in the soil (Shinzato et al., 2019). A grid resolution was used to model the geometry of the study site. The numerical simulations were performed in the summer, on 26th August 2018. As postulated by Tsoka et al., (2018), about 90% of the scientific studies on microclimate analysis used the ENVI-met model during summer. It shows that vegetation significantly influences the thermal condition of microclimates when the temperature is higher (Hami et al., 2019). The simulation day was determined based on the on-site measurements. A day with the highest air temperature and a clear sky (Roth & Lim, 2017) was used for the simulation. The simulation models were run for 24 hours (Tsoka, 2017). The Envi-met computer simulation software Version 4.4.2

was preset as a 10-minute time step. At the end of each domain simulation, hourly time steps were extracted for scenario comparison.

Model Area Geometry

The study site was developed based on physical measurements and google imagery. It has a domain size of 425.00m x 375.00m, designated within 85 x 75 x 15 grids. The grid cell size was 5.00m x 5.00m x 2.00m as dx, dy, and dz, respectively. The height of the total grids for the dz axis is 30m which is more than 2times of the highest building on the site (Ozkeresteci et al., 2003). Priorities were given to the buildings' geometry, vegetation on the site, ground surfaces, and the receptors for the microclimate condition measurements. The overall height of the buildings within the measurement site ranges from 5m to 12m. The ground surfaces were loamy soils and asphalt roads. The vegetation was a combination of grasses and trees, with an average height of 25cm, and 7.5m, respectively. The Leaf Area Density (LAD) for a tree is 1.2, used for the model domain. In the end, four receptors were placed at four places to record the existing climatic conditions. Table 1 shows the input data for model development and simulation initialization process.

Models Domains

Five outdoor models were simulated to evaluate the optimal thermal influence of vegetation coverage on the campus outdoor environment. The five different models were scenario with 0% vegetation cover, as the base model (Figure 4), the scenario with 9% vegetation cover as the existing condition of the study site (Figure 5a), the scenario with 15% vegetation cover (Figure 5b), the scenario with 30% vegetation cover (Figure 5c), and the scenario with 45% vegetation cover (Figure 5d). The numerical model simulations were run for 24hrs from 6:00:00hrs in the early morning. To let the software follow the atmospheric process (Forouzandeh, 2018; Salata et al., 2016).

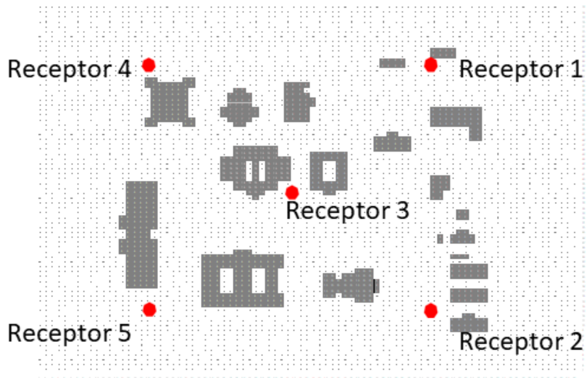


Figure 4. Shows the base model with 0% vegetation cover, with five receptors placed at different places

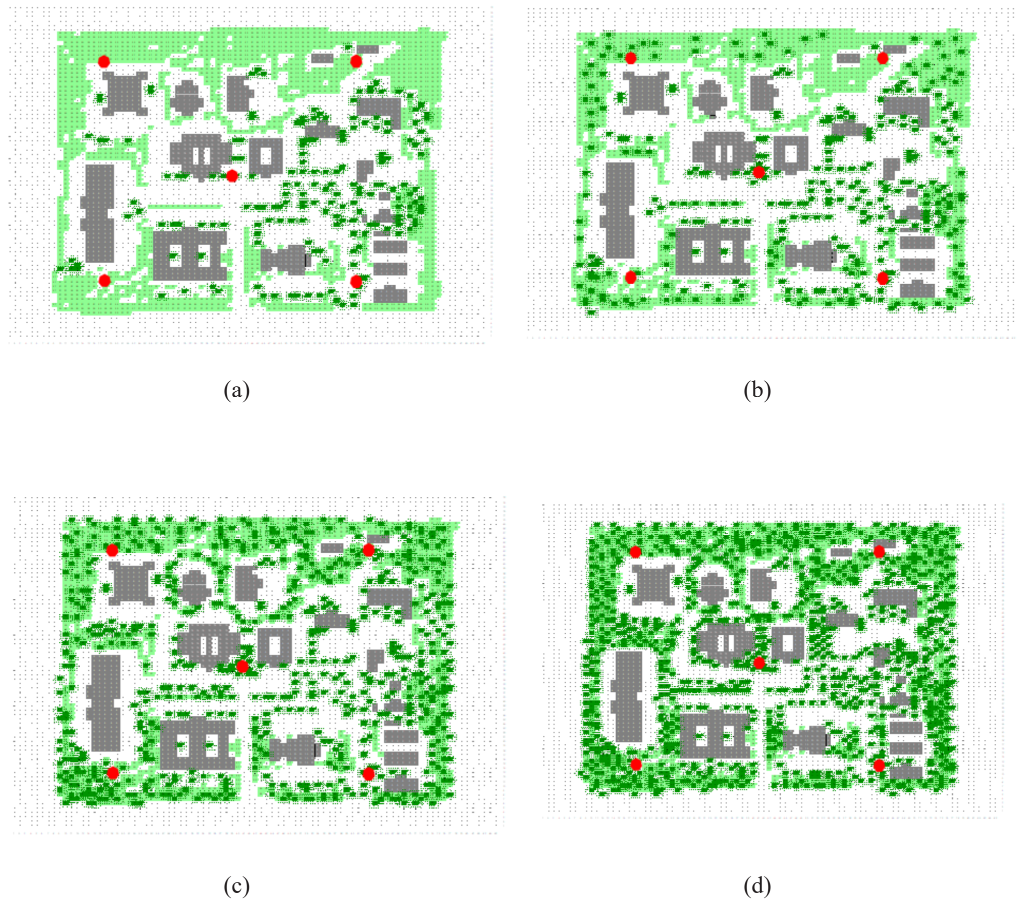


Figure 5. Model domains for different vegetation coverage; (a) the existing condition of site study with 9% of vegetation coverage, (b) Scenario with 15% of vegetation coverage (c) Scenario with 30% of vegetation coverage, and (d) Scenario with 45% of vegetation coverage

Table 1
Envi-met model domain initial input parameters

	ITEMS	INPUT DATA
Study site	Climate type	**Hot and dry**
	Soil	**Loamy soil**
	Latitude	**10^0 16' 45" N**
	Longitude	**09^0 47' 16" E**

Table 1 *(Continued)*

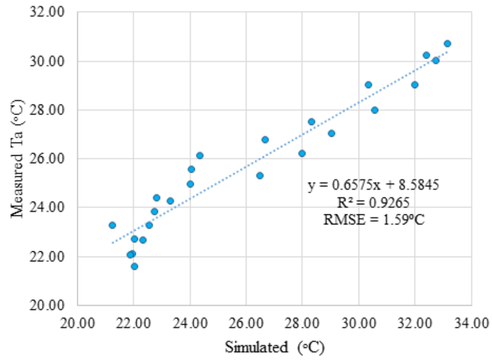
	ITEMS	INPUT DATA
Simulation input data	Simulation day	**On 26th August 2018**
	Effective simulation time	**24hrs**
	Domain size	**425.00m x 375.00m x 30.00m**
	Resolution	**5.00m x 5.00m x 2.00m**
	Roughness length	**0.01**
	Minimum Air temperature	**18^0C at 6:00hrs**
	Maximum Air temperature	**34^0C at 15:00hrs**
	Wind speed	**3.0m/s**
	Wind direction	**90^0**
	Minimum Relative humidity	**45% at 15:00hrs**
	Maximum Relative humidity	**99% at 06:00hrs**

RESULTS

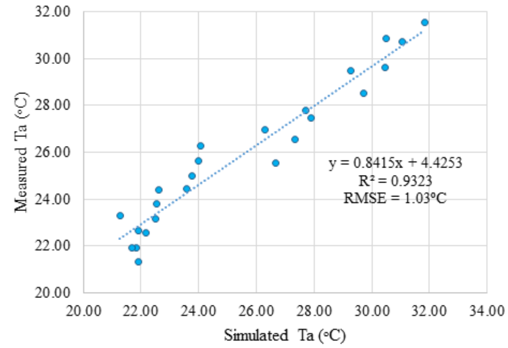
Software Validation

The validation process in this study compares the on-site measurements and the computer simulation outputs. Better validation results indicate the reliability and validity of the software in predicting the plant-surface-atmosphere interaction (Forouzandeh, 2018) within the campus microclimate. Equally, the validation process is an essential step in obtaining accurate results for domain simulation (Shinzato et al., 2019).

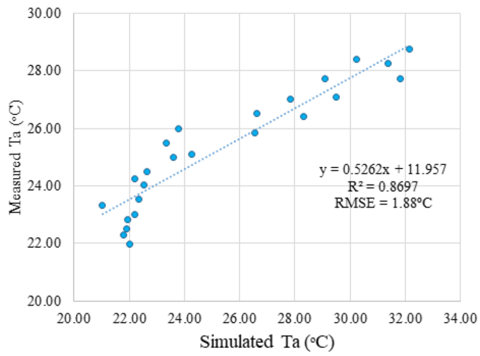
The on-site measurements were designed to measure the existing microclimate conditions of the study site at the ATBU campus. The air temperature on 26th August 2018 was selected as the parameter for the software validation. It was selected based on the day with the highest maximum air temperature and sky clarity. The measured air temperature values were compared with the obtained ENVI-met simulated results (Figure 6). The coefficient of determination (R^2) ranges from 0.8697 to 0.9323 for the four measurement points. Equally, the Root Mean Squared Error (RMSE) for the four measurement points was 1.59^0C, 1.03^0C, 1.88^0C, and 0.92^0C (Figure 6a-6d). The validation results showed that there was a good correlation between the measured values and the simulation results (Yang et al., 2018). The R^2 and the RMSE values suggest that the ENVI-met model can significantly represent the existing condition of the study area. Equally, indicate the software reliability for studying plant-surface-atmosphere interaction in the context of hot and dry climates. Notwithstanding, the ENVI-met underestimated daytime air temperature in all four scenarios, from 09:00hrs to 19:00hrs. Which was due to the anthropogenic heating from vehicles, and other moveable objects that were not accounted for in the simulation (Eniolu et al., 2017).



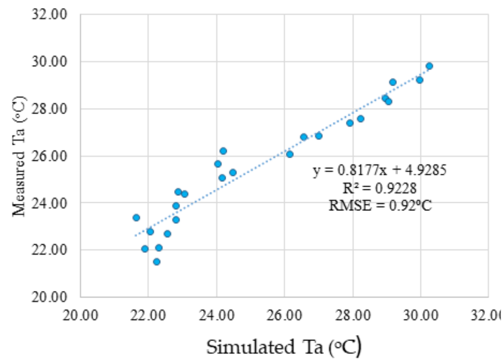
(a)



(b)



(c)

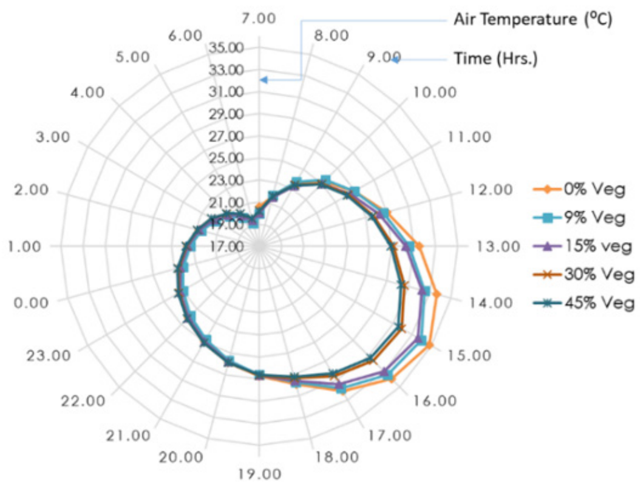


(d)

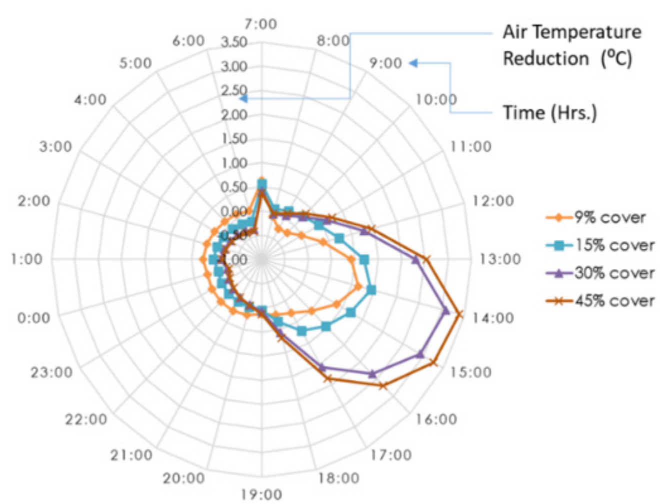
Figure 6. Envi-met software validation output for the four measurement points

Air Temperature

All four scenarios were compared with the base model to evaluate the total effects of the vegetation covers on the air temperature reduction. The existing situation that has the 9% vegetation cover was with the least reduction effects. The cover reduced the air temperature by a maximum of 1.14^{0}C at 14:00hrs (Figure 8) with a daily average reduction of 0.27^{0}C (Table 2). The 15%, 30%, and 45% tree canopy covers showed a daily average reduction effect of 0.32^{0}C, 0.55^{0}C, and 0.63^{0}C respectively. The simulation results showed that from 8:00hrs to 11:00hrs, the 9% vegetation cover has adverse effects on air temperature reduction. Within the stated period, the air temperature rises above that of the base model domain. Equally, from 21:00hrs to 6:00hrs the next day, any increase of the vegetation cover negates its influence on air temperature reduction. This is because the thermal effects of tree canopies are based on shading and evapotranspiration (Morakinyo & Lam, 2016). The shading effects occur significantly in the daytime, whereby the shortwave radiations were shaded from reaching surfaces. An increase in the percentage of vegetation coverage decreases the wind speed. Consequently, it traps the heated air within the densely vegetated environment. Thus, it raises the temperature at night time (Figure 7).



(a)



(b)

Figure 7. (a) Air temperature output on the simulation day **(b)** Outdoor air temperature reduction for different vegetation cover at every hour of the day

Table 2

Effects of different vegetation covers on air temperature reduction

Vegetation Cover	9%	15%	30%	45%
Maximum reduction (^{0}C)	1.14	1.43	3.08	3.38
Minimum reduction (^{0}C)	-0.27	-0.19	-0.37	-0.41
Average reduction (^{0}C)	0.27	0.32	0.55	0.63

Simulation outputs were imported into a Leonardo visualization program. Each output file has a multitude of information that has been translated into different layers in the program. The following layers shown in Figure 8 and 9 are visual output for five scenarios at 15:00hrs of the simulation day. The five scenarios have different vegetation cover. The visualized layer outputs for the models with vegetation cover 0%, 9%, and 15% as presented in Figure 8, 9a, and 9b, respectively, indicate a significant proportion of hotter areas in the respective models. These explain that the less coverage of the vegetation the scenarios lead to an increase in the daytime air temperature. Consequently, the daytime air temperatures rise to a maximum of 37.25^{0}C, 36.94^{0}C, and 36.21^{0}C, for scenarios with the vegetation cover of 0%, 9%, and 15%, respectively. Conversely, models with the vegetation cover 30% and 45% in Figure 9c and 9d indicated a remarkable decrease in air temperature during the day to a maximum of 36.06^{0}C and 35.97^{0}C, respectively. The visualized outputs were dominated by layers of blue and green at 15:00hrs. Therefore, it indicated a more significant improvement for outdoor air temperature reduction in the daytime. It was a result of the percentage increase in the vegetation cover above 30%.

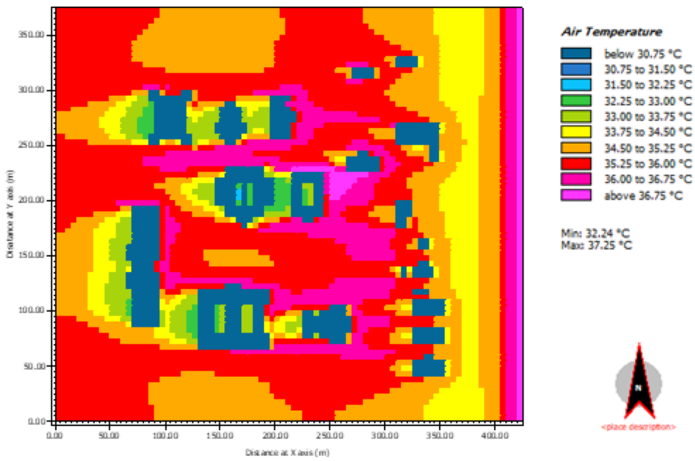
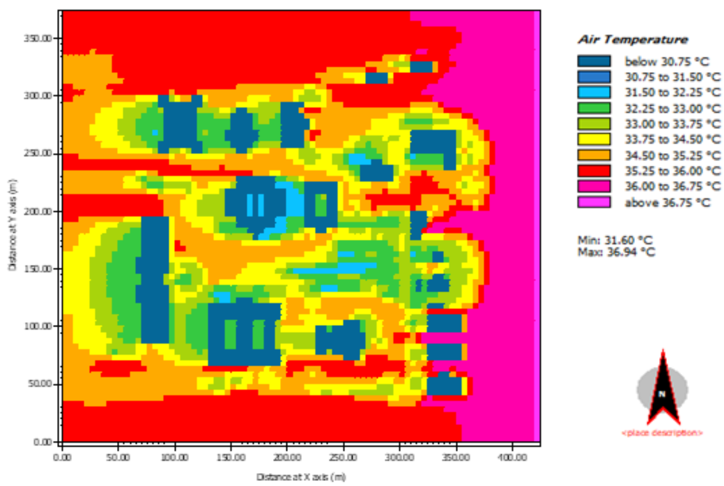
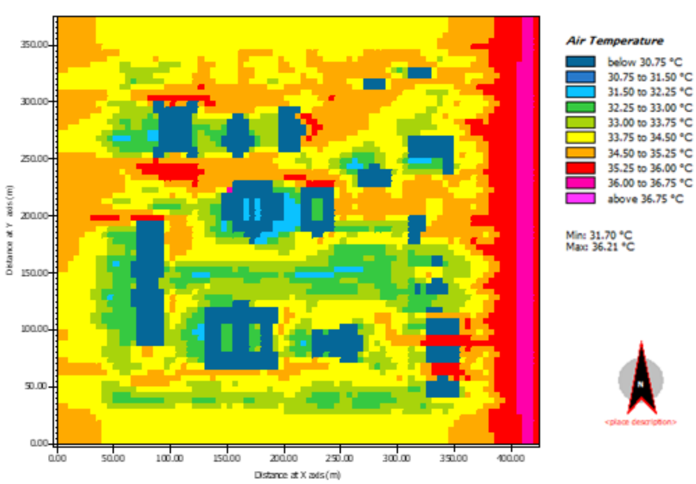


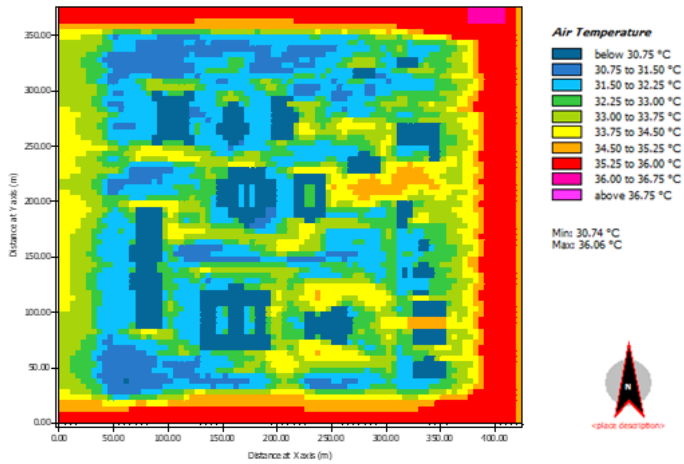
Figure 8. Air temperature visual output for the scenario with 0% vegetation cover at 15:00 hrs


Air Temperature
below 30.75 °C
30.75 to 31.50 °C
31.50 to 32.25 °C
32.25 to 33.00 °C
33.00 to 33.75 °C
33.75 to 34.50 °C
34.50 to 35.25 °C
35.25 to 36.00 °C
36.00 to 36.75 °C
above 36.75 °C
Min: 31.60 °C
Max: 36.94 °C
Distance at X axis (m)
Distance at Y axis (m)

(a)


Air Temperature
below 30.75 °C
30.75 to 31.50 °C
31.50 to 32.25 °C
32.25 to 33.00 °C
33.00 to 33.75 °C
33.75 to 34.50 °C
34.50 to 35.25 °C
35.25 to 36.00 °C
36.00 to 36.75 °C
above 36.75 °C
Min: 31.70 °C
Max: 36.21 °C
Distance at X axis (m)
Distance at Y axis (m)

(b)



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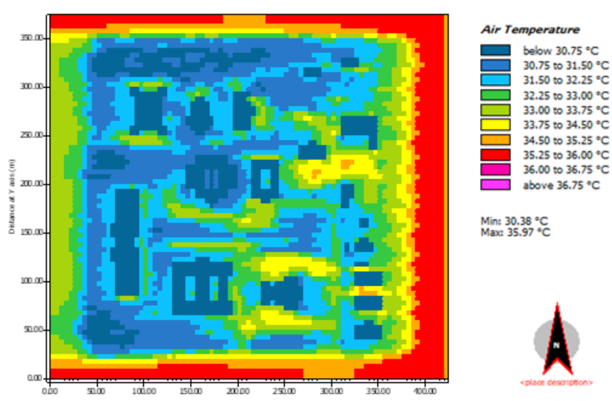
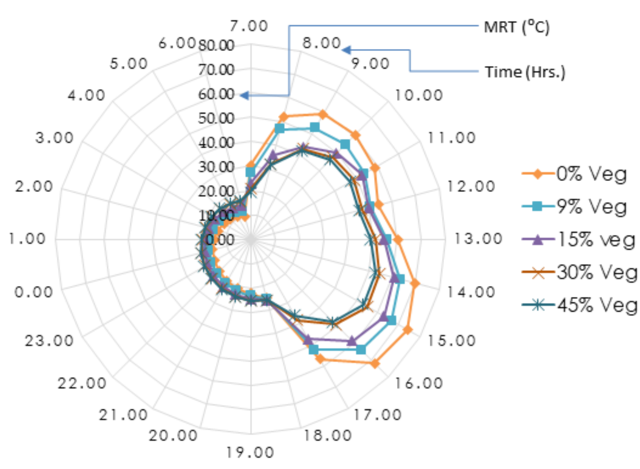


(d)

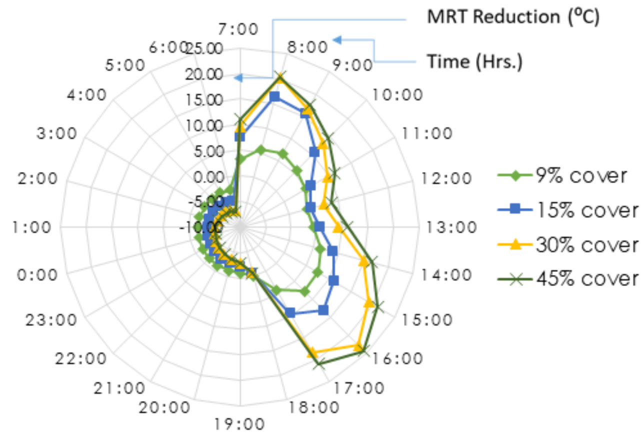
Figure 9. Air temperature visual output for different vegetation cover at 15:00 hours; (a) Scenario with 9% vegetation cover which is also the current condition of the study site, (b) Scenario with 15% vegetation cover, (c) Scenario with 30% vegetation cover, and (d) Scenario with 45% vegetation cover

Mean Radiant Temperature

In the context of the hot and dry urban climate, MRT changes due to the absence or less vegetation in the region (Soydan, 2020). The need for vegetation on campuses in such areas deemed essential to reduce the intensity of the MRT. For this reason, five different models were simulated to evaluate the effects of varying percentage coverage of tree canopies on MRT reduction. The four vegetated domains (Figure 10b) were compared with the base model, which has 0% tree canopy cover. The comparison was to ascertain the magnitude of the MRT reduction by different percentage coverage of tree canopies. The results showed that in all the models' domain, the MRT started magnifying its intensity precisely at 7:00hrs with a sudden decline at 17:00hrs. Among all the five simulated domains, the base model resulted in the highest daily maximum MRT of up to 74.27^{0}C at 15:00hrs. Equally, despite its 0% vegetation, the base model resulted in the lowest daily minimum MRT of 9.44^{0}C at 06:00hrs. The results demonstrated higher vegetation coverage lowers the MRT in the daytime. Increase in vegetation coverage resulting in a higher MRT from 18:00hr to 07:00hrs the next day (Figure 10a). Furthermore, all the simulation results showed that the thermal reduction effects on the MRT were more effective at 08:00hrs and 16:00hrs (Figure 10b). The 45% tree canopy cover showed the maximum MRT reduction effect. It reduced the MRT by 24.24^{0}C at 16:00hrs, with a daily average of 4.80^{0}C reduction effects (Figure 9b). The results showed a sudden drop in the MRT reduction at 12:00hrs for all the four vegetated domains. The significance of MRT reduction requires 15% vegetation coverage in the morning time (Figure 9b). In contrast, a minimum of 30% vegetation cover in the afternoon time for significant MRT reduction.



(a)



(b)

Figure 10. (a) Mean radiant temperature output on the simulation day (b) Effects of different vegetation covers on mean radiant temperature reduction.

Table 3

Average reduction for different vegetation covers on mean radiant temperature

Vegetation Cover	9%	15%	30%	45%
Maximum reduction (^{0}C)	7.79	16.32	22.73	**24.24**
Minimum reduction (^{0}C)	-2.52	-4.86	-6.59	**-6.95**
Average reduction (^{0}C)	1.62	2.72	4.23	**4.80**

All the results for the five scenarios were imported into Leonardo software for visual presentation. Figure 11 is the base model scenario that has 0% canopy cover. Figures 12(a) and 10(b) are scenarios with 9% and 15% vegetation cover, respectively. While Figures 12(c) and 10(d) are the scenarios with 30% and 45% vegetation cover, respectively. The MRT for the five different vegetation cover scenarios was illustrated at 15:00 hrs, whereas the MRT was at the peak point. The visual images showed a significant MRT reduction with the increase in the vegetation cover. The reduction effects were 2.82^{0}C, 4.88^{0}C, 7.53^{0}C, and 8.62^{0}C for scenarios with 9.%, 15.%, 30.%, and 45.% vegetation cover respectively. Thus, it demonstrated no significant difference between the base model and the current situation on campus with 9% vegetation.

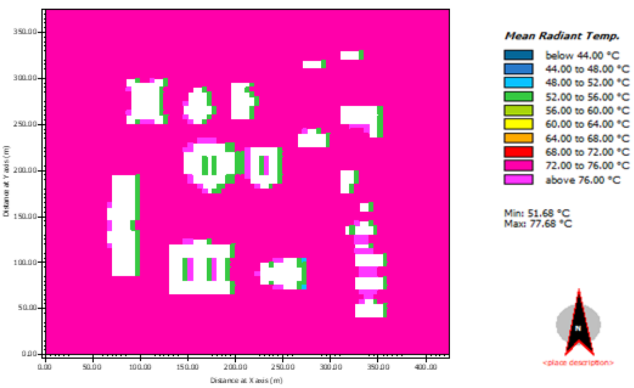
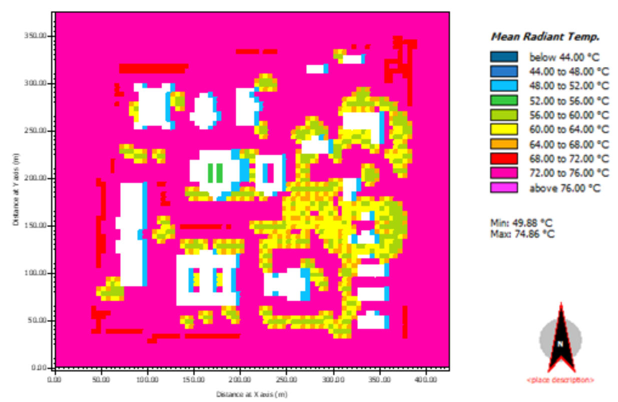
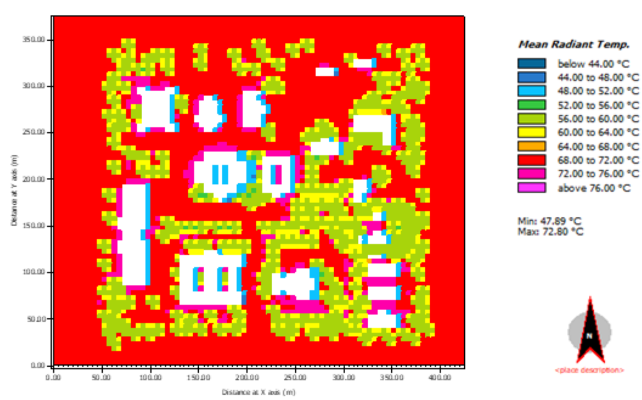


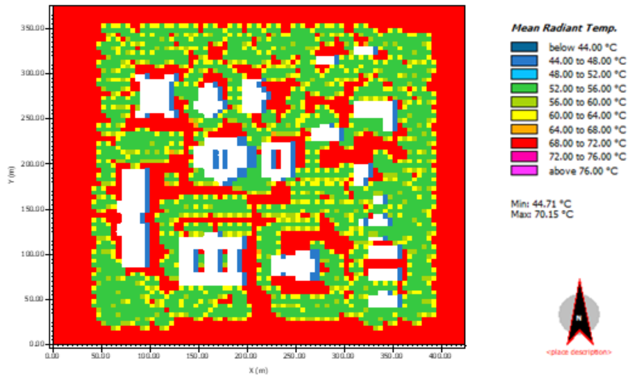
Figure 11. Mean radiant temperature visual output for the scenario with 0% vegetation cover



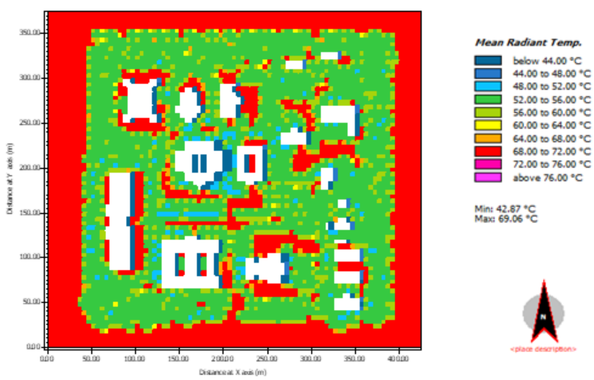
(a)



(b)



(c)



(d)

Figure 12. Mean radiant temperature visual output for; (a) Scenario with 9% vegetation, (b) Scenario with 15% vegetation cover, (c) Scenario with 30% vegetation cover, and (d) Scenario with 45% cover

DISCUSSION

Several anthropogenic and natural features in an urban centre influence the thermal condition of its microclimates (Soydan, 2020). The features lead to higher or lower thermal conditions of the urban environments. Vegetation forms part of the natural features that improve the thermal state of urban microclimates (Davtalab et al., 2020). Five modelled scenarios were simulated for 24hrs in evaluating the improvement capacity of different percentages of vegetation covers within a campus. The initial simulation inputs were based on the field measurements. The simulation outputs showed that the higher the tree canopy cover percentage, the higher the thermal reduction effects in the daytime. The base model with 0% tree canopy cover has the highest air temperature (Figure 7a) and the MRT (Figure 10a) in the daytime. The scenario with 45% vegetation cover has the lowest maximum air temperature and MRT in the day. The high level intensity of the parameters in the base model was due to the absence of vegetation cover. Lack of shaded areas from tree canopies allows direct solar radiation onto surfaces. The exposed surfaces, in turn, emit more heat to the surrounding atmosphere. The results showed that all the maximum thermal reduction effects are positive, while the minimum thermal reduction effects appeared in a negative value (Table 2 & 3). These indicate that vegetation does not render thermal reduction effects every hour of the day. The thermal reduction effects generally occur in the daytime, where the thermal properties of the climatic parameters are at their peak degrees.

The highest reduction effect of 0.63^0C was recorded with the tree canopy covers of 45%. The air temperature amelioration effect obtained in this study was lower than those obtained by Davtalab et al. (2020) and Nasir et al. (2015). Who found that a scenario with dense vegetation was lower by 1.0^0C than scenarios without any vegetation. The difference might have been due lack of inclusion of specific percentages of vegetation coverage in the Davtalab et al. (2020). Similarly, Nasir et al. (2015) used up to 80% of vegetation coverage to achieve the 1.0^0C temperature reduction. The 24.4% reduction of MRT in this study was achieved only when 45% of the tree canopy coverage was used. The insignificant MRT reduction effect found here agrees well with the study by Spangenberg et al. (2008). Whereby, they equally recorded up to 24.0^0C MRT reduction after using dense trees of 10m height. However, the maximum MRT reduction of 24.4% was lower than the 30^0C obtained by Taleghani et al. (2016). It was a result of differences in the base model scenarios, as Taleghani's base model receptor was placed directly above the unshaded asphalt concrete road.

CONCLUSION

Air temperature and MRT are important meteorological parameters that determine the thermal condition of campus outdoors in a hot and dry climate. This study evaluated the effects of different coverage of tree canopies on air temperature and MRT reduction in a campus environment in Bauchi, Nigeria. The study concludes that the thermal reduction effects of vegetation do not apply to every hour. The vegetation enhances the thermal condition of the campus microclimates, especially during the daytime. The study has identified the best thermal reduction provided by vegetation cover of 45% is in the daytime. The study suggests up to 45% vegetation cover at places used by students in the daytime. Such locations include academic areas and outdoor recreational areas. In contrast, up to 30% of vegetation cover be placed at places that engage students in the nighttime. In essence, the university authority needs to have proper planning and implementation of the campus outdoor green spaces. The proper planning, implementation and maintenance of the green space is the key factor in improving the thermal conditions of campus outdoor. Thus, adhering to the practical recommendations will significantly improve the amelioration of the rise in temperature on campus outdoors. The improved campus outdoors will equally improve the students' physical and psychological well-being. Similarly, it will enhance learning capacity due to the students' satisfaction with the thermal environment.

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