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Analysis and Modeling of Physiologic Equivalent Temperature of an Outdoor Environment

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Abstract

This study developed a model that depicts the relationship, strength, and direction of the causality between the predictor variables (microclimatic variables) and a response variable (ambient temperature) interpreted for the physiologic equivalent temperature of an environment. Data collected were microclimatic variables which include air circulation, relative humidity, mean radiant and ambient temperatures over land cover materials namely tarmac, grass, soil and concrete at the premises of Federal University Wukari, Taraba state of Nigeria at a guided height of 1.1 m. The data was collected using physical measurements with respect to time of the day; morning (8:00 – 9:00 am), afternoon (1:00 – 2:00 pm) and evening (6:00 – 7:00 pm) and season of the year; dry (November – March) and wet (April – October) from April 2016 to March 2017. Comparative analysis of the data obtained from the survey and that of the developed model gave percentage variation range of 0.5 – 6.8%. However, in both cases there is an association between the microclimatic variables and the ambient temperature on each of the considered materials, season and measurement intervals. The ranges of the physiological equivalent temperature for different grades of thermal sensation and physiological stress on the land cover materials in this study was 30.2 – 43.3 °C which of intense thermal range. The physiologic equivalent temperature analysis for the land cover materials showed that there was variation in the mean radiant temperature with intense thermal effect in season and measurement intervals. This study depicted that combined use of several land cover materials in a particular area has impact on the mean radiant temperature. This necessitate that the design of the land surface environment should be with due consideration to the convective heat exchange between the outdoor workers and the ambient environment for their thermal comfort and occupational heat stress.

Keywords: Land surface materials; Relative humidity; Air circulation; Mean radiant temperature; Season; Physiologic Equivalent Temperature (PET)

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Introduction

The peculiarity of lands cover design impact on the urban mean radiant temperature emanates from combined effect of several land cover materials used in a particular area [1]. Evaluation of the effect of changes in the prevailing climatic conditions on the temperature range deals with the adaptive features to the local climates. Climatic conditions of the outdoor space and the consequential effect on outdoor workers, basically for daytime works, witnesses a range of thermal sensation and physiologic stress from the combined effects of the solar radiation temperature, mean radiant temperature, relative humidity and air circulation issues of the environment. The key variable that governs human energy balance and thus affects the outdoor thermal sensation and physiological stress under sunny conditions is the mean radiant temperature [2–4]. Mean radiant temperatures of land surfaces are largely affected by the thermodynamic properties of the type of material used on the surface, which incorporates surface moisture, thermal absorption, and emission, radiation reflected and atmosphere [5–6]. The thermal capacities of various materials respond differently to incident solar radiation. Previous studies have shown that land mean-radiant temperatures are a factor of the different land cover appearances mostly caused by the differences in physical and biochemical properties of the land cover [7–8]. The improper dissipation of heat energy to the surrounding environment as a result of the alteration of the natural land surface with different kinds of land surface materials changes the temperature trends by increasing the sensible heat instead of the latent heat. The sensible heat flow rate intensity is often affected by the temperature differential of a particular land surface type and the air above it which translates to the observed environmental heat or ambient temperature.

The ambient temperature is an important microclimatic factor of the environment which influences human thermal sensation and physiological stress. The physiological equivalent temperature takes care of the human body skin and core temperature balance with the air temperature under the complicated outdoor conditions. The physiologic equivalent temperature (PET) represents the heat balance thermal index for the thermal assessment of a given environment [2]. The demonstration of physiological equivalent temperature as an energy-balance model based on the Munich Energy Balance Model for individuals account for the body heat regulation processes such as constrictions and dilation of peripheral blood vessels. The physiological heat strain experienced by an individual is expected to be related to the total heat stress to which he is exposed, serving the need to maintain the body-core temperature within a relatively narrow range of temperatures as the environmental heat stress and the correlate thermal sensation [9]. Wei [10] and Emmanuel [11] studies recognized that usage of impervious land surfaces intensifies environmental harshness and the PET as such suggested ways around them to reduce the intensity.

The adaptation behavior of human is often depicted in the primary responds of the human body to the change of the environment temperature. Of course, the variation in the temperature should be within the neutral physiological equivalent temperature range for comfort conditions. Fanger [12] study has shown that the convective heat loss of the human body and its heat loss through dry respiration decreases with increasing ambient temperature. Studies have been conducted in many fields of studies with the aim of establishing temperature range for thermal comfort regarding PET ranges intended for different grades of thermal sensation and physiological stress in different outdoor spaces and in different seasons across different geographical and climatic zones. These studies effectively demonstrated the associated impact of outdoor climatic conditions and thermal adaptation factors [13–14] on thermal sensation of people as well as the use of outdoor spaces [15]. Subjective literature review of outdoor comfort studies carried out in different climatic zones vividly explain the physiological equivalent temperature ranges for thermal comfort and adaptation ability of the people due to the variation of the climatic condition prevailing in various areas [16]. Many studies have applied PET in thermal sensation assessment [15, 17–21], in that the nation of Germany has adopted it as a guide for her urban development planning [22]. Supplementary material (SM) 1 shows the summary of authors and physiological equivalent temperature ranges obtained with respect to the prevailing climatic condition of the climatic zone of the area considered.

Despite individual's levels of tolerance to heat which are dependent on temperature, humidity, wind speed and type of work, the goal of heat stress monitoring over a range of temperature is basically to ensure that workers' deep body temperatures do not exceed 38°C. Frequent exposure to intense heat or high temperature for prolonged periods may induce greater occupational heat stress which potentially leads to more cases of fatigue, chemical tolerance, and heat-related illnesses such as heat stroke and heat exhaustion [33–35]. Among all outdoor works at risk of occupational exposure to heat and hot environments, worker compensation claims for heat illness experienced by outdoor workers are among the highest of any occupation [36]. There seems to be none publicly made available and accessible in Nigeria as Google search did not return any of information that depicted the impact that combined use of several land cover materials in a particular area has ambient temperature of the environment. This study tends to bridge the gap as the document from this study will give the environmental microclimatic effect of land cover materials has on the physiologic environment temperature on the environment. With due consideration to the outdoor modification using different land cover materials for ecstasy at large in urban centers for streets, sidewalks and parking lots, this study a developed model that depicts the relationship, strength, and direction of the causality between the predictor variables and a response variable interpreted for physiologic equivalent temperature of an environment.

Methodology

The procedure involved in the collection and analysis data for this study is presented in Figure 1.

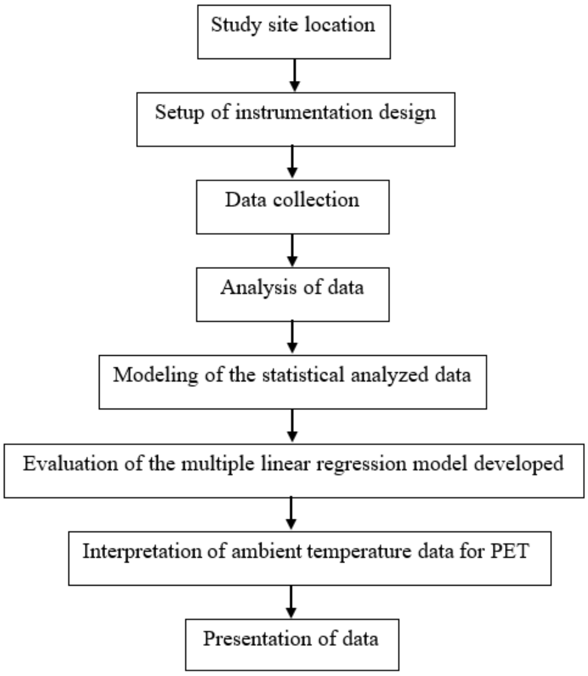

Figure 1 Methodology flowchart.

1) Area of the study

Wukari is one of the 16 local government areas (LGA) of Taraba state in the North Eastern part of Nigeria located on the coordinates of latitude 7°51′N to 7°85′N and longitude 9°46′E to 9°78′E with a population of 238,283 people made up of 124,285 males (52.2%) and 113,998 females (42.7%) at the 2006 National Population Census projected to be 318,400 people at 2016 by the National population commission of Nigeria with annual growth rate of 2.6% [37]. Wukari covers a land mass of area 4,308 km² with a very high population density of 73.91 people per km² bounded by Donga local government area to the East, Nasarawa State and Ibi local government area to the West, Benue State to the South, and Gassol local government area to the North. Wukari LGA is made up of 10 political wards and 8 districts. The headquarters of the Wukari LGA is situated in Wukari town in the southern part of Taraba state (Figure 2).

Figure 2 Map of Nigeria and Taraba state showing Wukari Local Government Area.

The town hosts the Federal University Wukari which is the study site location for this study. Wukari is on the elevation of 189 m above sea level. Wukari has a tropical climate characterized by savannah guinea and rainforest vegetation distribution [38]. The two climate seasons exhibited in the area set out with the wet season from April through to October (seven months) and then the dry season a period of five months from November – March [39]. The mean annual temperature and annual rainfall ranges are between 28 – 35 °C and 90 – 1400 mm respectively [40].

2) Research instruments used

The data collection was basically using objective research approach which was done through physical measurement. The physical measurement gave the quantitative information of the microclimatic parameters over the considered land cover materials in this study. The instrumentation used for the microclimatic parameters data collection above the assessed land surfaces in this study is as follows:

A) Digital anemometer of model GM816 (Shenzhen XRC Electronics Co., Ltd. Mainland China). This was used in air circulation measurement above the land surfaces (Figure 3a)

B) Mean radiant temperatures were measured using Dual laser digital infrared thermometers HT-819 (Yincali Instruments Store China) (Figure 3b)

C) Digital LCD thermometer hygrometer (At finger technology Co., Ltd China (Fujian) was engaged in determining the ambient temperatures and relative humidity (Figure 3c)

Figure 3 Instrumentation used for the microclimatic parameters data collection; (a) digital anemometer; (b) digital infrared thermometers; and (c) digital LCD thermometer hygrometer.

3) Collection of data

The data for this study were collected using physical measurements with respect to times of the day; morning (8:00 – 9:00 am), afternoon (1:00 – 2:00 pm) and evening (6:00 – 7:00 pm) and seasons; dry (November – March) and wet (April – October). The physical measurements and recording of the microclimatic variable was carried out within 5 – 10 min after the data collection instrumentation was set up and subsequently measured at the intervals of 5 min over each of the land cover materials giving a total of 3 reading per evaluation point. The daily time interval (morning, afternoon, and evening) selected for assessment covered the daily environmental microclimatic variation for time series interval over varied length of outdoor work duration. These were microclimatic variables such as air circulation, relative humidity, mean-radiant and ambient temperatures of land cover materials namely tarmac, grass, soil and concrete at the premises of Federal University Wukari, Taraba state of Nigeria at a guided height of 1.1 m being an average center of gravity height of an adult [2, 10]. These lands cover materials according studies are characteristically used rural, suburban and urban centers to replace field, farm and forest area on a daily basis [41–45]. The data collection duration was for a period of one year which began from April 2016 through to March 2017. The data was collected on a daily basis besides weekends (Saturdays and Sundays) and raining days. The total number of days for the data collection was 241 d; covering wet season 132 d and dry season 109 d.

4) Analysis of the obtained data from physical measurement

The data collected for this study were analyzed with the use of SPSS version 16.0 and Microsoft Office Excel version 2007 software. The relationship (regression analyses), strength (cointegration analyses) and direction of the causality (causality test) between the dependent and independent variables carried out using SPSS version 16.0 software. The two regression analyses used in the model development were multiple linear regression (MLR) and Analysis of variance (ANOVA). The multiple linear regression model predicts the effect of variation of the predictor variables (mean radiant temperature, measurement intervals, season, material, air circulation, relative humidity) and a response variable (ambient temperature). ANOVA and response ambient air temperatures above the four surface materials were conducted using SPSS software version 16.0. The model was obtained for the ambient air temperatures (responses), where factors were rejected when their significance level was less than $p < 0.01$, confidence limit 99%. The statistical parameters used for the model fitting in a linear equation order to observed data include multiple correlation coefficient (R^2), adjusted multiple correlation coefficient (adjusted R^2), and regression (P-value and F-value). This equation generated establish a correlation between the significant terms obtained from ANOVA analysis, namely, the season of the year, land surface material, measurement intervals, relative humidity, air circulation, mean radiant temperature and their interactions which describes the interaction among the parameters influencing the ambient temperature. The resultant ambient temperature (T_{amb}) was a standard multiple linear regression model equation [46] as shown in Eq. 1.

5) Evaluation of the MLR model developed

The MLR model developed was tested and verified using the microclimatic variables and the ambient temperature obtained by physical measurement data obtained from a different set up point in the study site. These were not included in the statistical analysis used for the model development. The values of the ambient temperatures for the measurement intervals and the seasons were determined. The results obtained were compared to values of the ambient temperature obtained from the physical measurement.

6) Interpretation of ambient temperature for PET

The relationship between the convective heat exchange and the ambient environment for an individual's thermal comfort and occupational heat stress is important as the raw data obtained from the field work or the MLR model can be best understood in its application. The effect of the environmental air temperature which influences human skin and core temperature regarding physiological responses the land surface material was interpreted. The ranges of the PET for different grades of thermal sensation and physiological stress on the land surface were interpreted using Matzarakis and Mayer [47] guide in Table 1. PET was used for the thermal sensation and physiological stress on the land surface analysis in this study because it was developed based on energy-balance model for an individual which independent on clothing and activity. It however covers a set standard effective temperature on mean temperature range values of temperatures other than monthly mean useful to explicitly evaluate the outdoor environment in terms of indoor standards [10, 48] The ambient temperature output values of the MLR model in this study was compared with the established PET ranges for different grades of thermal sensation and physiological stress for the outdoor environment thermal comfort and occupational heat stress interpretation. The corresponding the ambient temperature value with the different grades of thermal sensation and physiological stress was noted and recorded.

Table 1 Ranges of the PET for different grades of thermal sensation and physiological stress

PET	Thermal perception	Grade of physiological stress
	Very cold	Extreme cold stress
4°C	Cold	Strong cold stress
8°C	Cool	Moderate cold stress
13°C	Slightly cold	Slightly cold stress
18°C	Comfortable	No thermal stress
23°C	Slightly warm	Slightly heat stress
29°C	Warm	Moderate heat stress
35°C	Hot	Strong heat stress
41°C	Very hot	Extreme heat stress

Source: Matzarakis and Mayer [47]

$$T_{amb} = \gamma + \gamma_1 X_{cir} + \gamma_2 X_{surT} + \gamma_3 X_{ss} + \gamma_4 X_{minter} + \gamma_5 X_{rh} + \gamma_6 X_{mat} \quad \text{(Eq. 1)}$$

Where: γ, $\gamma 1$, $\gamma 2$, $\gamma 3$, $\gamma 4$, $\gamma 5$ and $\gamma 6$ are coefficients of predictor variables, air circulation, mean radiant temperature, season, parameters, measurement interval, material and relative humidity respectively. X_{cir}, X_{surT}, X_{ss}, X_{minter}, X_{mat} and X_{rh} are the linear coefficients for air circulation, mean radiant temperature, season, parameters, measurement interval, material and relative humidity respectively.

Results and discussions

1) The descriptive statistics of microclimatic parameters in the study site location

Table 2 shows the descriptive statistics of microclimatic parameters in the study site location. From Table 2 it was found that the mean radiant and ambient temperatures on tarmac material were highest for the seasons and measurement intervals. This was followed by concrete surfaces. Tarmac and concrete are characteristically impervious materials which have a low possibility of cooling effect by evaporation which makes them warmer compared grass and soil. This observation is similar to Weng [49], Xiao et al. [1], and Hart and Sailor [50] who considered related materials. The relative humidity of the across the four materials (tarmac, grass, concrete, and land) showed that the water in the atmosphere during the wet season is much higher than that during the dry season, a similar observation was made for the air circulation.

2) Analysis of variance for dependent variable (ambient temperature)

ANOVA test was used to identify the effect of individual factors and linear order interactions. Results from the analysis of variance highlight the statistical significance of each effect given by comparing the mean square against an estimate of the experimental error. The six parameters (season, material, measurement intervals, relative humidity, air circulation, and mean radiant temperature) considered had p-values less than 0.01, indicating that they are significantly different from zero at the 99% confidence level (Table 3).

The effect of the microclimatic parameters; mean radiant temperatures, air circulation, and relative humidity on the average ambient temperature of an environment with respect to the relationship, strength, and direction of the causality between the predictor variables and a response variable multiple linear regression analysis is employed. The R and R^2 values which represents the simple correlation and total variation of the dependent variable (ambient temperature), through the season of the year has 0.913 chances that the predators will affect ambient temperature (Table 4).

The ambient temperature value versus the unstandardized predicted value of the predator variables graph plotted was used to ascertain if the MLR model in this study satisfactory fit to the data. The graph in Figure 4 shows that the line of best fit approximately evenly split plotted data points. The analysis showed that the predator variable in this model is suitable for predicting the ambient temperature value of the environment over the land cover materials.

Table 2 Descriptive of the response variable and predators across the measurement time intervals and season

MI	MP	Wet season				Dry season			
		Impervious		Pervious		Impervious		Pervious	
		Tarmac	Concrete	Grass	Soil	Tarmac	Concrete	Grass	Soil
Morning	RH	75.3	76	76.1	75.6	51.7	51.8	51.5	52.3
	T_{surT}	34.4	29.4	26.2	27.8	33.9	32.3	32	32.1
	T_{amb}	30.3	30.2	30.2	30.2	32.9	32.6	32.5	32.3
	A_{cir}	2.6	2.3	2.2	2.5	2.7	2.8	2.6	2.7
Afternoon	RH	43.3	44	47.9	46.3	29	29.1	29.8	29.6
	T_{surT}	51.6	43.2	32.9	42.6	52.6	47.2	44	50.3
	T_{amb}	39.8	39.5	39.4	39.1	43.3	42.6	42.6	42.6
	A_{cir}	3	2.8	2.7	2.7	3.3	3.3	3.1	3.3
Evening	RH	61.2	61.7	62.7	62.3	40.7	41.2	41.3	41.3
	T_{surT}	36.9	33.2	27.7	29.4	39.2	37.6	33	34
	T_{amb}	32.7	32.5	32.3	32.6	34.9	34.8	34.7	34.7
	A_{cir}	1.5	1.3	1.1	1.2	0.7	0.8	0.7	0.9

Note: RH = Relative humidity (%), T_{surT} = Mean radiant temperature (°C), T_{amb} = Ambient temperature (°C), A_{cir} = Air circulation (m/s), MP = Microclimatic parameters, MI = Measurement interval.

Table 3 Analysis of variance for dependent variable (ambient temperature)

Tests of between-subjects effects					
Dependent variable: Ambient temperature					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F**	**p-value**
Corrected Model	62,237.779[a]	466	133.557	83.381	< 0.01
Intercept	343,756.662	1	343,756.662	2.147	< 0.01
Season	81.183	1	81.183	50.683	< 0.01
Material	225.397	3	75.132	46.906	< 0.01
MI	1,122.425	2	561.213	350.371	< 0.01
RH	3,805.983	64	59.468	37.127	< 0.01
A_{cir}	628.757	59	10.657	6.653	< 0.01
T_{surT}	1160.830	337	3.445	2.150	< 0.01
Error	3884.290	2425	1.602		
Total	3661007.444	2892			
Corrected Total	66122.069	2891			
a. R Squared = 0.941 (Adjusted R Squared = 0.930)					

Note: RH= Relative humidity (%), T_{surT} = Mean radiant temperature (°C), T_{amb} = Ambient temperature (°C), A_{cir} = Air circulation (m/s), MP = Microclimatic parameters, MI = Measurement interval, Df = the number of degrees of freedom, F = the ratio of variance group means to the mean within group variances used to decide whether to accept or reject the null hypothesis.

Table 4 Correlation between ambient temperature and the predator variables (unstandardized predicted value)

No of unstandardized predicted value	Ambient temperature	*r*-value	*p*-value
2892	2892	0.913**	0.00

Note: ** Correlation is significant at the 0.01 level (2-tailed).

Lee and Wang [51] and Zaibunnisa et al. [52] stated that a better empirical model fit is usually obtained with the experimental data when the R^2 value is close to unity. In this study R^2 value obtained was 0.941. It was observed that a relatively high R^2 value does not imply that the model is adequate, thus, Koocheki et al. [53] suggested that an R^2adj of above 90% is most appropriate to evaluate the model adequacy. Consequently, the adjusted R^2value obtained was 0.930.

The model in Eq. 2 gives the relationship between the predictor variable and a response variable by fitting a linear equation to observed data. Regression equation thus generated establishes a correlation between the significant terms obtained from ANOVA analysis, namely, mean radiant temperatures, air circulation, relative humidity associated with the materials season of the year and their interactions. The regression equation developed for ambient temperature is shown in Eq. 2.

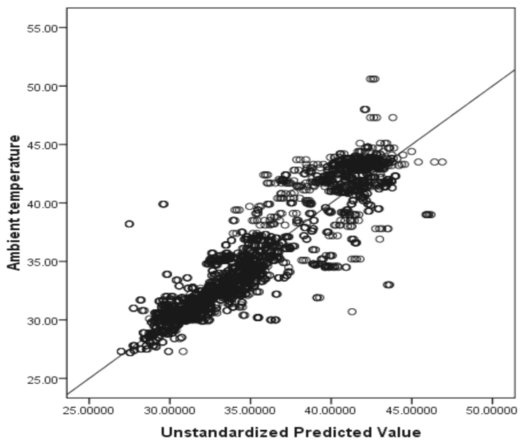

Figure 4 Plot of ambient temperature versus unstandardized predicted value

From Eq. 2, it is observed that the season of the year plays a major role on the ambient temperature of the environment, then the land cover material, followed by air circulation and mean radiant temperature of the various land cover materials assessed the relative humidity and measurement interval. This implies the ambient temperature differential of an environment is important to factor particular of the land surface type within a season. This agrees with Xiao et al. [1] that the anomalies of the urban mean radiant temperature stem from the combined impacts of several lands cover designs or patterns. It can also be inferred from the Eq. 2 that the negative value of the coefficient of the season of the year and relative humidity reveals that increase in the season of the year and relative humidity decreases the ambient temperature. This can be attributed to the water content of the atmosphere, which reduces heat and temperature of the environment, thereby decreasing the ambient temperature. Whereas as the parameters having, positive effects depict that as air circulation and mean radiant temperatures with respect to material and measurement intervals increases the resultant effect is increase on the ambient temperature. Similar observation was made by Emmanuel et al. [54] study who opined that microclimatic parameters characteristics on different land surface material have effect on the ambient temperature. However, all the six independent variables statistically significantly contributed added to the prediction of ambient temperature, $p < .01$ but for the measurement interval (Table 4). This is an indication that the regression model significantly predicted the outcome variable. The significant contribution of the microclimatic properties of the land surface materials in the prediction of ambient temperature showed that thermodynamic properties of the materials which include surface moisture, thermal absorption, and emission, reflected radiation and atmosphere should be considered in the choice of the land cover surfacing as it has been found to affect the mean radiant temperatures of land surfaces.

3) Comparison of survey data and developed model simulations

The occupational heat stress or heat exposure experienced by an outdoor worker in the work environment is a factor of the measurable environmental properties such as ambient air temperature, humidity, air velocity and mean radiant temperature can increase body heat storage. In an attempt to transfer the stored heat back to the environment the body experiences heat strain which is physiological response to the heat stress [55]. The developed model is given in Eq. 2 was tested for real situations and simulations using data in another environment with the premises other than the study site location. The results of the developed model and measured values for the ambient temperatures are present in Table 5 across the four materials, measurement intervals and seasons. The result showed that there was an indication of an association between the predictor variables and the response variable on each of the considered materials, season and measurement intervals with absolute minimum and maximum percentage variation of 0.5 and 6.8% respectively between the developed model and measured value.

$$T_{amb} = 31.330 + 0.347X_{cir} + 0.297X_{surT} - 1.686\ X_{ss} + 0.040X_{minter} + 0.948X_{mat} - 0.149X_{rh} \quad \text{(Eq. 2)}$$

Where; T_{amb} = ambient temperature, 31.330 = a constant, X_{rh} = linear coefficients for relative humidity, X_{surT} = linear coefficients for mean radiant temperature, X_{cir} = linear coefficients for air circulation, X_{minter} = linear coefficients for measurement interval, X_{mat} = linear coefficients for land cover material and X_{ss} = linear coefficients for season

Table 4 The coefficients for the dependent variable (ambient temperature) equation for the MLR model

Model	Unstandardized coefficients		Standardized coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	31.330	0.590		53.080	0.000
Season	-1.686	0.096	-0.175	-17.517	0.000
Material	0.948	0.038	0.222	25.057	0.000
MI	0.040	0.057	0.007	0.694	0.488
RH	-0.149	0.004	-0.544	-38.269	0.000
A_{cir}	0.347	0.034	0.099	10.316	0.000
T_{surT}	0.297	0.007	0.519	40.995	0.000

(Coefficients[a])

Note: [a] dependent variable: T_{amb}

Table 5 Comparison of survey data and developed model simulations over the land surface materials

Land surface material	Measurement interval	Wet			Dry		
		Model result (°C)	Measured value (°C)	Percentage variation (%)	Model result (°C)	Measured value (°C)	Percentage variation (%)
Soil	Morning	30.9	30.4	1.5	35.2	33.4	5.3
	Afternoon	40.3	40.9	-1.2	42.9	42.7	0.6
	Evening	34.1	34.6	-1.1	37.4	36.1	3.5
Grass cover	Morning	31.1	30.3	2.6	36.2	33.8	6.8
	Afternoon	38.8	41.8	-7	42.1	43.3	-2.8
	Evening	33.9	34.2	-0.6	36.9	36.1	2.3
Concrete surface	Morning	30.6	30.3	0.9	33.7	33.3	1
	Afternoon	40.1	41.3	-3	40.5	42.4	-4.5
	Evening	33.7	34.3	-1.5	36.1	36	0.6
Tarmac surface	Morning	31.3	30.2	3.6	33.3	33.4	-0.5
	Afternoon	40.7	39.4	3.8	41	42.7	-3.8
	Evening	34	34.2	-0.5	35.4	36.1	-1.8

The thermal sensation on the different grades of PET indices on the land surfaces assessed and interpreted with respect to measurement interval and the season of the year showed that the higher the ambient temperature the more associated thermal sensation. In this study it was found that physio-logical stress carried out on the different grades of PET indices showed that for the morning and evening measurement intervals with average ranges of 30.2 – 32.9 °C and 32.3 – 34.9 °C the associated grade of thermal sensation was moderate heat stress while for the afternoon session it was 39.1 – 39.8 °C which the range of strong heat stress effect for the wet season and 42.6 – 43.3 °C extreme heat stress for the dry season (SM 2–5). The ranges of physiologic equivalent temperature obtained in this study were higher than a range of 31 – 36 °C [30] obtained in another part of the nation. Modifications of radiation fluxes of an urban environment can result in a variation of mean radiant temperature over a range of more than 30°C which can correspond to three levels of thermal stress. It is expected that for continued normal body function of an individual irrespective of the environment, the deep body temperature should be maintained within a very narrow limit of ± 1°C around the acceptable resting body core temperature of 37°C. To achieve this, body temperature equilibrium requires a constant exchange of heat between the body and the environment since the heat transfer from the human body to the environment reduces as the environment air temperature gets closer to body temperature (37 °C) [9–10]. With an ambient wet-bulb temperature of 35°C the body at rest in a hot or extreme high environment a study found that such body can experience body fluid loss through sweating at the rate of 0.8 to 1.0 liter per hour. And when this is associated with an increase in air movement, it speeds up the rate of evaporation thereby makings the person to feel uncomfortable [10, 56]. The heat balance thermal index for the thermal assessment of a given environment demonstrated in the physiological equivalent temperature and its connection the ambient temperature demands that the factors which affect microclimatic condition of the environment such as land cover surfaces should be essentially planned for a maintained human body skin and core temperature balance.

Conclusions

The challenges associated with thermal sensation and physiological stress are experiences of heat lost from the body which is determined by air temperature, humidity, mean radiant temperature and air circulation, all of which are, to an extent, controllable. This study developed a model that depicts the relationship, strength, and direction of the causality between the predictor variables and a response variable interpreted for the physiologic equivalent temperature of an environment. The four land cover materials categorized as pervious (soil and grass) and impervious (tarmac and concrete) land surfaces found that the mean radiant and ambient temperatures on tarmac material were highest both in seasons and measurement intervals. This was followed by concrete. Tarmac and concrete are characteristically impervious materials which have a low possibility of cooling effect by evaporation which makes them warmer compared grass and soil. A multiple linear regression (MLR) model developed was observed showed that there was an indication of an association between the predictor variables and the response variable on each of the considered materials, season and measurement intervals. However, the season of the year plays a major role on the ambient temperature of the environment, then the land cover material, followed by air circulation and mean radiant temperature of the various land cover materials assessed the relative humidity and measurement interval. The real situations and simulations between the developed model and measured value revealed percentage variation with absolute proportions of 0.5 and 6.8% for minimum and maximum values respecttively. The ranges of the PET for different grades of thermal sensation and physiological stress on the land cover materials were mostly warm sensation and moderate heat stress in the morning and evening sessions while it was hot and strong heat stress in the afternoon of wet seasons. These translated to very hot and extreme heat stress in the afternoon of the dry seasons. This study depicted that combined use of several land cover materials used in a particular area has impact on the mean radiant temperature. The effect of the dependency of the ambient temperature on microclimatic variables such as mean radiant temperatures, air circulation, relative humidity of an environment on the PET of that environment found in this study require that in the design or remodeling of the outdoor natural environment using any kind of land cover material should be with the due consideration to the prevailing outdoor activity in that environment. It therefore becomes necessary further investigation on the effects of microclimatic variables of environment on the ambient temperature be carried out over these land cover materials; tarmac, grass, soil and concrete in dispersed settings.

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