# Temperature-humidity index and thermal comfort of broilers in humid tropics

Oluwafemi Owodunni Omomowo*, Fola Richard Falayi

(Department of Agricultural Engineering, Federal University of Technology, PMB 704, Akure, Ondo State, Nigeria.)

**Abstract**: In improving broiler welfare and ensuring better productivity thermal comfort of broilers is of utmost interest. To estimate the thermal comfort of broilers, the temperature humidity index(THI) model was developed using commonly available meteorological parameters, namely temperature and relative humidity. This research re-examined the model by using the Levenberg-Marquardt Algorithm (Excel Solver) based nonlinear regression model to reduce the error space and generate new model constants unique to Akure, Nigeria. Physiological data (cloacal temperature and body weight) were collected for a period of 6 weeks from 50 broilers raised in a poultry house. Environmental data on temperature and relative humidity were used to calibrate the THI of the broilers. For the period of the study, cloacal temperature ranged between 38.47 and 42.60°C while average final weight of broilers was 4.0 kg. Five THI models were developed taking into account the environmental conditions, all five developed model equations showed an improved performance when compared with the calibrated and the existing model based on the high value of the degree of accuracy ($R^2$) of 99.95%, 99.94%, 100.00%, 99.93% and 99.94% for the hourly, daily, morning, afternoon, and evening environmental conditions respectively. The validity of the established THI models shows a very high linearity with high degree of accuracy ($R^2$> 99%). The THI models generated showed that the wet bulb temperature has a significant effect on the comfort of the broilers in the humid tropics than is previously attributed to by earlier THI models.

**Keywords:** broilers, thermal comfort, temperature humidity index, cloacal temperature, temperature

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## 1 Introduction

An ever-increasing world population needs a higher quantity and quality of animal products to meet the demand for animal-derived protein. Therefore, the conditions for animal rearing should be designed to improve animal welfare in order to meet this demand. Broilers are good sources of animal protein and interact with their environment just like any other domesticated animals. Environmental conditions impact animal welfare and adequate environmental conditions are prerequisites for animals to stay healthy and to exhibit all their natural behaviors (Koknaroglu and Akunal, 2013). High temperature and relative humidity (RH) in the humid tropics are major environmental factors resulting in heat stress that affects animal productivity and physiological growth.

To combat heat stress and preserve internal body temperature broilers strive to maintain their body temperature close to 41°C by continuously controlling the thermal energy balance, i.e. heat generated by metabolism must equal heat loss to the environment (sensitive and

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***Corresponding author: Oluwafemi Owodunni Omomowo.** Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure.Tel: +234-813-9676-657. Email:omomowoowodunni@gmail.com.

latent heat loss). This physiological regulation is known as homeostasis. Homeostasis can be disturbed by thermal environment of the broilers as it affects mechanisms for heat transfer and control of thermal balance.

A ready balance can be achieved between the output of heat from the animals and the demand from the atmosphere within a limited range of environmental conditions commonly referred to as the thermoneutral region. The thermoneutral region, which varies with age, is the temperature where the bird uses no extra energy to lose or gain heat. When birds' body temperatures are in their thermoneutral zone, the energy from the feed can be utilized more efficiently for growth, immune system development and reproduction. If temperature falls below the thermoneutral zone, energy from the feed is used to generate heat rather than for growth and development. If the temperature rises above thermoneutral zone, body temperature starts to rise and the bird will utilize a portion of the energy to lose heat, becomes subject to stress and its productive efficiency decreases which result in reduced feed intake and feed conversion efficiency.

Thermal comfort indices were developed to characterize or measure thermal comfort zones according to animal species. Some common thermal indices used to characterize the thermal comfort zones of animals are wet bulb globe temperature (WBGT), wind chill factor, temperature humidity index (THI), temperature humidity velocity index (THVI), apparent equivalent temperature (AET), heat load index, environmental stress index, and comprehensive climatic index.

The most commonly used thermal comfort index is the THI. THI is a single value depicting the integrated effects of air temperature and humidity associated with the level of heat stress. The THI incorporates the effects of both temperature and RH and is commonly used to quantify the degree of heat stress on broilers at different locations.

The THI has proven a useful tool to gauge livestock productivity response as a function of climate (Dikmen and Hansen, 2009; Marai and Habeeb, 2010). It is based on air temperature and RH with different weighing for different species (Hahn et al., 2009) and is an empirical measure of the sum of forces external to the animal that acts to displace body temperature from its set point' (Dikmen and Hansen, 2009). A linear combination of dry–bulb and wet–bulb temperature ($T_{db}$, $T_{wb}$) can also be used to measure the THI, and this combination has been developed for various species including cows, pigs, laying hens, hen turkeys and tom turkeys (Tao and Xin, 2003).THI equations describe the relative importance of $T_{db}$ and $T_{wb}$ for the species based on physiological parameters (e.g., body temperature, respiration rate, or pulse rate), heat production, or production performance (e.g., milk production, egg production, or weight gain). In doing so, relative weighing factors are assigned to $T_{db}$ and $T_{wb}$. Weighing factors vary for different species and can also be affected by prevalent environmental variables.

The specific objectives of this study are to develop a modified THI model for predicting the degree of comfort or discomfort of broilers in a humid tropical environment, validate the developed model and compare the developed model with the existing THI model with a view to improve broiler comfort in South West, Nigeria.

## 2Materials and method

### 2.1Location

The study was conducted at the Federal University of Technology, Akure, Ondo State, Nigeria. Akure lies at about 7° N 5° E with an elevation of 346 m above sea level and it is classified as Aw (tropical savanna) by the Köppen and Geiger climate classification system, with an average annual temperature and rainfall of 25.3°C and 1455 mm respectively. This study was conducted between 9$^{th}$ of May and 16$^{th}$ of June, 2018.

### 2.2Poultry management

A total number of 50 broilers of four weeks' old were reared in an adaptive poultry housing system for a period of six weeks. The broilers were fed with broiler finisher diet and supplied with clean water *ad libitum* throughout the duration of the project. The effect of environmental variables (temperature and RH) on the physiological parameters of the broilers was studied.

### 2.3Physiological data collection

To model the effect of the environmental variables on the animal's physiology, cloacal temperature (CT) in degree Celsius (°C) was measured as stress parameter. The CT of the animal was measured using a Kris Alloy digital thermometer three times daily (morning, afternoon and evening) by inserting the cloacal thermometer in the cloaca of the broilers at approximately 4cm for 1 minute after which reading was taken. Body mass in kg was measured with 20 kg capacity spring platform scale.

### 2.4Environmental data collection

Micro-environment data of the broilers were collected during the study. To capture micro environment data such as temperature, RH, Campbell scientific data logger (PC200W CR200series) was placed in the immediate environment of the house. The ambient temperature and RH of the animal's microclimate were measured using BHT22 relative humidity and temperature sensor. This instrument was hung on the wall inside the poultry house to provide a record of the temperature and RH experienced by the broilers. For better accuracy the data was logged hourly and then divided into three parts representing morning**(6:00 a.m. to 9:00 a.m.),** afternoon**(12:00 m. to 3:00 p.m.)** and evening **(6:00 p.m. to 9:00 p.m.)** The logged data were harvested every week for the six-week duration of the study. The data from the experiment was separated into two parts 70% of the data was used for calibrating the model and 30% was used to validate the model using MS Excel. The data collected was subjected to appropriate statistical analysis using descriptive statistics, analysis of variance (ANOVA) and regression analysis.

### 2.4Temperature humidity index

THI was used to measure the thermal comfort of the broilers. It was determined using the equation reported by Marai et al. (2001):

$$THI = T_{db} - \{(0.31 - 0.31\, RH)(T_{db} - 14.4)\} \quad (1)$$

Where, $THI$ is the temperature humidity index, $T_{db}$ is the dry bulb temperature (°C) and $RH$ is the relative humidity (%)/100.

This equation was selected as a benchmark as it is one equation specifically adapted to the humid tropics for non-sweating livestock.

The THI was further modeled using the approach reported by Tao and Xin (2003), for predicting THI as a function of the dry and wet bulb temperature (Equation 2)

$$THI = A \times T_{db} + B \times T_{wb} \quad (2)$$

Where, $A$ and $B$ are model constants given by Tao and Xin as 0.85 and 0.15 respectively.

These model constants were used to initialize the THI model as well as the weather data from the data loggers.The resulting THI were then correlated with the CT in line with the method of Tao and Xin (2003). Thereafter, *Levenberg-Marquardt Algorithm* [Excel Solver] (Levenberg, 1944; Marquardt, 1963) was used to minimize the error space and generate new model constants specific for Akure.

The THI was then estimated using the new model and compared to the THI equation by Marai et al.(2001).The accuracy of the model was validated using statistical parameter such as coefficient of determination ($R^2$), sum of square error ($SSE$), root mean square error ($RMSE$) and chi square ($X^2$).

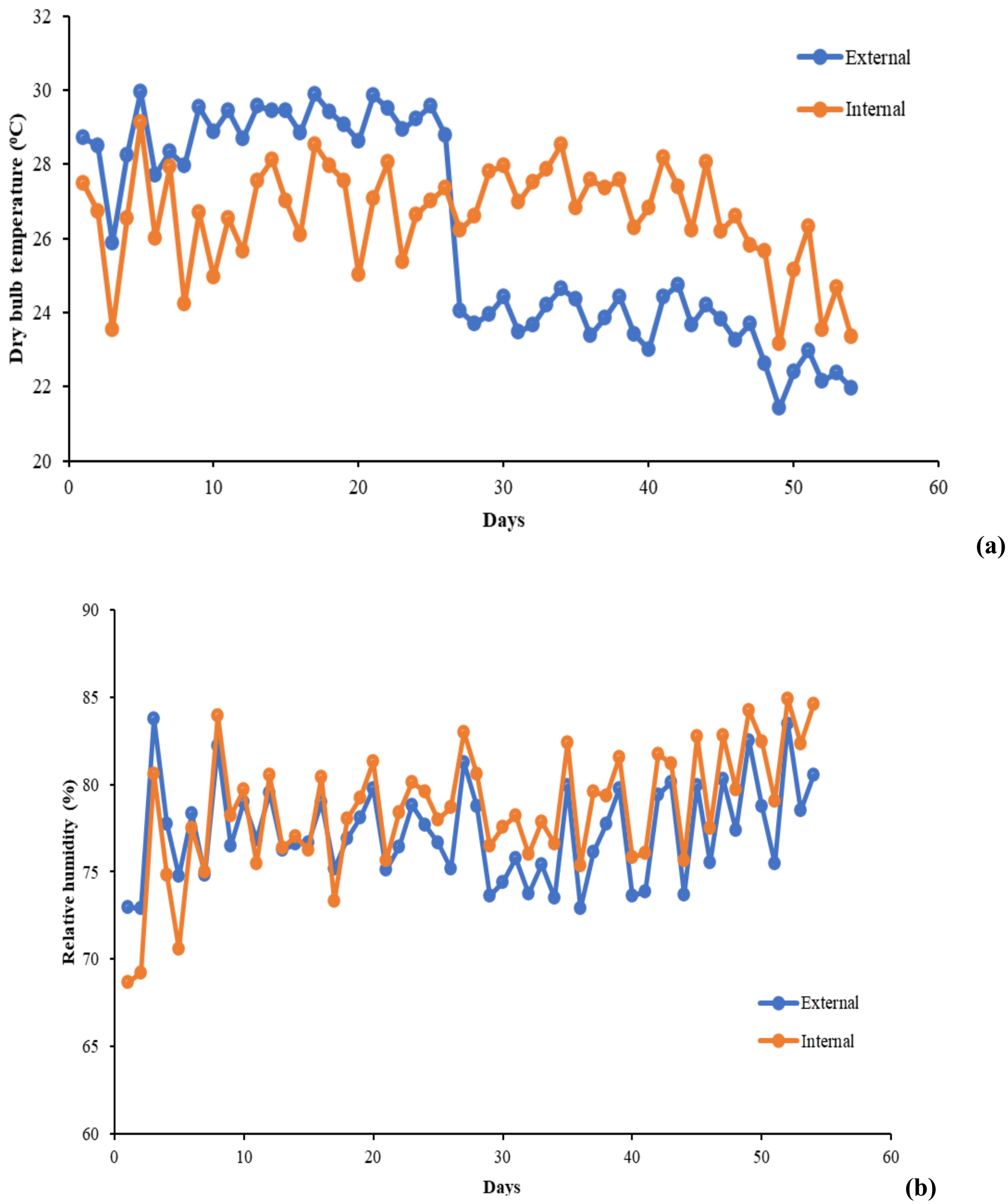
## 3Results and discussion

### 3.1Poultry house environment

The climatic data which includes ambient temperature and RH were measured during the research and the trends are shown in Figure 1. Climatic data was characterized as hourly, daily, morning, afternoon and evening for better understanding of the environment of the broilers as climatic factors vary with time. Table 1 presents mean, maximum, and minimum values of the climatic data. However, for the duration of the research the average daily temperature inside the poultry house was 26.61°C with a RH of 78.56%. Meanwhile in the immediate environment of the broilers house outdoor the daily average temperature and RH were 26.12°C, 77.29% respectively.

It was observed that between the 26th and 27th day, there was a temperature difference of about 4°C in the outdoor temperature due to the weather, this did not significantly affect the indoor temperature because of the presence of the structure and the homeostasis of the birds in the cage.

The high RH value can be attributed to the season when the study was conducted as rainfall increases the amount of water in the atmosphere.




(a)Dry bulb temperature (b) Relative humidity distribution

Figure 1Dry bulb temperature and relative humidity distribution for the duration of the experiment

**Table 1Descriptive statistics of environmental variables affecting the poultry house**

| Environmental Variables | | Period | | | | |
|---|---|---|---|---|---|---|
| | | Hourly | Daily | Morning | Afternoon | Evening |
| **Indoor Temperature** | Minimum | 20.12 | 23.16 | 20.59 | 22.25 | 20.49 |
| **(ºC)** | Maximum | 35.36 | 29.12 | 27.76 | 33.52 | 31.87 |
| | Average | 26.63 | 26.61 | 24.39 | 30.43 | 28.09 |
| | S.D | 3.53 | 1.39 | 1.22 | 2.32 | 2.69 |
| **Indoor Relative Humidity** | | | | | | |
| | minimum | 42.76 | 68.68 | 75.77 | 52.36 | 56.82 |
| **(%)** | Maximum | 84.90 | 84.87 | 84.90 | 84.87 | 84.90 |
| | Average | 78.62 | 78.56 | 84.30 | 70.03 | 75.09 |
| | S.D | 8.90 | 3.59 | 1.40 | 7.48 | 6.38 |
| **Outdoor Temperature** | | | | | | |
| | minimum | 18.74 | 21.43 | 21.16 | 23.71 | 18.94 |
| **(ºC)** | Maximum | 36.81 | 29.95 | 29.55 | 35.47 | 31.82 |
| | Average | 26.13 | 26.12 | 25.42 | 28.86 | 26.07 |
| | S.D | 3.58 | 2.86 | 2.93 | 4.41 | 2.57 |
| **Outdoor Relative Humidity** | | | | | | |
| | minimum | 46.07 | 72.88 | 77.56 | 49.58 | 64.74 |
| **(%)** | Maximum | 86.06 | 83.76 | 85.00 | 81.01 | 85.00 |
| | Average | 77.31 | 77.29 | 82.00 | 63.14 | 78.19 |
| | S.D | 10.09 | 2.79 | 2.22 | 6.99 | 5.18 |

## 3.2 Broiler cloacal temperature

For the period of the study CT of the broilers was lowest in the morning at 38.47ºC and highest in the afternoon at 42.60ºC. The highest CT in the afternoon can be explained by the effects of high environmental temperature as reported by Tan et al.(2010), Purswell et al.(2012) and Zahoor et al.(2016) who noted that exposure to high ambient temperatures (32°C, 35°C, and 38°C; RH 70.5%) resulted in significant increases in CT.

To determine the magnitude and influence of the micro-environmental data considered in this study on the CT of the broilers, Analysis of variance (ANOVA) and type II sum of square analysis of the regression model that predicts the CT as a function of the micro environmental condition (Internal dry bulb temperature and wet bulb temperature of the poultry) is shown in Table 2. The Table 2 shows that daily CT of the broiler significantly depends on the wet bulb temperature, dry bulb temperature and the RH in a respective order of importance at 5% probability level.

Among all the micro environmental parameter, the rectal temperature of the broilers depends on the wet bulb in the morning and evening whilst it highly depends on the dry bulb temperature in the afternoon, therefore the lower dry bulb temperature that was recorded in the morning and evening, the lower the CT of the broilers. Similar observation can be deduced from the report of Aluwong et al. (2017) for layers, Fitzgerald et al. (2009) for pigs and Schönhart and Nadeem (2015) for ruminant animal. However, the result of the overall analysis of variance (ANOVA) shows that the average daily CT of the broilers can significantly be predicted at $p= 0.0006$.

**Table 2Analysis of variance for cloacal temperature model**

| Period | Source | DF | Sum of squares | Mean squares | F | Pr> F |
|---|---|---|---|---|---|---|
| Daily | Model | 3 | 5.2062 | 0.8677 | 5.3581 | 0.0006 |
| | $TD_\varphi$ | 1 | 1.6027 | 1.6027 | 9.8970 | 0.0036 |
| | $TW_\varphi$ | 1 | 2.6055 | 2.6055 | 16.0891 | 0.0003 |
| | $TD_\varphi*TW_\varphi$ | 1 | 0.0154 | 0.0154 | 0.0950 | 0.7599 |
| | Error | 32 | 5.1821 | 0.1619 | | |
| | Corrected Total | 35 | 10.3883 | | | |
| Morning | Model | 2 | 0.2204 | 0.0735 | 0.1244 | 0.9451 |
| | $TD_\chi$ | 1 | 0.1778 | 0.1778 | 0.3010 | 0.5867 |
| | $TD_\chi*TW_\chi$ | 1 | 0.0143 | 0.0143 | 0.0242 | 0.8773 |
| | Error | 35 | 20.6753 | 0.5907 | | |
| | Corrected Total | 37 | 20.8957 | | | |
| Afternoon | Model | 3 | 8.4035 | 1.4006 | 2.2843 | 0.0601 |
| | $TD_\gamma$ | 1 | 4.8572 | 4.8572 | 7.9221 | 0.0083 |
| | $TW_\gamma$ | 1 | 0.3836 | 0.3836 | 0.6256 | 0.4348 |
| | $TD_\gamma*TW_\gamma$ | 1 | 0.0200 | 0.0200 | 0.0326 | 0.8578 |
| | Error | 32 | 19.6200 | 0.6131 | | |
| | Corrected Total | 35 | 28.0235 | | | |
| Evening | Model | 3 | 4.3711 | 0.7285 | 2.1479 | 0.0748 |

| | | | | | |
|---|---|---|---|---|---|
| $TD_\beta$ | 1 | 0.0702 | 0.0702 | 0.2071 | 0.6521 |
| $TW_\beta$ | 1 | 2.1595 | 2.1595 | 6.3667 | 0.0168 |
| $TD_\beta$*$TW_\beta$ | 1 | 0.1029 | 0.1029 | 0.3035 | 0.5855 |
| Error | 32 | 10.8539 | 0.3392 | | |
| Corrected Total | 35 | 15.2250 | | | |

Note: *TD, TW, φ, χ, γ, β are dry bulb temperature, wet bulb temperature, daily, morning, afternoon and evening respectively

### 3.3 Modelling of broilers body mass

The average daily body mass of the broilers was monitored; the average initial mass of the stocked broilers was 0.9 kg and the average final mass of the grown broilers after 42 days was4.0 kg. The results show an increasing trend which can be categorized as linear increment with 95.75% degree of the linearity as shown in Equation 3. The equation shows the direct relationship between the broilers body mass and the time spent in the poultry house. Also, the broilers have an average growth rate of 0.064kg per day as deduced from Equation 3and Figure 2 shows the graphical representation of the average body mass over time (days).

$$BM = 0.0644t + 1.1252 \tag{3}$$

Where BM is Body Mass in kg and t is time in days.

Analysis of variance and type I sum of square analysis of the regression model that predict the average body mass of the broilers as a function of the micro environmental condition (Internal dry bulb temperature and wet bulb temperature of the poultry) is shown in Table 3. The table shows that average daily mass of the broiler significantly depends on the dry bulb temperature and wet bulb temperature in a respective order of importance at $p$=0.0014.This makes the dry bulb temperature the most important parameter that influences the growth rate of broilers followed by the RH. This agrees with Nayak et al. (2015) who showed that the environmental temperature has a significant effect on the growth rate of broilers and as such a change in dry bulb temperature parameter without considering other environmental factors might retard the growth of the broiler.

### 3.4 Temperature Humidity Index (THI) function

The THI was annexed to show the heat stress in the adaptive cage used for the study. Figure 3 shows the derived average daily THI for the period of the study. The minimum hourly, maximum hourly and average daily THI was found to be19.85, 32.11 and 25.73 ± 2.93 respectively. In Table 4 the calculated THI was grouped into 3 classes: lower than 26 (<26), between 26 and 29 (26-29) and higher than 29 (>29) and this shows the degree of heat stress as: comfort limit, heat stress, and severe heat stress, respectively (Duduyemi and Oseni, 2012).

Table 4shows the distribution of the grouped data in days; it was observed that for the period of this research the THI was mostly below 26 keeping the birds in their comfort limit for most part. However, in the afternoon the THI was mostly in the severe heat stress zone as the THI value was found above 29 with 32 occurrences in the afternoon and it is significantly ($p$< 0.05) higher than the heat stress and comfort limit classification and this can be explained by the effect of high temperature and intensity of solar radiation in the afternoon.

**Table 3Analysis of variance for the broilers body mass**

| Source | DF | Sum of squares | Mean squares | F | Pr> F |
|---|---|---|---|---|---|
| Model | 3 | 4.3167 | 0.7194 | 5.0839 | 0.0014 |
| $TD_\varphi$ | 1 | 1.5432 | 1.5432 | 10.9047 | 0.0028 |
| $TW_\varphi$ | 1 | 0.6059 | 0.6059 | 4.2818 | 0.0486 |
| $TD_\varphi$*$TW_\varphi$ | 1 | 0.1658 | 0.1658 | 1.1719 | 0.2890 |
| Error | 26 | 3.6793 | 0.1415 | | |
| Corrected Total | 29 | 7.9960 | | | |

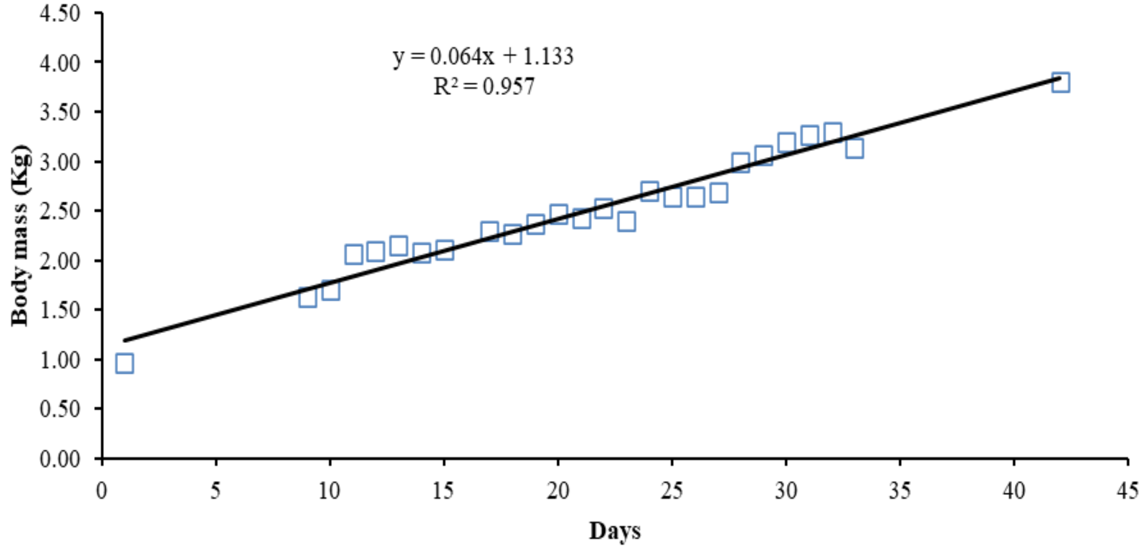



Figure 2The graphical representation of the average body mass over time (days)

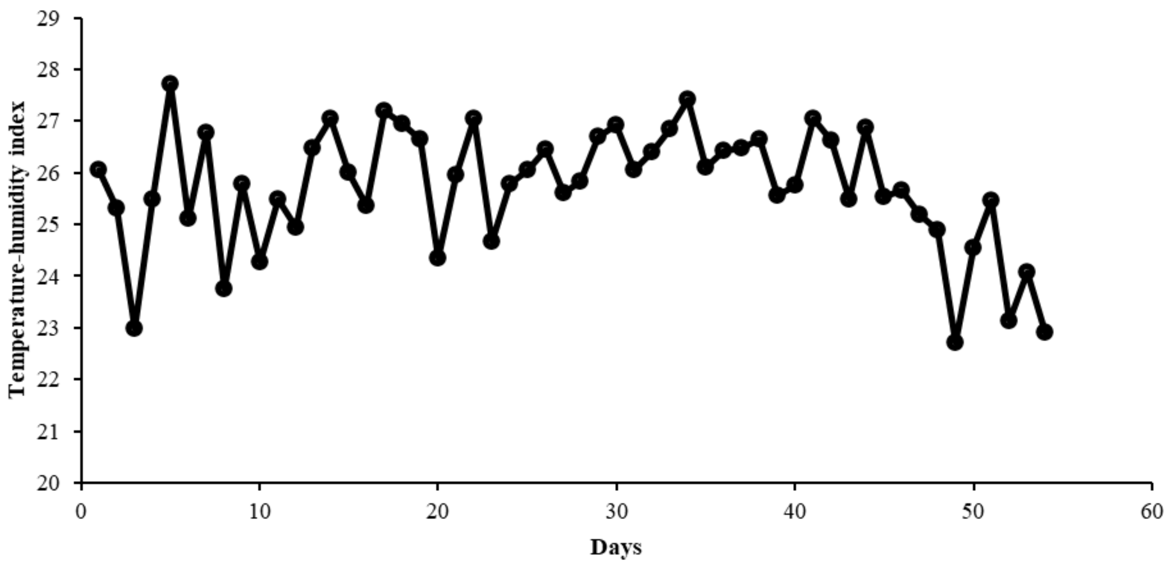



Figure 3Daily Temperature Humidity Index over the period of the experiment

**Table 4THI grouping and distribution**

| THI category | Evening | Afternoon | Morning | Daily | Hourly |
|---|---|---|---|---|---|
| <26 | 13A | 4A | 52A | 29A | 761A |
| 26 – 29 | 29B | 18A | 1B | 25B | 254B |
| >29 | 11C | 32B | | | 255C |

The THI shows number of occurrences, days for morning, afternoon, evening and daily columns, and hours for the hourly column. THI categories <26, 26-29 and >29 denotes comfort limit, heat stress, and severe heat stress respectively. The THI group with different alphabet are significantly different along the column at $p$<0.05

### 3.5 THI model calibration and validation

The model constants and goodness of fit parameters which includes$R^2$, $SSE$, $RMSE$ and $X^2$ value of the calibrated and developed model in comparison Tao and Xin model are shown in Table 5. The table reveals that the calibrated model ($THI_{new}$) for THI which was calibrated as a function of dry bulb and wet bulb temperature has a very high degree of accuracy value of 99.95%, 99.94%, 100.00%, 99.93% and 99.94% for the hourly, daily, morning, afternoon, and evening environmental conditions respectively. The accuracy of the calibrated model is slightly higher than that of Tao and Xin (2003) whose accuracy was99.74%, 99.59%, 99.95%, 99.38% and 99.75% for the hourly, daily, morning, afternoon, and evening environmental condition respectively. Model constants for $THI_{new}$ reveals that $T_{db}$ has far greater impact on the homeostasis of the broilers than $T_{wb}$ and this has also been observed in other poultry THI equations developed till date (Purswell et al., 2012).

**Table 5 The model constant and goodness of fit parameter**

| Period | Model | *A* | *B* | $R^2$ | *SSE* | *RMSE* | $X^2$ |
|---|---|---|---|---|---|---|---|
| Hourly | $THI_{new}$ | 0.601 | 0.412 | 0.9995 | 8.0322 | 0.0795 | 0.0063 |
| | Tao and Xin | 0.850 | 0.150 | 0.9974 | 458.4585 | 0.6006 | 0.3613 |
| Daily | $THI_{new}$ | 0.632 | 0.378 | 0.9994 | 0.1453 | 0.0519 | 0.0028 |
| | Tao and Xin | 0.850 | 0.150 | 0.9959 | 11.7044 | 0.4656 | 0.2251 |
| Morning | $THI_{new}$ | 0.703 | 0.301 | 1.0000 | 0.1196 | 0.0475 | 0.0023 |
| | Tao and Xin | 0.850 | 0.150 | 0.9995 | 2.0716 | 0.1977 | 0.0406 |
| Afternoon | $THI_{new}$ | 0.625 | 0.383 | 0.9993 | 0.2851 | 0.0727 | 0.0055 |
| | Tao and Xin | 0.850 | 0.150 | 0.9938 | 44.6429 | 0.9092 | 0.8585 |
| Evening | $THI_{new}$ | 0.612 | 0.399 | 0.9994 | 0.3368 | 0.0797 | 0.0066 |
| | Tao and Xin | 0.850 | 0.150 | 0.9975 | 21.7467 | 0.6406 | 0.4264 |

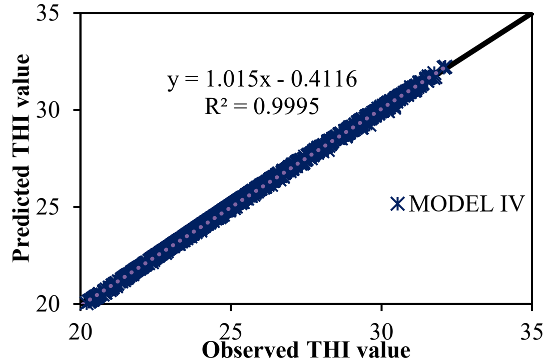
Note: *A and B are the model constant in the following model THI $= ATdb + BTwb$

Lack of sweat glands and the relatively small surface area-to-volume ratio of these broilers may have contributed to their relatively less dependence on $T_{wb}$, or humidity (Tao and Xin, 2003). Nevertheless, compared to Tao and Xin (2003) the effect of the wet bulb temperature on the THI equation is more significant this can be attributed to the weather condition in the humid tropics and the breed of the broilers.

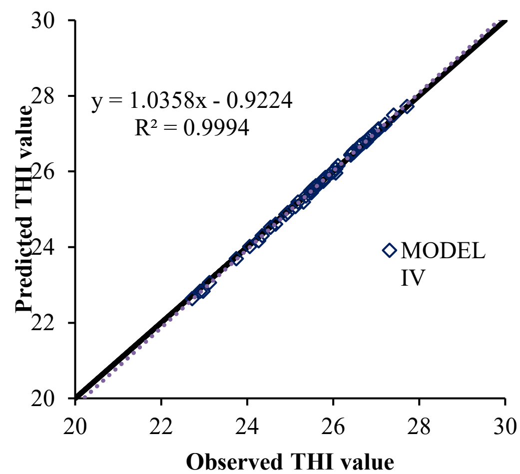
$$THI_{New} = A \times T_{db} + B \times T_{wb} \quad (4)$$

Where, THI is the temperature-humidity index, $T_{db}$ is the dry bulb temperature (℃), $T_{wb}$ is the wet bulb temperature(℃), and A,B are model constants shown in Table 5.

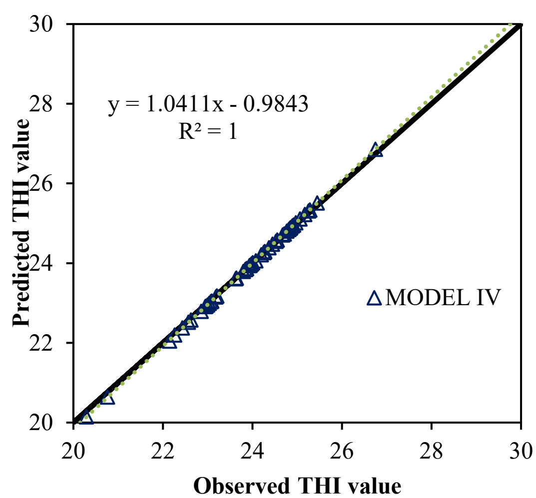
Figure 4 shows the graphical representation of the predicted THI values resulting from the new model against the calculated THI values from Marai et al.(2001), the figures depict the validity of the established THI model as it shows a very high linearity with high degree of accuracy ($R^2$> 99%).



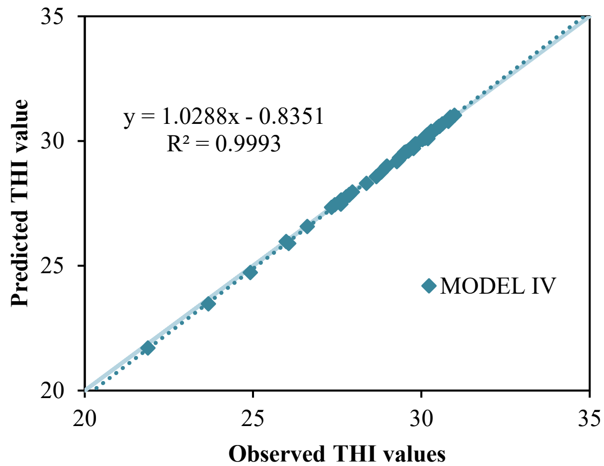

(a) Hourly



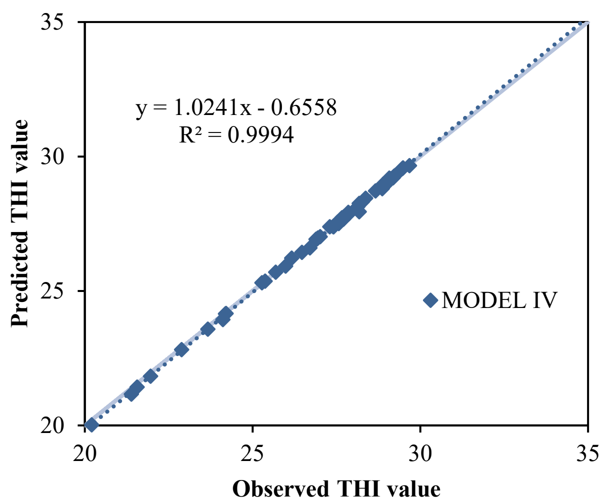

(b) Daily




(c) Morning




(d) Afternoon




(e) Evening

Figure 4 Graphical representation of $THI_{new}$ validation

## 4 Conclusion

This study examined the interaction between broiler birds kept in a poultry house and their environment, focusing on the effects of temperature and RH on the homeostasis of the birds. The study led to the following conclusions:

The THI that was calibrated as a function of dry bulb and wet bulb temperature showed a slightly improved performance when compared with Tao and Xin (2003) based on the high value of degree of the accuracy ($R^2$) and low value of the analysis of residual (*SSE, RMSE,* $X^2$).

The THI model generated showed that the wet bulb temperature has a significant effect on the comfort of the broilers in the humid tropics than is previously attributed to by earlier THI models.

The CT and body mass of broilers can be adequately predicted by environmental variables, with dry bulb temperature having the greatest effect.

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