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Estimation of Diffuse Solar Radiation for Yola, Adamawa State, North-Eastern, Nigeria

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Abstract - ***This present study evaluates the performance of four well-established models to estimate the diffuse solar radiation on a horizontal surface. The diffuse solar radiation using measured global solar radiation during the period of thirty one years (1980 – 2010) for Yola, North Eastern, Nigeria (Latitude 09.14^{0}N, Longitude 12.28^{0}E and altitude 186.1 m above sea level) has been estimated by using the following models; Page, Liu and Jordan, Colleras-Pereira and Rabi and Chandrasekeran and Kumar. The reliability of the estimated diffuse solar radiation based on coefficient of determination for all the considered models gives values greater than 98%. The monthly average ratio of daily diffuse to global solar radiation and the values of the clearness index reveals that Yola enjoys clear sky conditions for most of the year which attests to the abundant of solar energy and its potential to produce clean energy sources in this area and its environs.***

Key Words: *global solar radiation, diffuse solar radiation, clear sky conditions, clearness index, Yola.*

1. INTRODUCTION

Solar energy is one of the most promising renewable sources, this is because it is environmentally friendly, abundant and easy to utilize. This shows that among the renewable resources, solar energy has the greatest potentiality, availability and is free from environmental hazards. The knowledge of the amount of the available solar energy and its variability over any geographical region is very paramount for solar energy utilization, especially in the absence and scarcity of reliable monthly solar radiation data. The global solar radiation is divided into two components; diffuse solar radiation, which results from scattering of solar radiation caused by gases in the Earth's atmosphere, dispersed water droplets and particulates while direct solar radiation, sometimes called beam radiation is used to describe solar radiation travelling on a straight line from the sun down to the surface of the Earth. That is, one that have not been scattered. Global solar radiations in Nigeria are measured at some stations while diffuse solar radiation is not observed experimentally in any meteorological station of the country. However, empirical correlations are usually used to extract diffuse and direct solar radiation from the global solar radiation obtained over a horizontal surface from the location under study. The monthly average daily diffuse solar radiation is usually estimated using an empirical formula developed by Page [8] which correlates the diffuse components of the solar radiation to the daily measured total radiation. [6] proposed a model relating the ratio of diffuse to global solar radiation incident on a horizontal surface with the clearness index and developed by [5]. In another study, [2] proposed a fourth order polynomial relation using data from five stations in United States. Similarly, [1] proposed another fourth order polynomial relation using data from India. [7] used measurements of global and diffuse solar radiations at the Earth's surface, in the city of Sao Paulo, Brazil to develop correlation models to estimate hourly, daily and monthly diffuse solar radiation on horizontal surfaces.

The objective of this paper is to examine a comparative study for estimating diffuse solar radiation for Yola during the period of thirty one years (1980 – 2010) based on four relevant existing well-known proposed models.

2. METHODOLOGY

The measured monthly average daily global solar radiation covering a period of thirty one years (1980-2010) for Yola, Adamawa State, North – Eastern, Nigeria was obtained from the Nigeria Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria. Monthly averages over the thirty one years of the data in preparation for correlation are presented in **Table 1.**

The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) in $(MJm^{-2}day^{-1})$ can be calculated for days giving average of each month [4] and [9 - 10] from the following equation [4] and [10]:

$$H_o = \left(\frac{24}{\pi}\right) I_{sc}\left[1 + 0.033Cos\left(\frac{360n}{365}\right)\right]\left[Cos\varphi Cos\delta Sin W_s + \left(\frac{2\pi W_s}{360}\right) Sin\varphi Sin\delta\right] \quad (1)$$

where I_{sc} is the solar constant (=1367 Wm^{-2}), φ is the latitude of the site, δ is the solar declination and W_s is the mean sunrise hour angle for the given month and n is the number of days of the year starting from 1^{st} of January to 31^{st} of December.

The solar declination, δ and the mean sunrise hour angle, W_s can be calculated using the following equation [4] and [10]:

$$\delta = 23.45sin\left\{360\left(\frac{284+n}{365}\right)\right\} \quad (2)$$

$$W_s = Cos^{-1}(-tan\varphi tan\delta) \quad (3)$$

[8] Proposed a model for estimating diffuse solar radiation which is given by the relation

$$\frac{H_d}{H} = 1.00 - 1.13K_T \quad (4)$$

[6] Proposed a correlation which was developed by [5] and is given by the relation

$$\frac{H_d}{H} = 1.390 - 4.027K_T + 5.531K_T^{\ 2} - 3.108K_T^{\ 3} \quad (5)$$

[2] proposed a fourth order polynomial relation using data from five stations in United States and is given by the relation

$$\frac{H_d}{H} = 1.188 - 2.272K_T + 9.473K_T^{\ 2} - 21.856K_T^{\ 3} + 14.648K_T^{\ 4} \quad (6)$$

[1] Proposed another fourth order polynomial relation using data from India and is given by the relation

$$\frac{H_d}{H} = 1.006 - 0.317K_T + 3.124K_T^{\ 2} - 12.760K_T^{\ 3} + 9.717K_T^{\ 4} \quad (7)$$

From equations (4 – 7) H_d is the diffuse solar radiation$(MJm^{-2}day^{-1})$, H is the global solar radiation $(MJm^{-2}day^{-1})$ K_T is the clearness index. The clearness index (K_T) is calculated using [3] as

$$K_T = \frac{H}{H_o} \quad (8)$$

The global solar radiation (H) diffuse solar radiation (SR_{diff}) and direct solar radiation (SR_{dir}) are related by the equation:

$$H = SR_{diff} + SR_{dir} \quad (9)$$

where H, is the global solar radiation, SR_{diff} is the diffuse solar radiation and SR_{dir} is the direct solar radiation. H, SR_{diff} and SR_{dir} are measured in $(MJm^{-2}day^{-1})$ In this study, equations (4 – 7) are the four existing models to be examined.

3. RESULTS AND DISCUSSION

Table 1: Input parameters for estimation of monthly average daily diffuse solar radiation for Yola (1980 – 2010)

Month	H_0 ($MJm^{-2}day^{-1}$)	H_{mea}($MJm^{-2}day^{-1}$)	H/H_0
Jan	32.3897	22.8410	0.7052
Feb	34.7332	24.8447	0.7153
Mar	36.9554	25.5292	0.6908
Apr	37.8132	24.7991	0.6558
May	37.3244	22.6668	0.6073
Jun	36.7167	21.1485	0.5760
Jul	36.8609	18.6553	0.5061
Aug	37.3762	19.0701	0.5102
Sep	37.0400	20.8539	0.5630
Oct	35.2198	23.5338	0.6682
Nov	32.7995	24.1519	0.7363
Dec	31.5076	22.5009	0.7141

Table 2: The diffuse solar radiation for Yola (1980 – 2010) based on the considered models, equations (4 – 7)

Month	H_d(Page)	H_d(L&J)	H_d(C&R)	H_d(C&K)
Jan	4.6397	4.8147	5.8135	6.0359
Feb	4.7630	5.0176	6.0979	6.2480
Mar	5.6007	5.6929	6.8893	7.2557
Apr	6.4208	6.2300	7.8635	8.4326
May	7.1119	6.5322	9.0475	9.7336
Jun	7.3836	6.5890	9.6838	10.3844
Jul	7.9865	6.8229	11.0498	11.7368
Aug	8.0752	6.9107	11.1471	11.8464
Sep	7.5866	6.7006	10.0700	10.7796
Oct	5.7643	5.6821	7.0359	7.5134
Nov	4.0557	4.4149	5.5942	5.5224
Dec	4.3431	4.5673	5.5444	5.6904

In Table 2 H_d(Page), H_d(L&J), H_d(C&R) and H_d(C&K) are measured in $(MJm^{-2}day^{-1})$

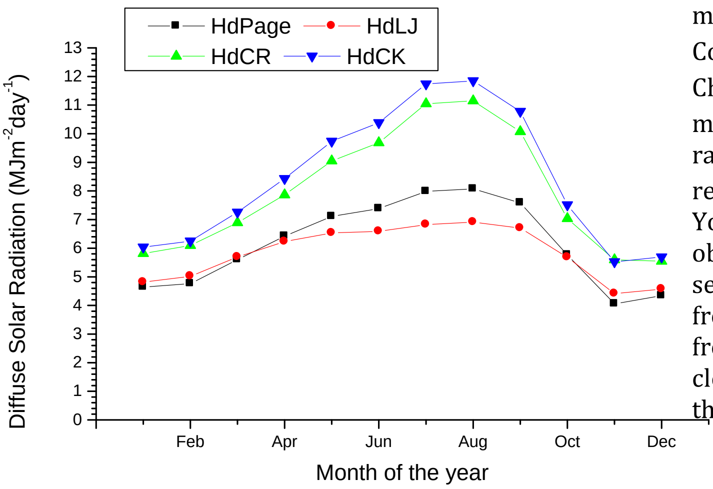

Figure 1: Monthly average daily diffuse solar radiation based on adopted models for Yola (1980-2010)

The monthly average daily diffuse solar radiation (DSR) is computed for Yola using the adopted models in equations (4 – 7) using the measured clearness index during the period of thirty one years (1980 – 2010). The resulting monthly average of daily DSR is shown in Figure 1. It is clear from the figure that the highest values of DSR was recorded for Chandrasekeran and Kumar model, except in the month of November where the Colleras-Pereira and Rabi overestimated that of the Chandrasekeran and Kumar model. The Page and the Liu and Jordan models produce the lowest values of DSR.

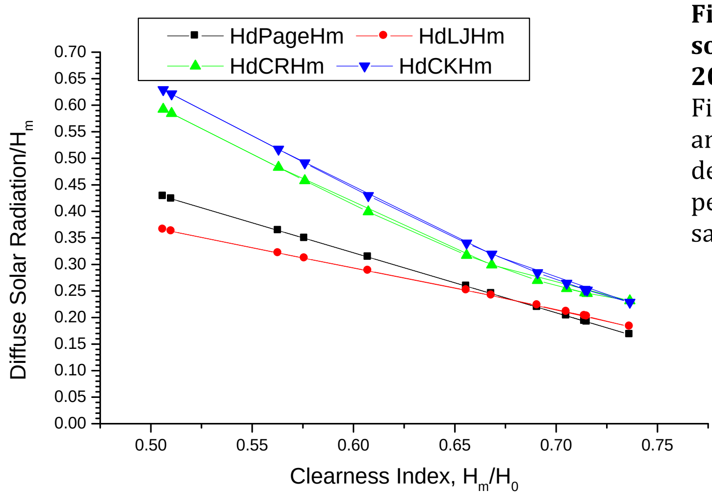

Figure 2: Ratio of diffuse to global solar radiation as a function of Clearness index for Yola (1980-2010)

Figure 2 shows the plots of the diffuse to global solar radiation ratio verses the clearness index for the aforementioned models. All the four considered models for the diffuse solar radiation have nearly linear trends with coefficient of determination for Page model($R^2 = 100\%$), Liu and Jordan model($R^2 = 99.9\%$), Colleras-Pereira and Rabi ($R^2 = 98.9\%$) and Chandrasekeran and Kumar model($R^2 = 99.6\%$). The measured clearness index data for Yola lie within the range $0.5061 - 0.7363$ with the lowest and highest values recorded in the months of July and November respectively. Yola like most other regions in Nigeria are known to observe two distinct weather conditions, that is, the rainy season and the dry season. The rainy season months are from April to October, while the dry season months are from November to March. This implies that the lowest clearness index was recorded during the rainy season and the highest during the dry season.

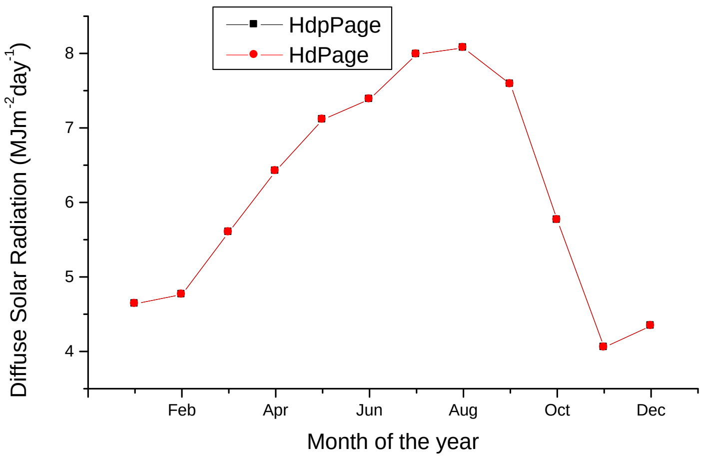

Figure 3: Comparison between the predicted diffuse solar radiation and the Page model for Yola (1980-2010)

Figure 3 shows the comparison between the Page model and the predicted diffuse solar radiation based on the developed regression equations, it can be seen that a perfect correlation existed between them as both has the same values of the DSR.

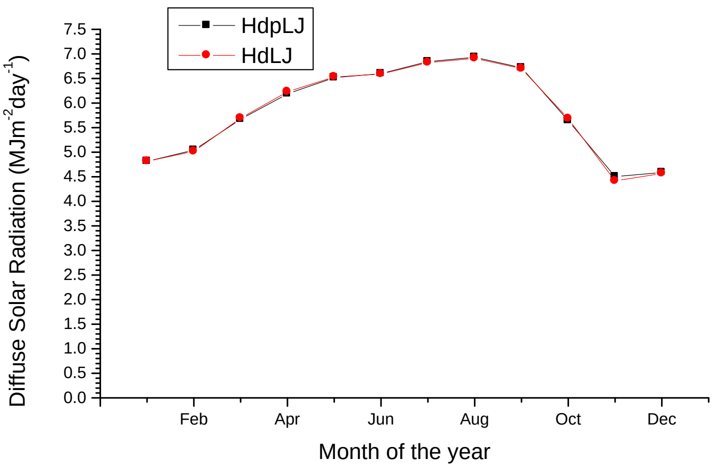

Figure 4: Comparison between the predicted diffuse solar radiation and the L & J model for Yola (1980-2010)

Figure 4 shows the comparison between the Liu and Jordan model and the predicted diffuse solar radiation based on the developed regression equations, it can be seen that a good correlation existed between them, though, a noticeable overestimation of the Liu and Jordan model can be seen in the month of November.

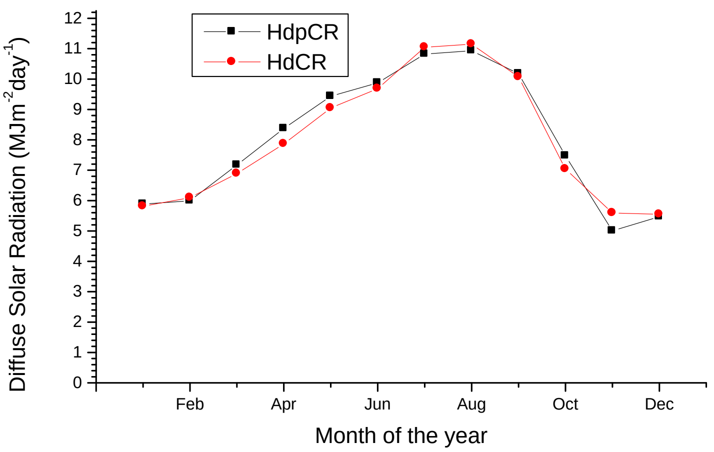

Figure 5: Comparison between the predicted diffuse solar radiation and the C & R model for Yola (1980-2010)

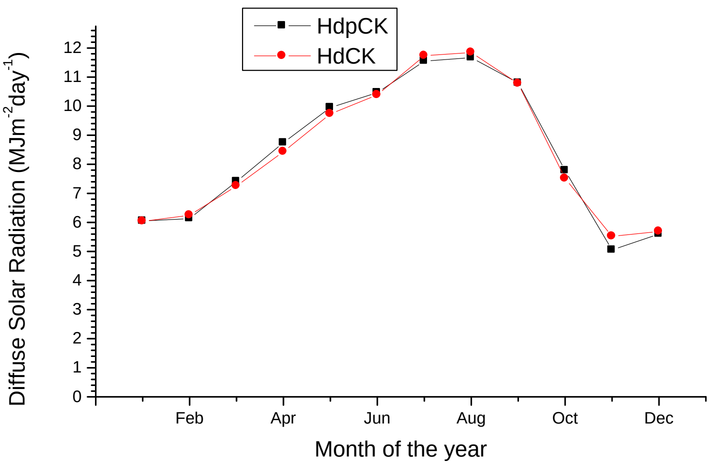

Figure 6: Comparison between the predicted diffuse solar radiation and the C&K model for Yola (1980-2010)

Figure 5 and 6 gives a fairly good correlation between the predicted diffuse solar radiation and the models. It can be observed from the figures that there are noticeable underestimation and overestimation in the predicted values.

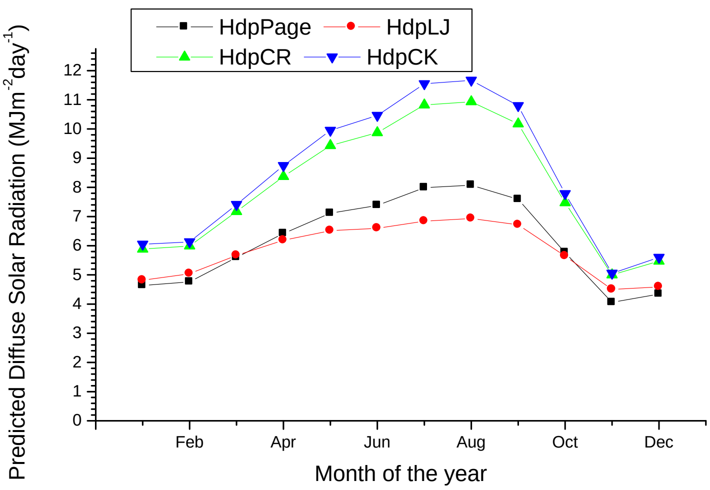

Figure 7: Predicted monthly average Diffuse Solar Radiation for Yola (1980-2010)

The predicted average daily diffuse solar radiation computed based on developed models using the measured clearness index for the respective months are displayed in figure 7

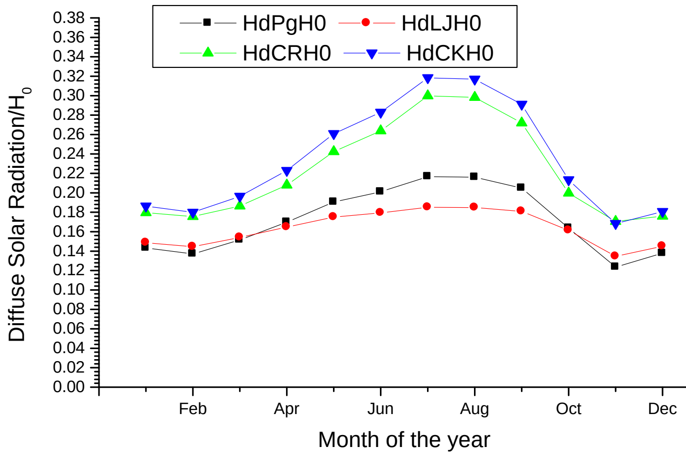

Figure 8: Monthly average daily ratio of diffuse to extra-terrestrial solar radiation for Yola (1980 – 2010)

Figure 8 shows the ratio of diffuse to extraterrestrial solar radiation for Yola during the period of thirty one years (1980 – 2010). It is interesting to note that the contribution of the diffuse solar radiation does not exceed 31.90%. The highest being 31.84% during the month of July for Chandrasekeran and Kumar model and the lowest as 16.84% in the month of November, the Page and Liu and Jordan models underestimated the diffuse radiation. However, in the absence of measured values of diffuse radiation it is difficult to establish the superiority of one over the other in terms of the best predicting model (Chandrasekeran and Kumar, or Page and Liu and Jordan models).

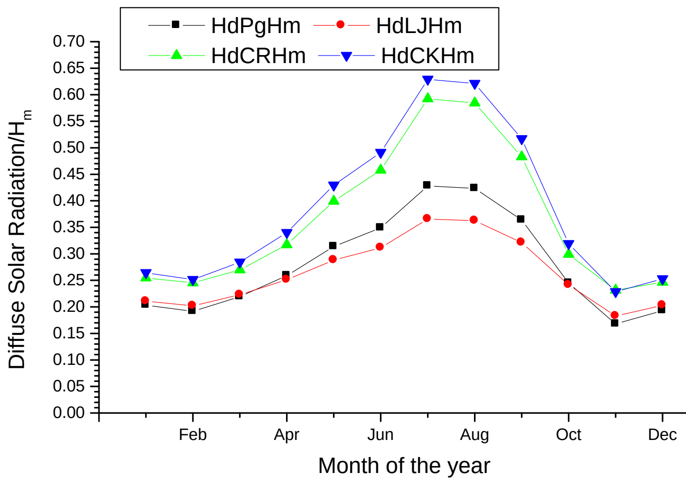

Figure 9: Monthly average of diffuse to global Solar Radiation for Yola (1980-2010)

Figure 9 shows the monthly average ratio of daily diffuse to global solar radiation for Yola during the period of thirty one years (1980 – 2010). Based on the Page model the diffuse radiation does not exceed 42.81% during the month of July with a low value of 19.17% in February. This implies that the direct solar radiation in Yola will be between 57.19% in July and 80.83% in February. Similarly, based on Chandrasekeran and Kumar model the diffuse radiation does not exceed 62.91% during the month of July with a low value of 22.87% in November. This implies also that the direct solar radiation in Yola will be between 37.09% in July and 77.13% in November. Hence, it can be estimated that Yola enjoys clear sky weather condition of at least 38% during the rainy season and at least 78% during the dry season throughout the year.

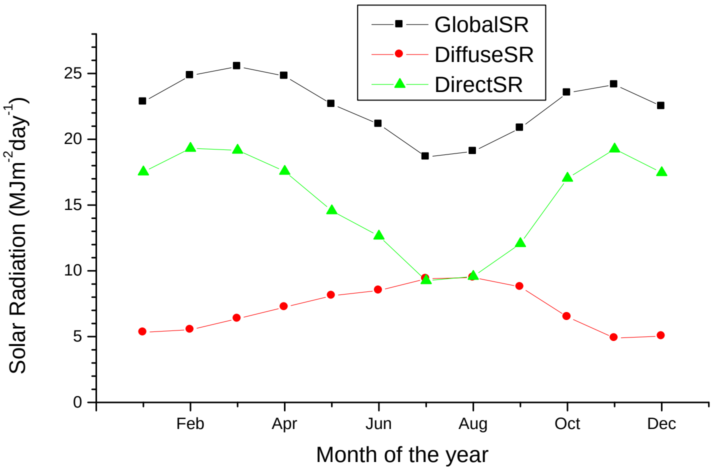

Figure 10: Comparison between the Global, Diffuse and Direct Solar Radiation for Yola.

Figure 10 shows the variation of the global, diffuse and direct solar radiation. It is interesting to note from the figure that the lowest global and direct solar radiation was recorded in the month of July and August; this is the period of heavy rainfall in Yola, Nigeria. On the other hand, the maximum diffuse solar radiation was recorded in the months of July and August. The global and direct solar radiation depicts almost the same pattern while the diffuse solar radiation shows almost opposite or inverse pattern. The overall results shows that the global solar radiation has the highest values of solar radiation as compared to that of the direct and diffuse solar radiations while diffuse solar radiation has the least values. Though, this is expected as the global solar radiation is the sum of the direct and diffuse solar radiation.

4. CONCLUSIONS

The daily diffuse solar radiation for Yola during the period of thirty one years (1980 – 2010) has been estimated based on four well-known existing models namely; Page, Liu and Jordan, Colleras-Pereira and Rabi and Chandrasekeran and Kumar. However, due to the absence of measurement of diffuse solar radiation to carry out the statistical test analysis, the best predicting models has not been established (Chandrasekeran and Kumar or Page, Liu and Jordan models). The coefficient of determination for all the models shows values greater than 98%. The diffuse solar radiation was correlated with the measured global solar radiation and the extraterrestrial solar radiation. The ratio of diffuse solar radiation to measured global solar radiation gives minimum values of 19.17% in February for Page model and 22.87% in November for Chandrasekeran and Kumar model. The maximum values were recorded in the month of July as 42.81% and 62.91% for Page and Chandrasekeran and Kumar respectively. The variation of global, direct and diffuse solar radiation reveals global solar radiation to have the highest value of solar radiation and diffuse solar radiation as the least; this is expected for Yola and shows a very strong platform for energy strategists and planners to utilize the solar energy potential for Yola and its environs.

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