Models of Dry-Bulb Temperature and Relative Humidity for Ilorin and Ikeja Suitable For Engineering Applications

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Abstract

Hourly dry – bulb temperature and relative humidity data for Ilorin and Ikeja for the periods 1978 to 1992, and 1995 to 2008 were obtained from Nigerian Meteorological Agency Oshodi, Lagos state, Nigeria. The monthly – average hourly dry – bulb temperature ($\overline{T}_h$) and relative humidity ($\overline{R}_h$) were computed for each month of the year using the data obtained for the two periods. Statistical analyses were carried out on the sets of data for the two periods for the two weather variables to get $\overline{T}_h$ versus time, $\overline{R}_h$ versus time, $\overline{T}$ and $\overline{R}$, $\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ for each month of the year and for each of the two locations. Using these $\overline{T}$ and $\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ and $\overline{R}$ and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ obtained from 1995 to 2008 as input data in the Fourier series developed from 1978 to 1992 data, values of $\overline{T}_h$ versus time and $\overline{R}_h$ versus time were predicted for each of the 12 months and for each location and compared with those obtained directly from 1995 to 2008 data. The agreement between results of the model and those from the data were very good. It is convenient to use these models as input in computer programs for simulation of refrigerators and air conditioners.

Keywords: *Dry-Bulb Temperature, Relative Humidity, diurnal and Fourier series*

1.0 Introduction

The operation of air breathing engines is controlled so that aspiration of surrounding air at different temperatures and moisture content will not significantly affect power output, fuel efficiency, combustion stability, and exhaust gas emissions (Valo and Paasima, 2009). In line with Valo and Paasima (2009), Wideskog and Astrand (2010) reported that gas turbines are very sensitive to high temperatures.

Increase in both ambient temperature and relative humidity affect the performance of gas turbines in two ways: firstly, the compressor consumes more power, leaving less power produced by the turbine available as useful output; and secondly, there is condensation of water vapour as the static temperature of air intake falls below the saturation temperature across the first row of compressor blades. Therefore, Hart (1994) proposed cooling and dehumidifying unit for the air intake. The proposed unit works on air intake before entering the compressor. For developing air conditioning cooling load models, the variation of heat flows and temperatures associated with the building and conditioning equipment must be analyzed and modeled. To develop such models, it is necessary to input the weather variables which affect the load or equipment performance for each time step in the simulation which is usually an hour or less in size (Erbs, 1984). A Fourier series model was developed by Erbs (1984). The model can be used to predict hourly dry-bulb temperature for nine cities in United States of America.

The aim of this work, therefore, is to develop Fourier series models for dry – bulb temperature and relative humidity for Ilorin and Ikeja in Nigeria, similar to Erbs model; to serve as convenient input data for simulation models for refrigerator and air-conditioners and to know the varying ambient conditions in which stationary air - breathing engines operate in the two places. The major difference between the proposed models and Erbs model is that a model was developed for each of the two locations unlike Erbs model in which a single model was developed for the United States of America using data for nine cities. These models can be applied to places in the tropics that have climates similar to those of Ikeja and Ilorin, while Erbs model can be applied in some places in temperate region.

2.0 Materials and Method

2.1 Development of Models

Hourly dry – bulb temperatures and relative humidity data for Ilorin (Lat. 8° 26′N, Long. 4° 29′E) and Ikeja (Lat. 6° 40′N, Long. 3° 20′E) for the periods 1978 to 1992 and 1995 to 2008 were obtained from Nigerian Meteorological Agency, Oshodi, Lagos state, Nigeria. Statistical analyses were done on the 1978 to 1992 data to obtain the monthly average hourly dry – bulb temperature ($\overline{T}_h$) and relative humidity ($\overline{R}_h$) for each month of the year. The mean monthly average for each of the two weather variables $\overline{T}$ and $\overline{R}$ were also computed. The maximum and the minimum values among the 24 hourly values of each of $\overline{T}_h$ and $\overline{R}_h$ were found and used to determine $\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$. The $\overline{T}_h$ versus time and $\overline{R}_h$ versus time curves for each month were standardized by changing them to $\left(\overline{T}_h - \overline{T}\right)/\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ versus time and $\left(\overline{R}_h - \overline{R}\right)/\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ versus time, respectively. The average of the 12 standardized temperature variable ($\left(\overline{T}_h - \overline{T}\right)/\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$) versus time were computed. The day was divided into 24 hours of π/12 radians intervals. There are 24 data points and from the rule of thumb of Fourier series harmonics (Beckwith et al, 1982), six harmonics were to be obtained. Following the procedure for obtaining Fourier series described by Beckwith et al (1982) using Microsoft Excel 2007 version, the results obtained are:

$$\left(\overline{T}_h - \overline{T}\right)/\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right) = 0.4646\ Cos\left(t^* - 3.6892\right) + 0.1544\,Cos\left(2t^* - 0.4405\right) + 0.0119\,Cos\left(3t^* - 1.5087\right) + 0.0298\,Cos\left(4t^* - 3.8615\right) + 0.0052\,Cos\left(5t^* - 3.3592\right) + 0.0456\,Cos\left(6t^* - 1.4991\right). \quad (1)$$

for Ikeja and

$$\left(\overline{T}_h - \overline{T}\right)/\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right) = 0.4611\ Cos\left(t^* - 3.9579\right) + 0.1225\,Cos\left(2t^* - 0.8496\right) + 0.0104\,Cos\left(3t^* - 0.5365\right) + 0.0187\,Cos\left(4t^* - 4.0581\right) + 0.0003\,Cos\left(5t^* - 4.179\right) + 0.0363\,Cos\left(6t^* - 1.5026\right) \quad (2)$$

for Ilorin,

The Fourier series for the average of the 12-standardized relative humidity versus time is

$$\left(\overline{R}_h - \overline{R}\right) \Big/ \left(\overline{R}_{h\max} - \overline{R}_{h\min}\right) = 0.4893\,Cos\left(t^* - 0.5529\right) + 0.1608\,Cos\left(2t^* - 3.7892\right) + 0.0147\,Cos\left(3t^* - 5.0691\right) + 0.0339\,Cos\left(4t^* - 1.2869\right) + 0.0059\,Cos\left(5t^* - 0.2488\right) + 0.0082\,Cos\left(6t^* - 0.0232\right) \quad (3)$$

for Ikeja and

$$\left(\overline{R}_h - \overline{R}\right) \Big/ \left(\overline{R}_{h\max} - \overline{R}_{h\min}\right) = 0.4123\,Cos\left(t^* - 0.7979\right) + 0.1153\,Cos\left(2t^* - 3.9831\right) + 0.0213\,Cos\left(3t^* - 4.9796\right) + 0.0274\,Cos\left(4t^* - 0.8111\right) + 0.0074\,Cos\left(5t^* - 0.9855\right) + 0.0038\,Cos\left(6t^* - 0.0048\right) \quad (4)$$

for Ilorin

where, $t^* = \dfrac{2\pi t}{24}$, and t = 0, 1, 2, . . ., 23 Greenwich Mean Time(GMT)

It was found that the first four harmonics were accurate enough for representing temperature and relative humidity as was obtained by Erbs (1984).

2.2 Testing the Models

From the hourly dry – bulb and relative humidity data for 1995 to 2008, the diurnal variation of the average hourly temperature ($\overline{T}_h$) and average hourly relative humidity ($\overline{R}_h$) and also the mean monthly average values of dry – bulb temperature ($\overline{T}$) and relative humidity ($\overline{R}$), were obtained. The peak–to–peak amplitude for the curves for ($\overline{T}_h$) and ($\overline{R}_h$) i.e. $\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ were also determined. These values of ($\overline{T}$) and $\left(\overline{T}_{h\max} - \overline{T}_{h\min}\right)$ were used as input data in equations (1) and (3) to obtain the diurnal variation predicted by the equations. These were compared with $\overline{T}_h$ *versus* time obtained directly from the hourly data for 1995 to 2008 in Figures 1 through 4.

Similarly predicted diurnal variation of $\overline{R}_h$ using ($\overline{R}$) and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ as inputs in equations (2) and (4) are compared with results obtained directly from 1995 to 2008 data in Figures 5 through 8.

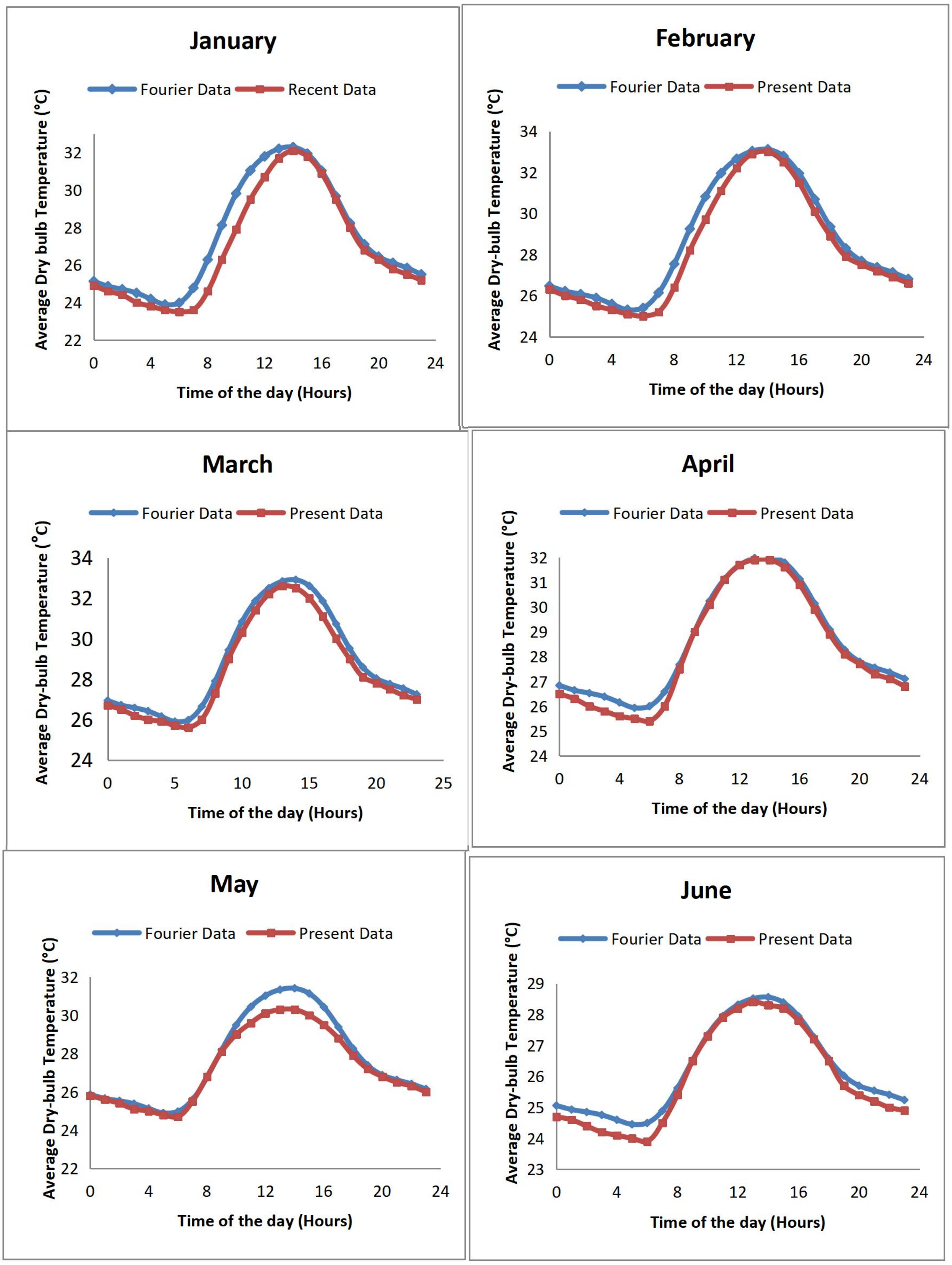

Figure 1: Comparison of results predicted with Fourier series model with results obtained directly from the weather data for dry-bulb temperature for January to June for Ikeja

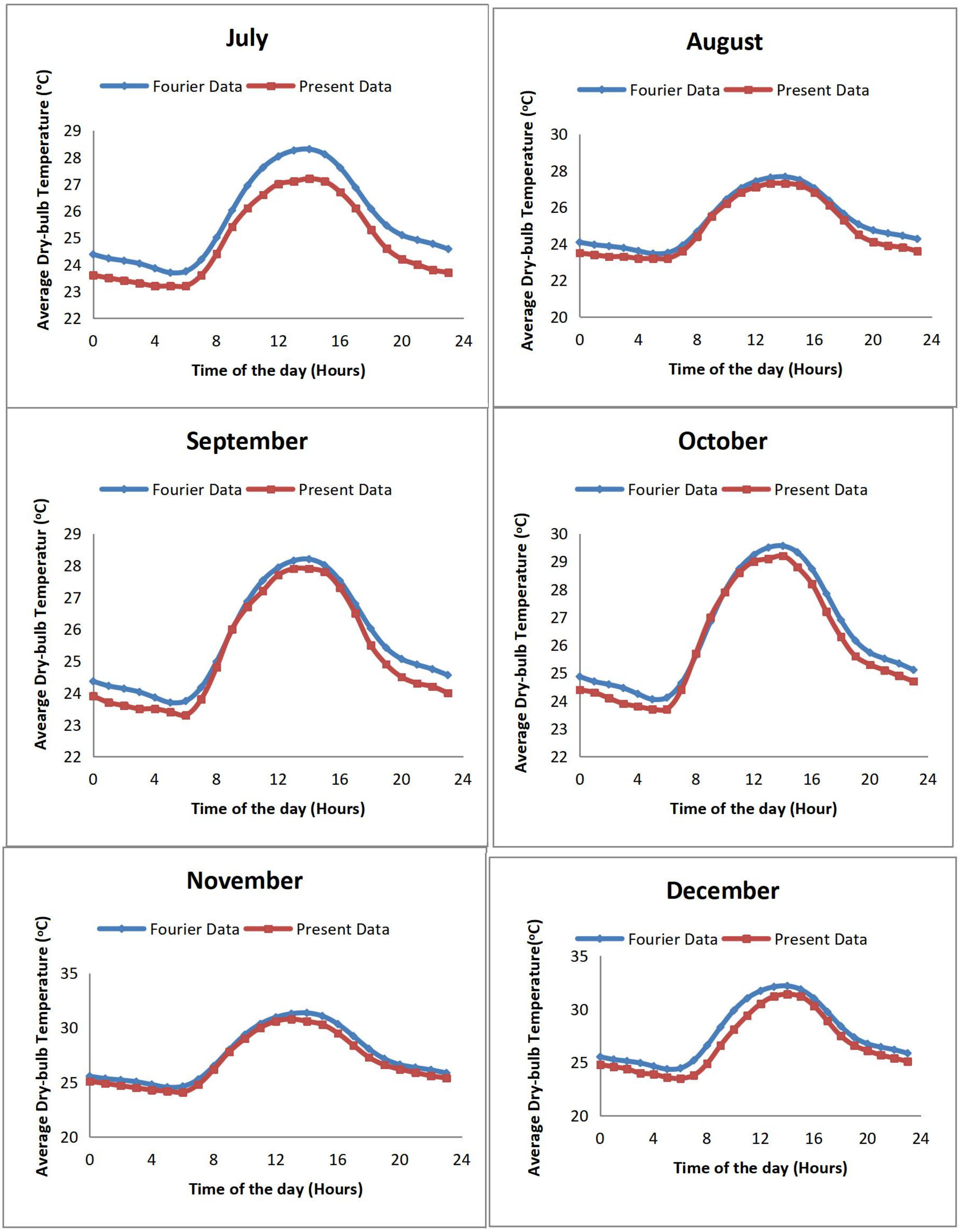

Figure 2: Comparison of results predicted with Fourier series model with results obtained directly from the weather data for dry-bulb temperature for July to December for Ikeja

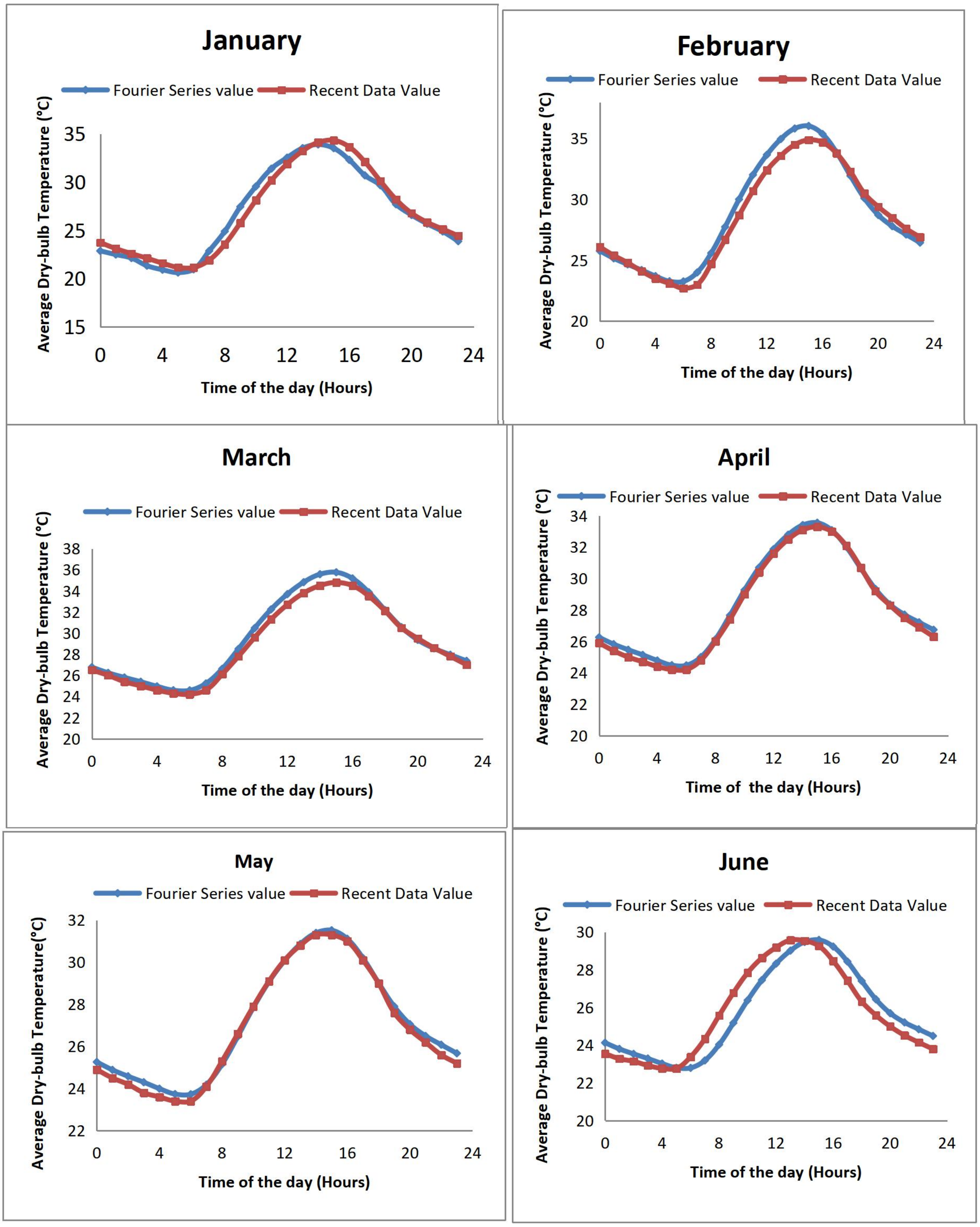

Figure 3: Comparison of results predicted with the propose model with the actual weather data for dry-bulb temperature for January to June for Ilorin

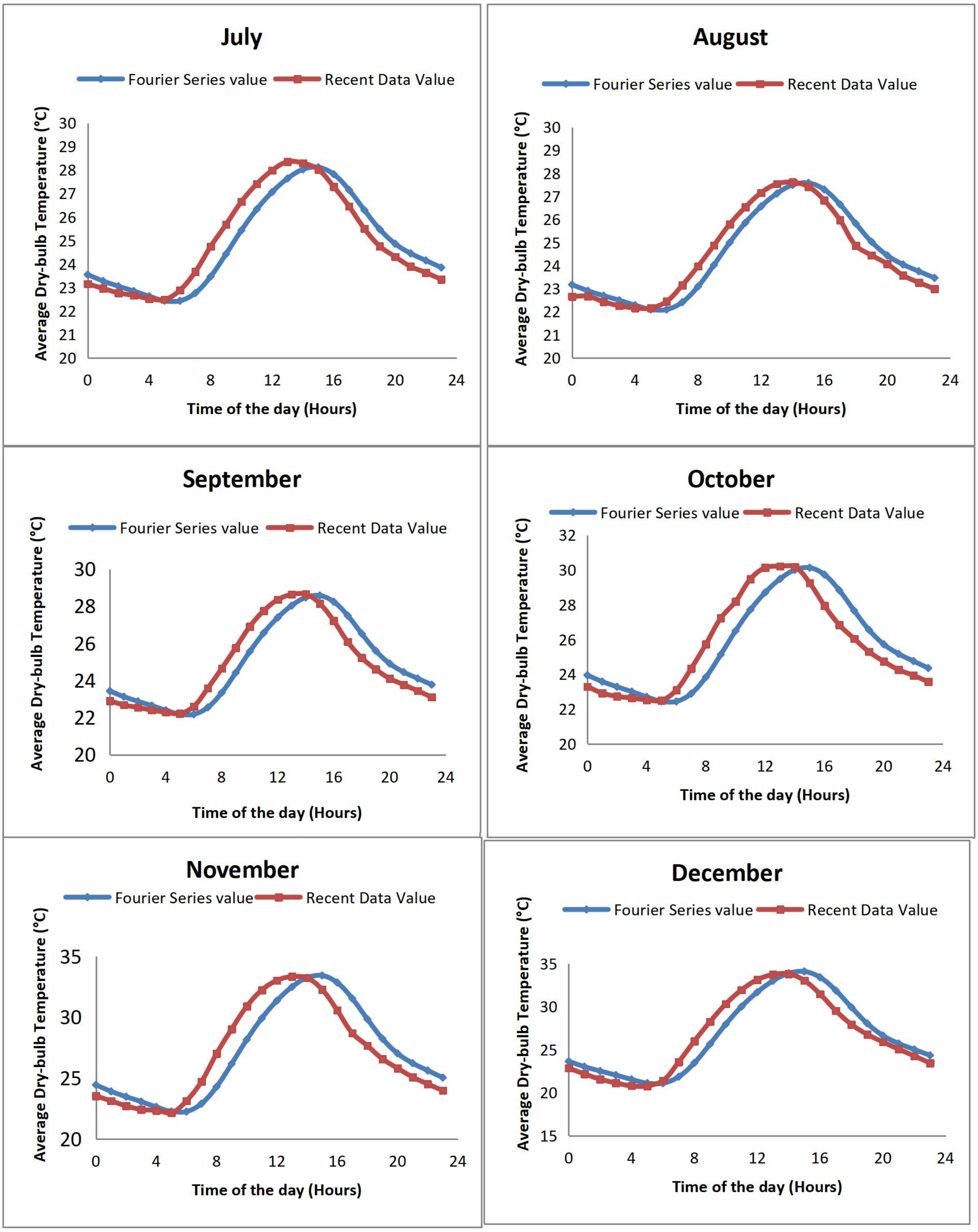

Figure 4: Comparison of results predicted with the proposed model with the actual weather data for dry-bulb temperature for July to December for Ilorin

Similarly predicted diurnal variation of $\overline{R}_h$ using ($\overline{R}$) and $\left(\overline{R}_{h\max} - \overline{R}_{h\min}\right)$ as inputs in equations (2) and (4) are compared with results obtained directly from 1995 to 2008 data in Figures 5, 6, 7 and 8.

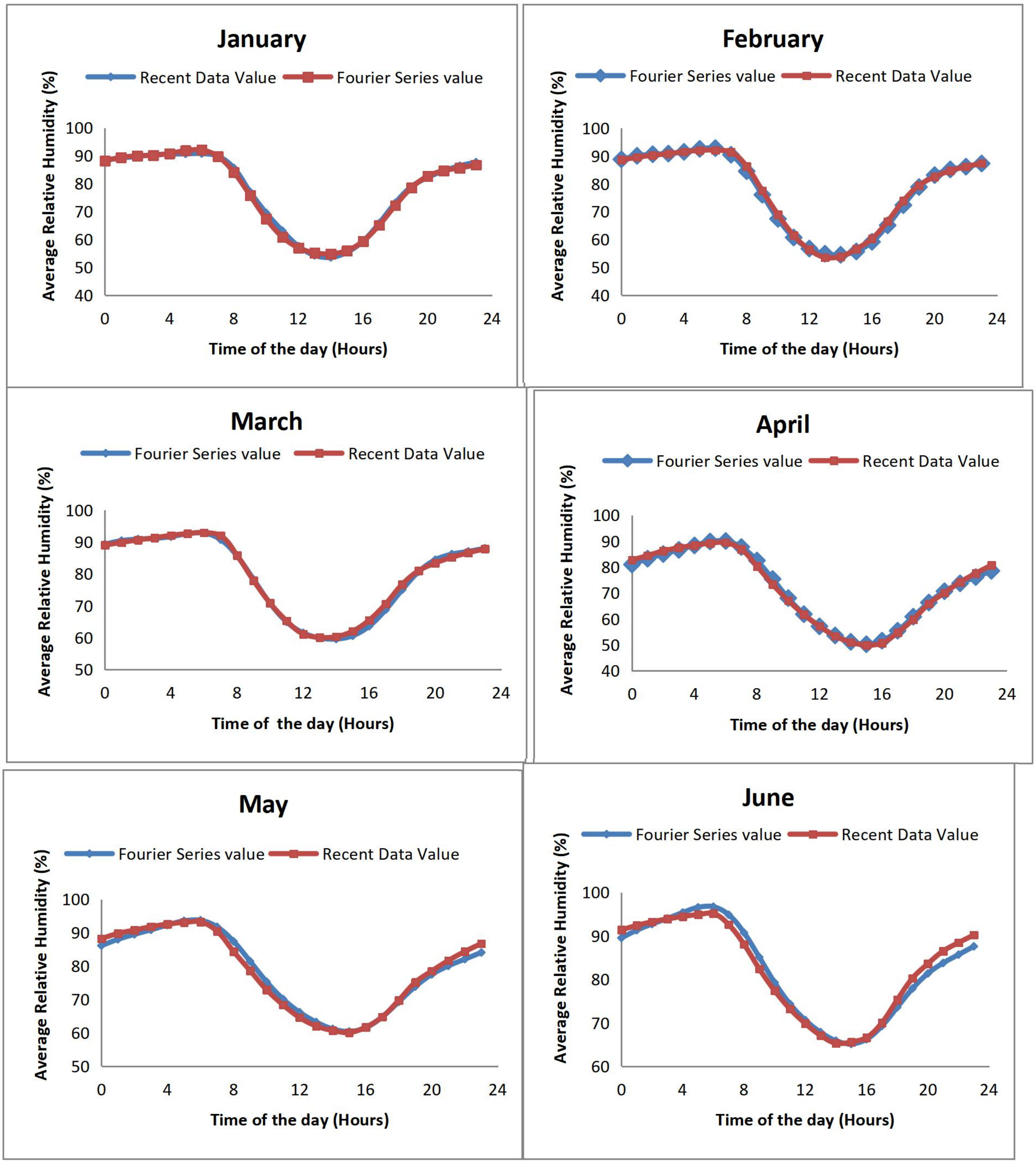

Figure 5: Comparison of results predicted with the proposed model with the actual weather data for relative humidity for January to June for Ikeja

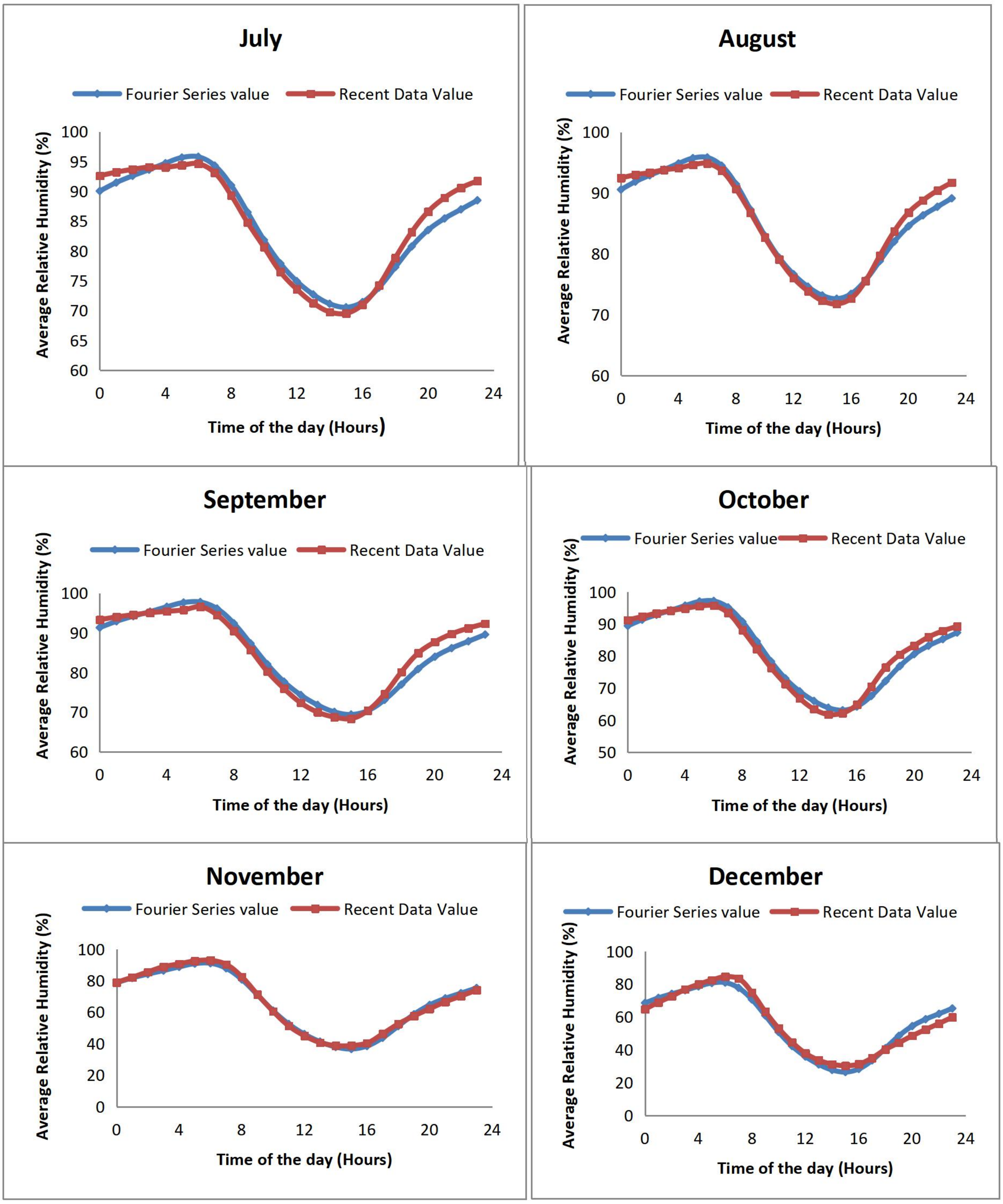

Figure 6: Comparison of results predicted with the proposed model with the actual weather data for relative humidity for July to December for Ikeja

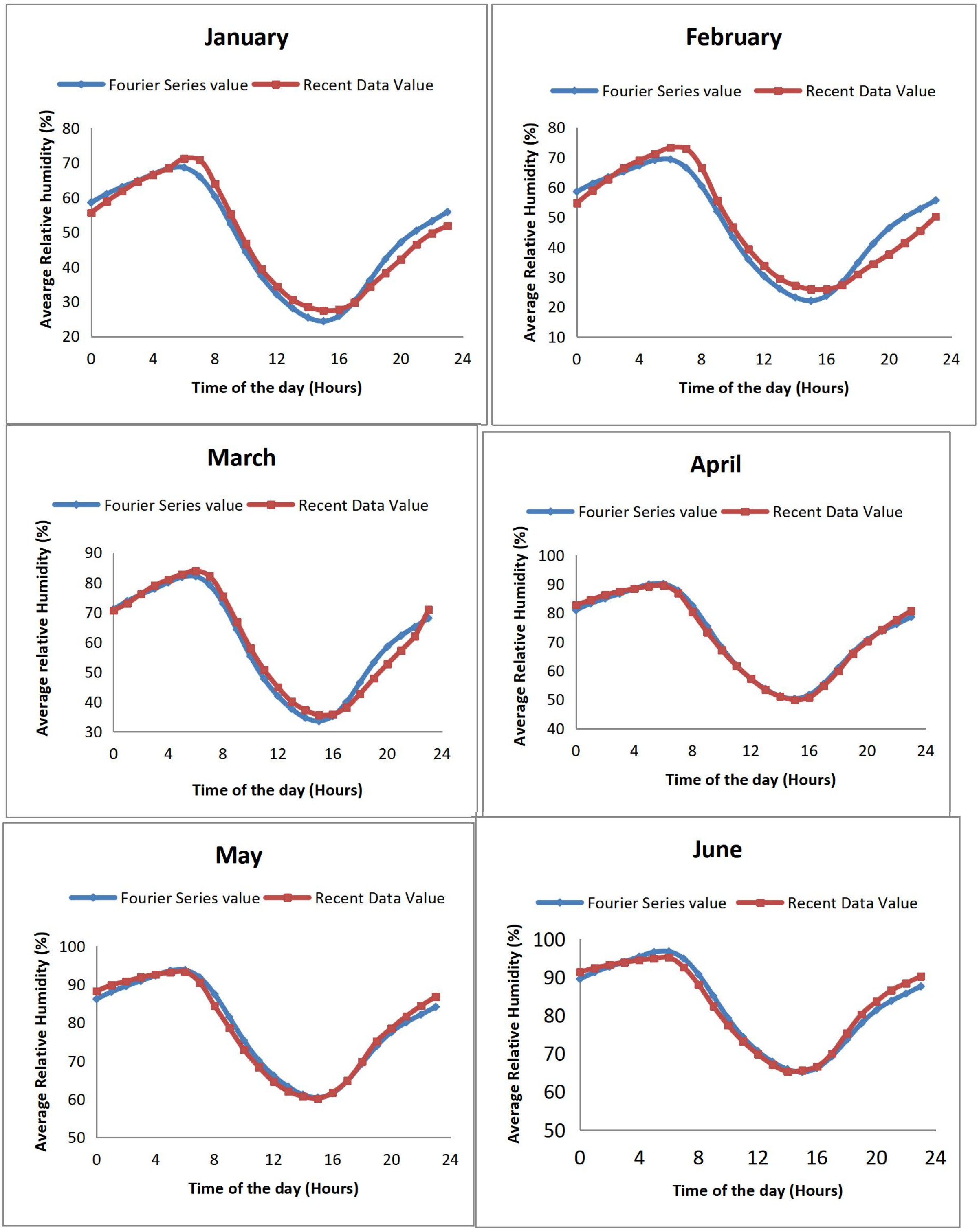

Figure 7: Comparison of results predicted with Fourier series model with the actual weather data for relative humidity for January to June for Ilorin

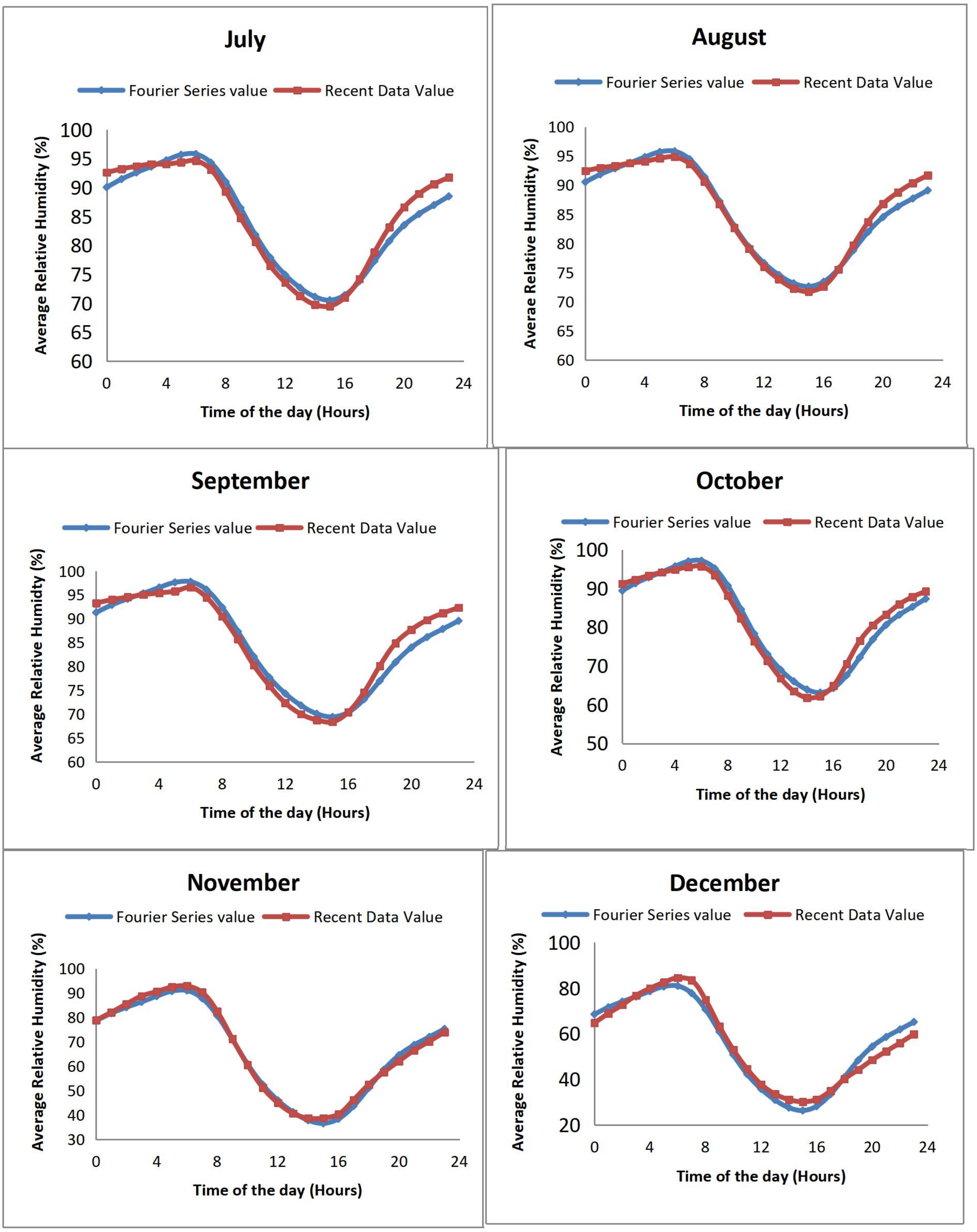

Figure 8: Comparison of results predicted with Fourier series model with the actual weather data for relative humidity for July to December for Ilorin

2.3 Determination of Accuracy of proposed models

The accuracies of the proposed models were determined by using Mean Absolute Percentage Error (MAPE). In accordance with Stellwagen (2015), MAPE of a model is determined using

$$\text{MAPE} = \left(\frac{1}{n}\sum_{i}^{n}\frac{|AV_i - FV_i|}{|AV_i|}\right)x100 \qquad (5)$$

Table 1 presents the MAPE for the determination of the accuracy of the two proposed models.

Table 1 The MAPE for comparison of results predicted using proposed models with the actual weather data

	Ikeja		Ilorin	
	Dry – bulb Temperature	Relative humidity	Dry – bulb Temperature	Relative humidity
January	2.29	1.08	2.76	5.82
February	1.59	1.06	2.33	9.65
March	1.43	0.85	1.68	4.55
April	1.00	0.95	0.97	1.19
May	1.50	0.79	0.92	1.66
June	1.11	0.54	2.89	1.81
July	3.27	0.78	2.37	1.93
August	1.64	0.55	1.95	1.23
September	1.51	1.53	2.98	2.20
October	1.44	0.82	4.03	2.45
November	1.91	0.90	5.14	2.37
December	3.69	1.67	4.63	6.33

3.0 Results and Discussion

The MAPE reveals that the models have percentage errors which are less than ten for all the months for the two locations and weather variables. The values were less than four percent for both dry-bulb temperature and relative humidity for Ikeja for the 12 months. It is only three months for dry-bulb and four months for relative humidity that MAPE values are greater than 4% for Ilorin. The agreement between dry - bulb temperature predicted using proposed models and those obtained from recent actual weather data are very good for both places but the agreement for the relative humidity are better.

Olorunmaiye et al (2012) reported that the average hourly temperature obtained for 1995 to 2008 data were higher than those obtained for 1978 to 1992 data for all the months of the year for both locations. Despite the manifestation of global warming, the proposed models revealed that the pattern of variation of dry bulb temperature and relative humidity are approximately the same for the two periods considered.

The proposed models may be applicable to some other tropical locations elsewhere having approximately the same latitudes as the two locations considered in this study.

4.0 Conclusion

Models for diurnal variations of dry-bulb temperature and relative humidity have been proposed. All that is needed to use them are input of monthly average values and of peak to peak amplitude of the cyclic diurnal variations of the weather variables.

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