Estimating Black Globe Temperature Based on Meteorological Data

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Abstract. *An automatic weather station, comprising of temperature and humidity sensors, a pyranometer, an anemometer, and a thermocouple inside a black globe, was installed in a grassed area at the University of the State of Bahia - UNEB, Juazeiro County, Bahia State, Brazil. Half of the data collected at this station was used to generate models (simple or multiplicative) for estimating the Black Globe Temperature (BGT). Model performance was evaluated by using the second half of the data. Statistical precision and accuracy indices and statistical errors were used to analyze the collected data and the Student`s t test was used to evaluate the significance of the model parameters. Two models to estimate the BGT using meteorological variables were obtained:* $BGT_d = [1.360\ T_{air\ d} - 2.358]\cdot[0.075\ ln(Rs) - 0.562]$ *and* $BGT_n = [0.942\ T_{air\ n}]$*. One model was elaborated for daytime* BGT_d*), when the air temperature (*$T_{air\ d}$*) and solar radiation (Rs) were combined to generate a multiplicative model (*$R^2 = 0.877$*), and a second model was developed to determine the BGT values for night-time (*BGT_n*) based on the night-time air temperature (*$T_{air\ n}$*) (*$R^2 = 0.962$*). The models developed resulted in great performance to predict the black globe temperature, allowing the estimation of bioclimatic indices to assess the conditions of the environment, to accomplish regional studies, and to indicate best house designs for animals.*

Keywords. *Animal comfort index, Bioclimatic index, Temperature model*

Introduction

Bioclimatic indices have been developed to express the comfort or discomfort of the animals in relation to a specific environment. In 1958, Thom developed the Temperature and Humidity Index (THI).

Similar indices have been applied by many researchers to determinate effects of the environment on animals' feed uptake, reproduction, lactation and production (García-Ispierto et al., 2006; Hahn, 1999; West et al., 2003).

Quayle and Doehring (1981) showed that the THI is not particularly sensitive to small changes regarding to humidity and a disadvantage of this index is the small interval of unfavorable conditions.

According to Bond and Kelly (1955), the animal exposed to radiation can receive higher thermal load than the metabolic heat production. This process can result in a larger discomfort. In such a case, the THI does not seem to reflect the radiant heat load, resulting in failure to predict animal discomfort, and, subsequent, in the estimation of production losses.

Buffington et al. (1981) proposed an index to measure the thermal environment, incorporating the effects of humidity, air velocity, dry-bulb temperature, and radiation data into an index called the Back Globe Temperature and Humidity Index (BGHI). Temperature values are obtained from a sensor inside a copper hollow sphere with 0.05 wall thickness and 15 cm diameter, painted with black ink. Those same authors mentioned that the THI and the BGHI does not present significant differences in animal facilities, however the BGHI is more efficient in that kind of condition.

A disadvantage of the BGHI is the lack of measurements of the black globe temperature (BGT) in weather stations.

Thus, the objective of this work was to propose models for estimating the Black Globe Temperature (BGT) using meteorological data.

Methodology.

The experiment was carried out in a grassed area at the University of Bahia State - UNEB, Juazeiro county, Bahia State, Brazil, where an automatic weather station (AWS) (Campbell Scientific, Logan, Utah, USA) was installed. It consisted of a temperature and humidity sensor, a pyranometer, an anemometer, and a thermocouple inside a black globe. The sensors were connected to a CR10X datalogger that recorded the temperature reading every 60 seconds and stored 30 minutes averages.

Half of the data was used to generate the models for estimating the Black Globe Temperature values (BGT). First, simple correlation was used to identify appropriate independent variables aiming to explain the variability of BGT values and to determine the parameters of each model.

The multiplicative model method proposed by Jarvis (1976) was used in this study. This model allows separating the contribution of each independent variable in the estimation of the BGT which is expressed as follows: BGT = f(x) f(y), where f(x) and f(y) are linear or curvilinear functions.

The independent variables used to fit the simple models and/or the multiplicative model were air temperature and relative humidity, solar radiation, and wind speed, since these meteorological data are more directly related to the thermal comfort or discomfort of the animal.

The performance of the models was evaluated by using the other half of the data not used to generate the models. The BGT models were used to calculate this series data and the results were compared with the observed values.

Statistical precision, accuracy indices and statistical errors were used to analyze the results (Table 1). The Student's t test was used to evaluate the significance of the model and of their parameters.

Table 1. Statistics indexes and errors used to evaluate model performance**.**

Index	Symbol	Equation*	Range	Ideal value
Coefficient of correlation	r	$\dfrac{\left[\sum \mathrm{Pi}\,(\mathrm{Oi} - \overline{\mathrm{Oi}})\right]}{\left[\sum_{n=1}^{n}\left(\mathrm{Oi}-\overline{\mathrm{Oi}}\right)^2 \sum_{n=1}^{n}\left(\mathrm{Pi}-\overline{\mathrm{Pi}}\right)^2\right]^{1/2}}$	≥ -1 and ≤ +1	-1 and +1
Index of agreement	d	$\left[1-\dfrac{\sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{Oi})^2}{\sum_{i=1}^{n}(\lvert\mathrm{Pi}-\overline{\mathrm{Oi}}\rvert+\lvert\mathrm{Oi}-\overline{\mathrm{Oi}}\rvert)^2}\right]^{1/2}$	≥ 0 e ≤ +1	+1
Mean bias error	MBE	$\dfrac{1}{n}\sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{Oi})$	> 0 e ≤ 0	0
Root mean square error	RMSE	$\left[\dfrac{1}{n}\sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{Oi})^2\right]^{1/2}$	≥ 0	0

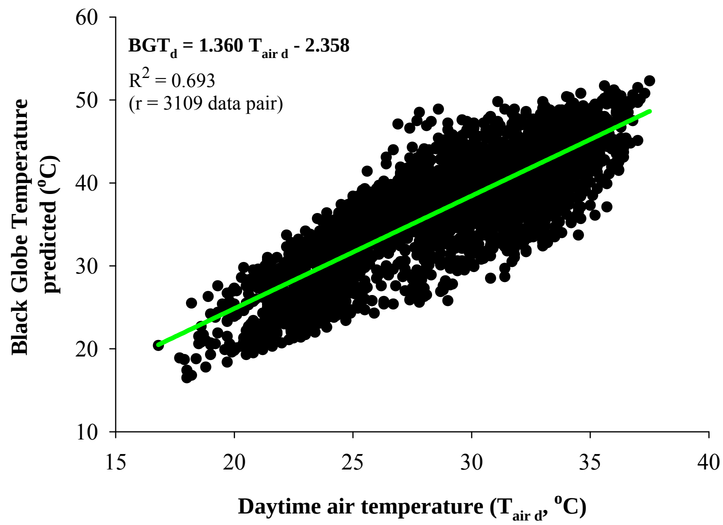
* Pi = value predicted by the model; Oi = value observed; $\overline{\mathrm{Pi}}$ = mean of value predicted; $\overline{\mathrm{Oi}}$ = mean of values observed; and n = number of data pairs.

Results and Discussion

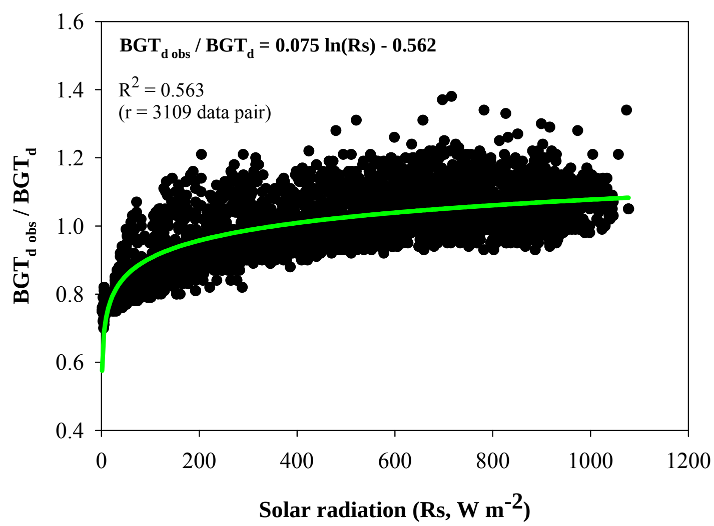
Two models were developed to estimate the BGT by using meteorological variables. One model was elaborated for daytime, when the air temperature ($T_{air\ d}$) and solar radiation (Rs) provided the best fit to explain the BGT_d values variability.

The $T_{air\ d}$ values presented the best correlation with the BGT_d values. The function that had the best fit was a linear equation (R^2 = 0.6928) (Figure 1A).

The variability of BGT_d ($T_{air\ d}$) not explained by the $T_{air\ d}$ was studied by the ratio between $BGT_{d\ obs}$ and estimated by the function. The results have been correlated with solar radiation (Rs) data. This relationship was a logarithmic function that is shown in Figure 1B.



(A)



(B)

Figure 1. A) Correlation between daytime black globe temperature (BGT_d) and air temperature ($T_{air\ d}$), and B) Correlation between daytime black globe temperature (BGT_d) and solar radiation (Rs).

The functions shower on Figures 1A and 1B were combined to generate a multiplicative model (R^2 = 0.877) that explained a great part of the black globe temperature measured at the weather station for the daytime period (Figure 2).

The evaluation of this model is shown in Figure 3. The correlation (r) and agreement (d) indices were equal to 0.910 and 0.951, respectively, showing great accuracy and performance of the model in estimating the BGT_d values for the daytime period. The errors (MBE and RMSE) were 2.617°C and 0.150°C, indicating mean error for a specific time and overestimation of the results of the model, respectively. The multiplicative model and its parameters were significant according to the Student's t test.

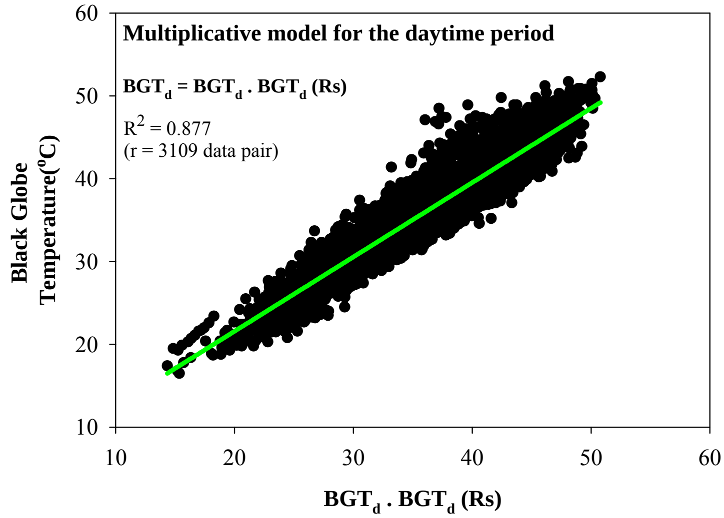


Figure 2. Multiplicative model for estimating black globe temperature for the daytime period (BGT_d).

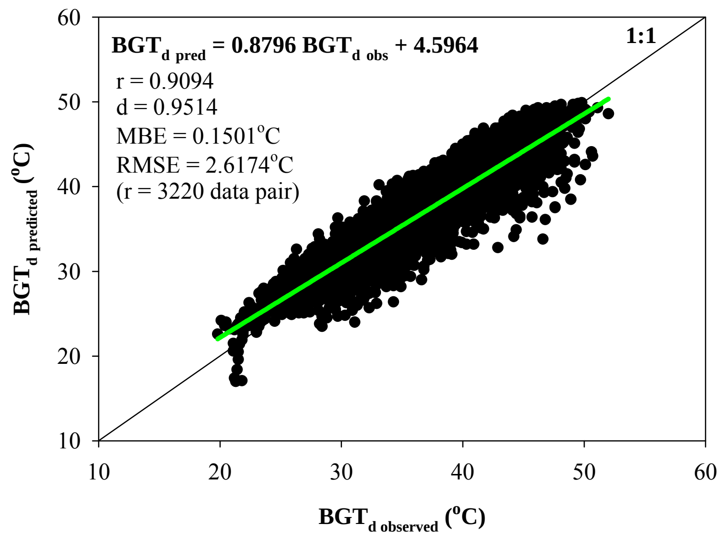


Figure 3. Evaluation of the model's performance for estimating the black globe temperature for the daytime period (BGT_d).

The second model was developed to determine the values of BGT for the night-time period. It was verified that the night-time air temperatures ($T_{air\ n}$) explained the night-time black globe temperature (BGT_n) variability. Figure 4 illustrates the relationship between the values of BGT_n and $T_{air\ n}$. The function was linear and the coefficient of determination was equal to 0.962.

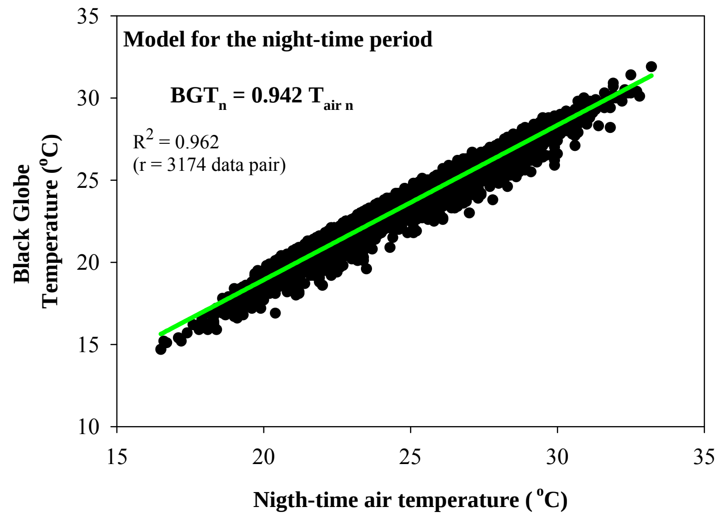


Figure 4. Model for estimating the black globe temperature for the night-time period (BGT_n).

In the evaluation of this model, the values of r and d were 0.977 and 0.986, respectively (Figure 5). It demonstrates a good performance as it was observed in the model for the daytime period. The error of estimation of the night-time black globe temperature was 0.5663^{o}C (RME) and the average of the observed black globe temperature ($BGT_{n\ obs}$) underestimated the average of the predicted black globe temperature ($BGT_{n\ pred}$) by -0.238^{o}C.

The model for the night-time was significant according to the Student's t test, however, the intercept of the linear model was not significant, so it was not considered.

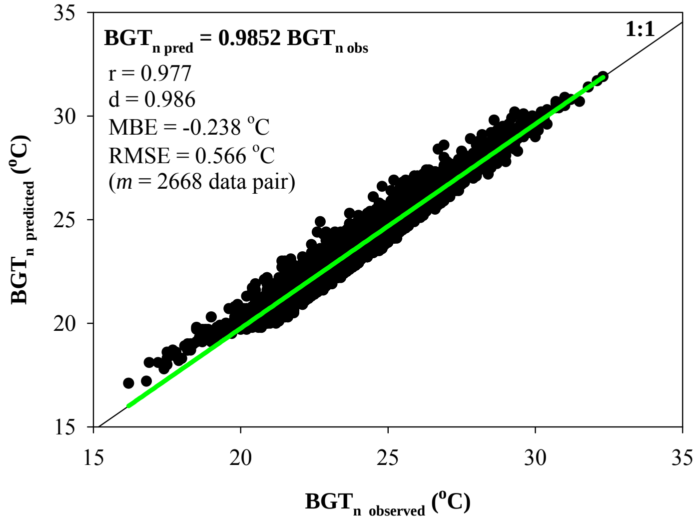


Figure 5. Evaluation of model performance for estimating the black globe temperature for the night-time period (BGT_n).

Conclusion

Using the meteorological data temperature and radiation were developed two models for estimating the black globe temperature for the daytime and night-time period: $BGT_d = [1.360\ T_{air\ d} - 2.358]\cdot[0.075\ \ln(Rs) - 0.562]$ and $BGT_n = [0.942\ T_{air\ n}]$, respectively. The models showed a great performance for predicting black globe temperature values. These models will assist in estimating of bioclimatic indices, assess environmental conditions, accomplishing regional studies, and determining best facilities for animals.

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