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EVALUATING THE IMPACT OF VEGETATION ON CAMPUS OUTDOOR AIR TEMPERATURE AND RELATIVE HUMIDITY IN A HOT AND DRY CLIMATES: A CASE STUDY AT UNIVERSITY OF MAIDUGURI, NIGERIA

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ABSTRACT

Campuses located in urban centers in a Hot and dry climate has been characterized by an intense rise in the diurnal temperature. Consequently, students on campuses within such urban centers have been affected by the thermal condition of the microclimates. Thereby, negatively affects their well-being, as well as their learning capacities. Fewer strategic emphases were

Introduction

Humans, as one of the living creatures, have preferential attitudes in place selection and the activity to perform within such areas. The preferential choice over outdoor spaces mostly depends on the thermal condition of the environment. Equally, the thermal condition of an outdoor space depends

put in place to improve the situation. The use of greeneries lacks emphasis on such campuses. Equally, empirical studies were less conducted on the thermal improvement of the campuses. This study is aimed at evaluating the impacts of different vegetation situations on outdoor thermal improvement. The study was conducted on a university campus located in the city of Maiduguri, Nigeria. For capturing the influence of different situation of vegetation on air temperature and relative humidity, HOBO UX100-011 data loggers were used. It was found that the thermal reduction proportionally improves with the increase in the vegetation cover most especially in the day time. Conversely, the thermal reduction proportionally improves with the decrease in the vegetation cover at night. The study suggests more vegetation cover at areas where students spend their day time. While less of vegetation cover, in the areas where students engage at night.

Keywords: Campus Outdoor, Thermal improvement, HOBO data logger, Air temperature, Relative humidity

on its air temperature (Ta), relative humidity (RH), and wind speed ("American Society of Heating, Refrigerating and Air-Conditioning Engineers.," 2010). The hot and dry region of Nigeria witnesses the highest degree of temperature among other areas of the country. Air temperature rises to 42°C in late May. The excessive rise in outdoor climatic parameters emanates due to less vegetation in the region that can provide shades over surfaces against direct solar radiation. The rising situation of the climatic conditions occurs most, in spaces where the ground surfaces are bared. The vegetated areas are replaced with hard surfaces that absorb more heat and light (Hami et al., 2019; Hertel & Schlink, 2019).

University campuses require a higher percentage of greenery to create a conducive learning environment, well-being, and thermal comfort improvement. These were postulated in similar studies by Wong et al., (2007); Abbas & Arigbede, (2012), and Srivanit & Hokao, (2013) conducted in different campus environments of hot tropical regions. Lack of green spaces negatively alters the microclimate thermal environment of campuses. In turn, it results in students' academic performance drawbacks and well-being due to dissatisfaction with their thermal environments (Cho, 2017; Goodman et al., 2018; Zhang & de Dear, 2017). Campuses as a place for learning and other academic activities require a conducive environment, most especially in thermal comfort (Montacchini et al., 2017; N. H. Wong et al., 2007; Nyuk Hien Wong & Jusuf, 2008). Greeneries are provided in an academic environment to lower the ambient temperature for such outdoor environments and improve the thermal comfort of its users (Tan et al., 2014; Nyuk Hien Wong & Jusuf, 2008). Similarly, Nasir, Ahmad, Zain-Ahmed, & Ibrahim, (2015) postulated that vegetation density plays a significant role in the human thermal balance, to be in a comfortable range. A study by Lin, Matzarakis, & Liu, (2009) carried out on a campus environment in a hot-humid region found the outdoor comfort range as 22°C – 26°C. While Ogbonna & Harris, (2008), in their study conducted in a tropical sub-Sahara of Africa, which is quite hot and dry, found the comfortable range to be 24.88°C – 27.66°C. Furthermore, environments within or near greenery have a high surface and air temperature tendency reduction by shading and evapotranspiration (Tan et al., 2014; N. H. Wong et al., 2007). In the same way, the impact of greenery influences the outdoor thermal environment and the indoor spaces (Jaafar et al., 2013). In other words, trees shield building envelopes from absorbing direct solar radiation. Greenery as a ground cover influences the prevention of heat transfer into indoor spaces (Nyuk Hien Wong & Jusuf, 2008). In similar researches carried out by Jaafar et al., (2013); Kawashima, (1990); McPherson et al., (1988); Nasir et al., (2015); Takakura et al., (2000); C. L. Tan et al., (2014); N. H. Wong et al., (2007) and Nyuk Hien Wong & Jusuf, (2008) identified the roles and influence of greenery in mitigating the longwave and shortwave radiations, ambient air and surface temperature through shading and evapotranspiration.

Researchers in the field of passive architecture and urban planning have been trying tremendously in improving outdoor thermal environments in urban centers. Efforts were made towards mitigating the phenomena associated with thermal environments. Researchers recommended practical solutions as a means of achieving the mitigating effects. Thus, increasing the green areas (Aboulnaga & Mostafa, 2020), proper natural ventilation (Al Mohsen et al., 2020), provision of shades from natural and built elements (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 with regards to improving our microclimates. Authorities and scholars around the globe put less emphasis on climate change at regional and urban scales (Dhakal, 2002). Furthermore, most studies on thermal improvement were indoors; few were conducted on the outdoor spaces. Hence, the few conducted in urban areas were centered towards the improvement of parks, street canyons, office environments, and residential neighborhoods. Equally, emphasized mostly on other climate conditions rather than the hot and dry climates.

Vegetation is embraced for many reasons in the context of urban sustainability. Vegetation, in general, serves as one of the fundamental tools for improving 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; Nyuk Hien Wong et al., 2007, 2010). Vegetation contributes a lot to the environment by improving thermal conditions and other aspects related to the quality of life (Nasir et al., 2015). Designing outdoor spaces, vegetation planning, and its implementation are paramount for optimum air temperature and Mean Radiant Temperature reduction (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, vegetation has a vital influential factor in the outdoor as well as indoor thermal condition improvement (Tong et al., 2017). Tree cover, in particular, helps in the provision of shade against direct solar radiation that reaches absorbed by building envelopes and other surfaces. Furthermore, the evapotranspiration by its leaves is equally paramount in dispersing heats in the microclimates (Dhakal, 2002).

This study aims to investigate the effects of vegetation on outdoor thermal environment of a university campus situated in the city of Maiduguri, Nigeria. The study investigated the reducing effects of greens on outdoor climatic conditions in a campus setting. It equally hypothesized the significant positive effects of the vegetation in improving the outdoor thermal comfort of students.

STUDY AREA

The study was conducted at University of Maiduguri (UNIMAID). The campus is located in Maiduguri town of Northern Nigeria (see Fig. 1). The geographical location of the city is categorized as a hot and dry climate. Maiduguri is equally a Sahel Savanna, with less grass and sparse trees. Maiduguri is located between the Latitude of 11.85 N and Longitude of 13.08 E (Hassan et al., 2017). In a study conducted by Eludoyin et al., (2014) reveals that the mean maximum temperature of the town from 1951 to 2009 was 35.3 ^{O}C. While the mean minimum temperature for the same span of period was 20.1^{O}C. The town has an average temperature and relative humidity of 27.7 and 39.9 respectively. The sunshine hours range from 5.5 hours to 9.0 hours. October to February usually record the longest sunshine hours in the city of Maiduguri. The months for the rainy season are June to September with the annual precipitation ranges from 263mm to 1076mm (Hassan et al., 2017). The University of Maiduguri has a student enrolment of about 30,000 for the 2016/2017 academic session.

Figure 1: Study area at University of Maiduguri (UNIMAID), Borno State;. *(Google map 2019)*

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MATERIALS AND METHODS

The research work was mainly field measurements where by meteorological data were collected on-site using HOBO UX100-011 data loggers. Two microclimate parameters of the UNIMAID campus outdoor were measured for 21 days during summer, from 28th September to the 19th of October 2018. The parameters measured are air temperature, and relative humidity. The data loggers were placed at the height of 1.5m above the ground (Evola et al., 2017) to capture the climate parameters at the pedestrian level (Ghaffarianhoseini et al., 2019). Before the commencement of the actual measurement, a 10days pretest measurement was conducted for the climatic condition parameter. It was carried out to ensure the functionality and reliability of the data loggers. All the data loggers were set to commence capturing at 8:00hrs on the first day. Data logger points were selected for the on-site measurements as; location without vegetation (Fig. 2a), location with grasses only (Fig. 2c), location with trees only (Fig. 2b), and location with both trees and grass (Fig. 2d). The four different data loggers 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. The measurements were simultaneously taken for all the 4 locations. It was devised to record all the possible outcomes for the climatic parameters as influenced by different existing vegetation situations. The captured air temperature and relative humidity data were exported from the HOBO UX100-011 data loggers to a computer system for onward analysis.


(a) Location with no vegetation


(b) Location with trees only

(c) Location with grass only

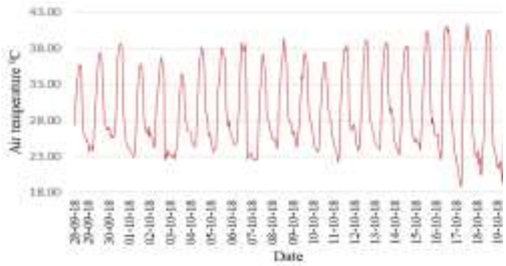
(d) Location with trees & grass

Figure 2: Position of Hobo data Loggers at four different strategic locations

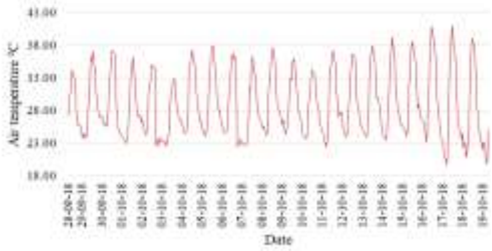
RESULTS

Air temperature

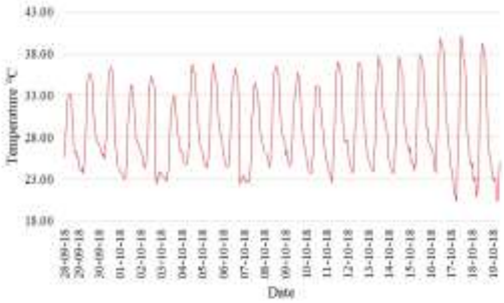
The locations with no vegetation [$T_{a\ (no\ veg.)}$] and that with grass only [$T_{a(grass)}$], recorded their highest air temperature of 41.43°C and 40.90°C respectively on the 18th September 2018. Equally, the two locations recorded the minimum air temperature of 18.75°C and 19.63°C on 17th of September 2018 respectively. The location with no vegetation has an average $T_{a\ (no\ veg.)}$ of 29.27°C (Figure 5). Also, the location with grass only has an average $T_{a(grass)}$ of 28.98°C for the entire 21 measurement days. In like manner, the area with trees only has recorded $T_{a(trees)}$ of 40.13°C and 20.32°C on the 18th September 2018 as its maximum and minimum value respectively (see Figure 3b). The location has an average $T_{a(trees)}$ of 28.99°C for the 21 measurement days. Lastly, the location with both trees and grass has recorded $T_{a\ (trees\ \&\ grass)}$ of 38.46°C on the 17th September 2018 as its maximum value. The lowest $T_{a\ (trees\ \&\ grass)}$ of 19.80°C at 06:00 hours occurred on the same day (see Figure 3d). The location has an average $T_{a\ (trees\ \&\ grass)}$ of 28.75°C (see Figure 5). The place with no vegetation recorded the highest air temperature for all the measurement days.



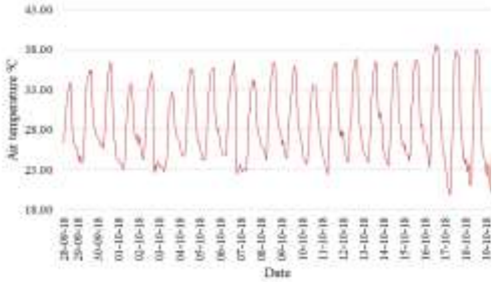
(a) Location with no vegetation [$T_{a\,(no\ veg.)}$]



(b) Location with trees only [$T_{a(trees)}$]



(c) Location with grass only [$T_{a(grass)}$]



(d) Location with trees & grass [$T_{a\,(trees\ \&\ grass)}$]

Figure 3: Daily changes for air temperature for the 21 measurement days from the 28th September 2018 to 19th of October 2018

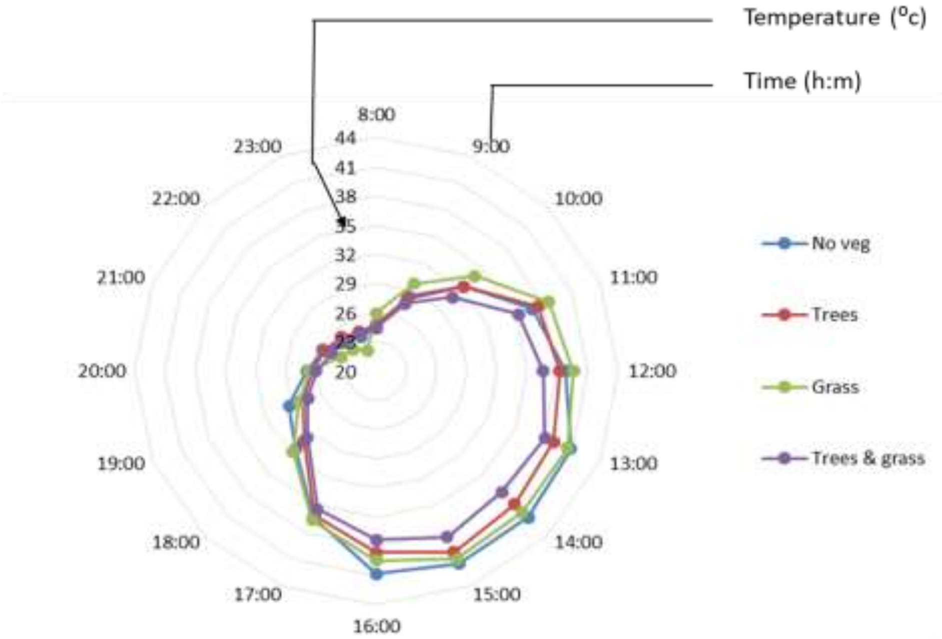


Figure 4: Hourly air temperature reduction for four measurement locations with regards to vegetation scenarios on 18th October 2018 (day with the highest air temp.)

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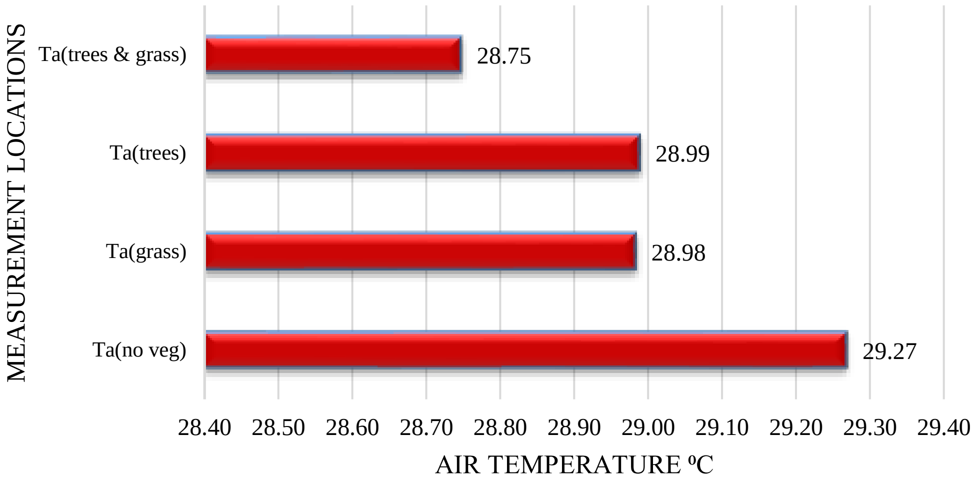
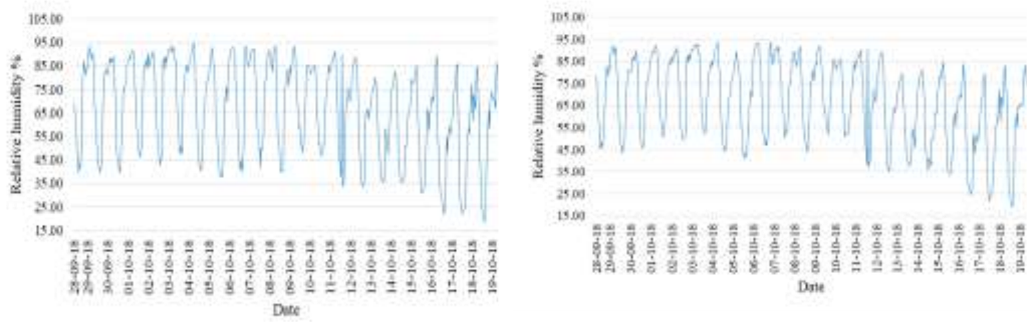


Figure 5: Average air temperature for the 21 measurement days

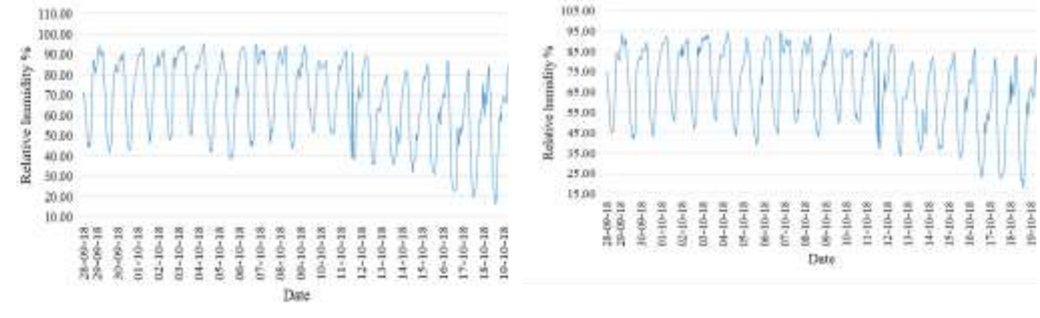
Relative Humidity

The data for the relative humidity were collected from four different locations on the campus outdoor. All the four measurement locations were termed based on the vegetation configuration at the particular point. The observed relative humidity at locations without vegetation, with grass only, with trees only, and location with both trees and grass are recorded as $RH_{(no\ veg.)}$, $RH_{(grass)}$, $RH_{(trees)}$, and $RH_{(trees\ \&\ grass)}$, respectively.

The location without vegetation recorded $RH_{(no\ veg.)}$ of greater than 90% in several days, especially during the first 11days. The location possessed its maximum relative humidity of 94.97% on the 4th of September 2018. The lowest value of the $RH_{(no\ veg.)}$ was 18.67%, which occurred on the summer day of the 18th of September 2018 (see Figure 6a). The location has an average relative humidity of 66.49% for the 21 measurement days (see Figure 8). In the same vein, the receptor at the location with grass only recorded $RH_{(grass)}$ of 95.26% as the maximum value during the measurement period. The maximum value of the relative humidity was recorded on the 7th of September 2018 (see Figure 6c). The location possessed its lowest value of 16.19% on the 18th of September 2018. The location also has an average relative humidity value of 67.06% for the 21 measurement days (see Figure 8).



(a) Location with no vegetation (b) Location with trees only



(c) Location with grass only (d) Location with trees & grass

Figure 6: Daily changes for relative humidity for the 21 measurement days from the 28th September 2018 to 19th of October 2018

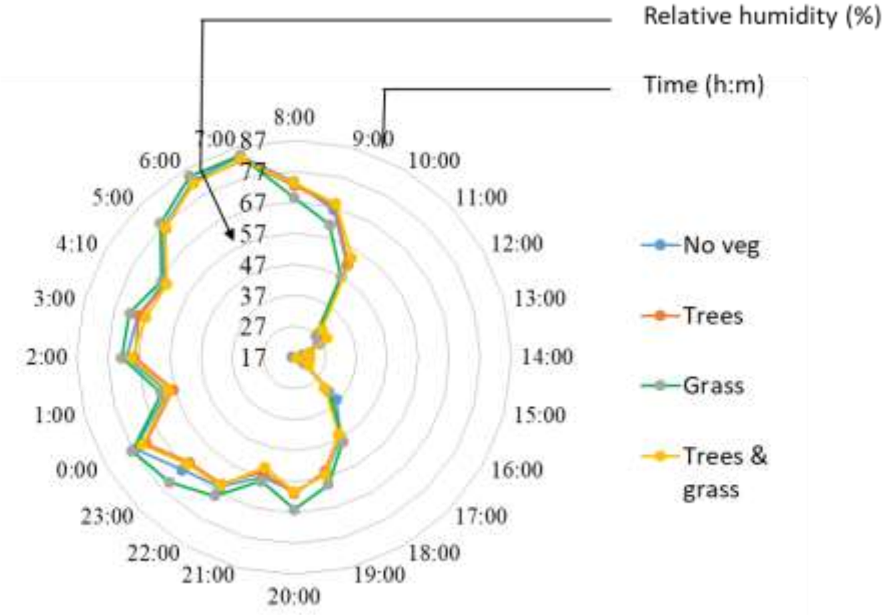


Figure 7: Hourly relative humidity reduction for four measurement locations with regards to vegetation scenarios on 18th October 2018 (day with the highest air temp.)

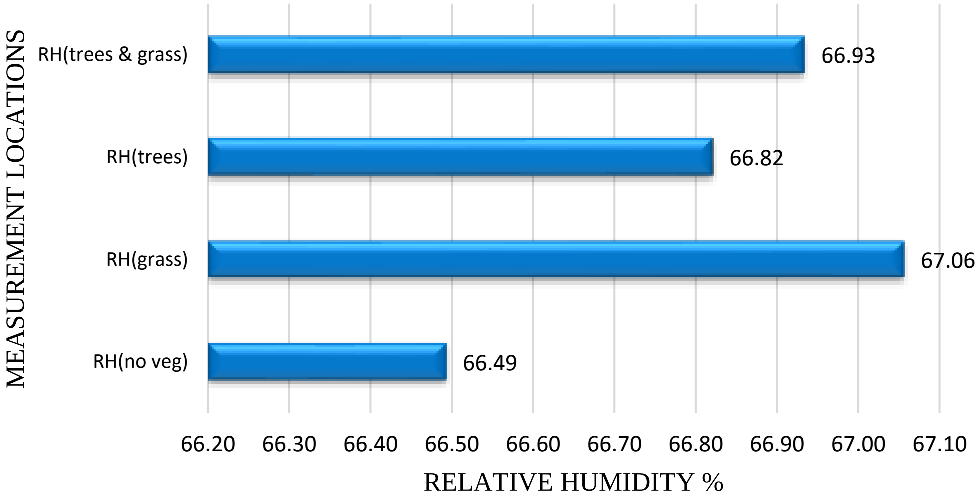


Figure 8: Mean, observed relative humidity for the 21 measurement days

The data logger at the area with trees only recorded $RH_{(trees)}$ of 93.75% as its maximum value within the 21 measurement days. The maximum value of the $RH_{(trees)}$ emanated on the 7th of September 2018 as the later location. The lowest $RH_{(trees)}$ of 18.90% occurred on the 18th of September 2018 (see Figure 6b). Equally, the location has an average value of 66.82% for the 21 measurement days (see Figure 8). The location where by trees and grass are combined, differs from other measurement locations in terms of the relative humidity levels. The data logger recorded $RH_{(trees\ \&\ grass)}$ of 94.68% as the maximum. The maximum value of the $RH_{(trees\ \&\ grass)}$ was recorded on the 7th of September 2018. The lowest $RH_{(trees\ \&\ grass)}$ of 17.69% occurred on the 18th of September 2018 (see Figure 6c). The location has an average of 66.93% for the 21 measurement days (see Figure 8). The relative humidity was slightly lower than the location with no vegetation in terms of its maximum value. Hence, higher than it in terms of the average value.

Discussion

Air temperature

There is a strong negative correlation between canopy coverage and air temperature. Equally, the results were consistent with the study by Xu et al., (2020), who found the coefficient of correlation "R" for the two parameters to be -0.779 to -0.923. The study showed that the higher the vegetation coverage, the higher the evapotranspiration rate, the lower the intensity of the air temperature. From the results, the location without vegetation has the highest levels of daily maximum and the total average air temperature (see Figures 4 and 5). While the location with the combination of trees and grass has the lowest of both the hourly and the total average air temperature. The difference between the two measurement locations regarding the daily maximum and total average was 2.36°C and 0.52°C, respectively (see Figures 4 and 5). The differences were a result of the combined effects of the evapotranspiration and shading of the vegetation present. The finding of this onsite measurement is partially in line with a recent study by Davtalab et al., (2020). The study recorded a difference in the average air temperature of 1°C between the stations with vegetation to stations without vegetation. Because both studies were conducted in hot and dry climates, the slight difference might have been due to the differences in the canopy coverage and the anthropogenic condition of the two contexts.

The onsite measurements suggest that all three locations with different vegetation configurations reduce the air temperature to certain levels. The reduction depends on the canopy coverage and its structures. As indicated by the onsite measurement results for UNIMAID, the findings opposed those of Hsieh et al., (2016) who suggested that not all of the vegetated areas lowered urban air temperature. The negation was a result of contextual differences. However, in the context of this study, it has been identified that the location with trees and grass slightly possessed the highest daily minimum air temperature. Usually, higher than the remaining three measurement locations with less or no vegetation at all. The slight increase in the daily minimum air temperature resulted from the reduction in evapotranspiration rate and the absence of solar radiation at night time.

Relative Humidity

The location with no vegetation possessed the highest daily maximum relative humidity values in all the measurement days, as shown in Figures

6. While the location with the combination of both trees and grass has the minimum daily values (Figure 6d). Similarly, the location with 0% vegetation recorded the minimum average value of the parameter as shown in Figure 8. It has been identified that the daily maximum relative humidity for all the measurement locations was above 80%. The relative humidity percentage was calculated for the 21 measurement days, except for the 13th day of September 2021, which was less than 80%. The high levels of relative humidity were a result of the frequent precipitation during the measurement period. The 13th day of September 2018, which possessed a relative humidity value of less than 80.00%, was observed to be a clear day with no precipitation. The results showed that the relative humidity was at its peak percentage. The result is consistent with Eludoyin et al., (2014), who found that relative humidity starts to increase from April and reaches its peak in August and September.

Generally, the study area recorded a mean relative humidity of 66.83%, which almost doubled from the measurement results by Oyenike Mary Eludoyin, (2014), who found 39.90% as the average. The disagreement arose due to differences in the duration of data collection and daily effective collection hours. Additionally, the results reveals that grass provides microclimates with a higher percentage of relative humidity than tree foliage and canopies (see Figures 7 and 8). The locations with grass only have a significant influence in maintaining a higher level of relative humidity than places without any vegetation, as shown in Figure 8

Conclusion

Vegetation plays a significant role in improving the thermal condition of both indoor and outdoor environments. Trees and grass significantly affect microclimate thermal environments of campuses. They lower the intensity of air temperature and increase the levels of relative humidity. Those effects are dependent on the conditions of the vegetation. Fewer and sparse greens characterized campuses in hot and dry climate regions especially Savannahs where University of Maiduguri (UNIMAID) is located. The less coverage of the greens affects the climatic conditions of the campuses. The UNIMAID and possibly other university campuses located at the Sahel Savannah have slightly higher temperatures than those outside the region due to their differences in geographical locations. Based on this study, combining both trees and grasses in campus outdoors significantly improves the thermal condition of the microclimate. Evidently, combining both trees and grasses reduced the ambient temperature to about 2.97^{0}C in the daytime. Based on the results, the study suggests more vegetation cover that includes both trees and grasses, most especially at areas where students spend most of their day time. Examples of those places are academic areas.

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