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Evaluation and Comparison of Temperature-Based Models for The Prediction of The Monthly Average of Daily Global Solar Radiation for Baghdad City-Iraq

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Abstract

The solar energy is the major source of power for the future and an important source of renewable energy in Iraq and the world. Suitable climate conditions for solar energy are available in Iraq, especially the high temperature in the summer season which extends for more than six months in the year. Hence, the global solar radiation is abundant with high intensity, which is very essential in applicable models for researchers and solar applications. Therefore, nine first-order regression empirical equations of Angstrom-type correlations were used to estimate the more appropriate global solar radiation model for Baghdad city. Two equations were developed empirically in this work, using the most available and easy to get meteorological data, which is the temperature value in various forms. The results of the comparison between the real and calculated values showed reasonable agreement for most equations (including the development of R^2- at 99%) as well as the least values of types of errors RMSE and MBE. As an exception, two equations of models failed in this study because of inability to apply to such climate conditions of Baghdad city.

Keywords: Global Solar Radiation, Temperature, Empirical Models, Angstrom-Type.

تقييم ومقارنة النماذج المعتمدة على درجة الحرارة لتقدير الاشعاع الشمسي الكلي بمعدل الشهري اليومي لمدينة بغداد ، العراق

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الخلاصة

الطاقة الشمسية هي المصدر الرئيسي للطاقة في المستقبل ، وهي مصدر مهم للطاقة المتجددة في العراق والعالم. بسبب الظروف المناخية المناسبة للطاقة الشمسية في العراق ، خاصة ارتفاع درجة الحرارة في أشهر الصيف والتي تزيد عن ستة أشهر في السنة ، لذلك الإشعاع الشمسي العالمي وفير ذو شدة عالية ، حيث إنه من الضروري للغاية في النماذج المطبقة للباحثين و تطبيقات الطاقة الشمسية. لذلك ، تم استخدام تسعة معادلات من الدرجة الأولى ذات انحدار كمعادلات تجريبية من نوع أنجستروم لتقدير الإشعاع الشمسي العالمي الأكثر ملاءمة

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لمدينة بغداد ، حيث تم تطوير معادلتين تجريبيا في هذا العمل. استخدام بيانات الأرصاد الجوية المتاحة والأكثر سهولة في الحصول عليها، وهي قيم درجات الحرارة في أشكال مختلفة. أظهرت نتائج المقارنة بين القيم الحقيقية والقيم المحسوبة اتفاقًا معقولًا لمعظم المعادلات (بما في ذلك المطورة) لـ (R^2) عند 99% ، وكذلك اقل قيم لأنواع الأخطاء RMSE وMBE ، باستثناء معادلتين من النماذج فشلت في هذه الدراسة بسبب عدم امكانية تطبيقها على شروط مناخ مدينة بغداد.

INTRODUCTION

Calculating global solar radiation (GSR) using temperature as an independent variable is an important issue, especially for developing countries, for many reasons, such as the high cost of GSR data collection as well as the lack of maintenance for measurement equipment of GSR and the daily recording of GSR data. In another meaning, the limited coverage of the measurement of GSR indicates that there is a need to establish theoretical methods for estimating GSR. The applied methods include those based on empirical correlations using meteorological data to lower data requirement and computation cost. Thus, it is important to search for models to estimate the GSR using various meteorological data.

The focus of recent research has been on estimating GSR, such as the common meteorological data estimation in Spain reported by Javier ALMOROX [1]. Empirical models for estimating GSR were proposed by Besharat *et al*. as a review and case study in Iran [2] and in a review of solar models presented by Katiyar and Pandey in India [3]. Huashan *et al.* worked on a temperature –based model for estimating monthly average daily GSR in China [4], while by Okonkwo and Nwokoye estimated GSR from temperature data in Minna [5]. A new temperature-based model for estimating GSR in Nigeria was proposed by Akootu and Sanusi [6], while other reports described the temperature-based models for estimating GSR in India and Egypt in the same year [7,8].

This paper presents first-order regression Angstrom-type correlations which used maximum and minimum temperatures as abundant data. In this work, two correlations were newly developed empirically along with the other seven well-known correlations. All of these correlations were performed in the form of mathematical equations that relate the clearness index as the dependent variable with maximum and minimum temperature as an independent variable, in addition to sunshine duration. The calculated data obtained were tested for errors using popular errors test methods, such as coefficient of determination (R^2), root mean square error (RMSE) and mean bias error (MBE) errors to compare the measured with the calculated values.

DATA AND METHODOLOGY

The temperature (S_o)and monthly average daily GSR data were obtained from the Meteorological Centre and Seismic Monitoring in Baghdad (MCSM) for a period of 25 years (2009-2015). In our work, H_o terrestrial radiation (W/m^2) [9] was theoretically calculated depending on latitude and longitude for H_o use on monthly average daily values.

These nine first-order type linear regression equations were employed to calculate monthly average daily global solar radiations H_c using input available from maximum (T_{max}) and minimum (T_{min}) temperatures data and in ^{o}C and S_o of the sunshine for Baghdad city in hours, as follows:

$$\frac{H_c}{H_o} = b + a\Delta T^{0.5} \quad (1)$$

$$\frac{H_c}{H_o} = b + a\left(\frac{T_{max}}{T_{min}}\right) \quad (2)$$

$$\frac{H_c}{H_o} = b + a\left(\frac{\Delta T}{S_o}\right) \quad (3)$$

$$\frac{H_c}{H_o} = b + a\, ln(T_{mean}) \quad (4)$$

$$\frac{H_c}{H_o} = b + a\, ln(\Delta T) \quad (5)$$

$$\frac{H_c}{H_o} = b + a\,(T_{max}) \quad (6)$$

$$\frac{H_c}{H_o} = b + a\left(\frac{T_{mean}}{S_o}\right) \quad (7)$$

$$\frac{H_c}{H_o} = b + a\left(\frac{T_{min}}{S_o}\right) \quad (8)$$

$$\frac{H_c}{H_o} = b + a\left(\frac{T_{min}}{T_{max}}\right) \quad (9)$$

Where a and b are constants and empirical coefficients for each equation, $T_{mean} = \frac{T_{max}+T_{min}}{2}$ is the monthly average daily, and ΔT is the monthly average daily for the difference between T_{max} and T_{min}, all in (°C).
Equation (1) was based on the HS model [4].
Equation (2) was based on Pandey and Katiyar [3].
Equation (3), was based on Garcia model, while Equations (4and (5) depended on another method [6].
Equation (6) was based on a previous report [5].
Equations (7) and (8) were developed empirically in this work.
Equation (9) was based on a previous report [10].
The empirically developed equations (7) and (8) are an adaptation of Angstrom-Prescott model given as $\frac{H_c}{H_o} = b + a\left(\frac{\Delta T}{S_o}\right)$, where it relates the clearness index ($\frac{H_c}{H_o}$) and the ratio of the monthly average daily of temperature range to the monthly average daily of day length ($\frac{\Delta T}{S_o}$), which is the modification of the original Angstrom equation. Subsequently, it is possible to use (T_{mean}) and (T_{min}) as a temperature range divided by (S_o). The empirically developed equations (7) and (8) showed excellent matching between the measured and calculated values of monthly average daily of global solar radiation. In general, the developed models for this study were in a form of mathematical equations that relate the clearness index as the dependent variable with temperature as the independent variable [6].

RESULTS AND DISCUSSION

The first-order Angstrom-type regression linear equations were carried out between the monthly average daily of measured (real data) global solar radiation on horizontal surface (H_m) (in w/m^2) and the meteorological parameter (temperature, T) as the independent variables (in °C). This was performed to obtain the values of empirical coefficients of the nine stated equations. (a and b) as listed in Table- 1, where the stations reported that the coefficients are site-dependent due to the use of local data bases, re-applied to predicting the calculated values of global solar radiation (H_c) in w/m^2.
The coefficient of determination (R^2) index was used to determine how well the regression linear approximates the real data points:

$$R^2 = 1 - \left[\frac{\sum(H_{im}-H_{ic})^2}{\sum\left(H_{im}-H_{average\,m}\right)^2}\right] \quad (10)$$

where the more perfect coefficients model is when R^2 is close to1. The results in Table- 2 show that most of the selected equations give an R^2 value that was higher than 95%, indicating a very good fitting between the measured monthly average daily global radiations (H_m) with the calculated values (H_c).

Table 1

Model	***a***	***B***
1	0.1394	0.0996
2	-0.0304	0.6511
3	-0.0473	0.6405
4	0.0523	0.4294
5	0.2386	-0.098
6	0.003	0.5016
7	0.0333	0.5256
8	0.0434	0.5306
9	0.1742	0.4969

Table 2

Model	R^2	***RMSE***	***MBE***
1	0.99	0.75	-0.01
2	0.99	2.67	-0.14
3	0.97	4.28	-0.22
4	0.89	17.04	-1.89
5	0.67	46.80	-3.45
6	0.99	0.65	-0.03
7	0.99	2.61	-0.13
8	0.99	1.67	-0.08
9	0.99	1.94	-0.10

The performance of developed Equations 7 and 8 (basically as an adaptation of the Angstrom-Prescott) and the other equations 1, 2, 3, 6, 9 were used to predict the global solar radiation on the horizontal surface (H_c). They showed a good agreement with the measured real data (H_m) values, except equations 4 and 5 which showed not good performance. Comparisons were performed based on the root mean square error (RMSE) and mean bias error (MBE) indicators, presented in table 2, where, for a higher equation accuracy, RMSE and MBE indices should be closer to zero.

$$RMSE = \left[\frac{1}{N_{obs}}\sum(H_{im} - H_{ic})^2\right]^{0.5} \tag{11}$$

$$MBE = \frac{1}{N_{obs}}\sum H_{im} - H_{ic} \tag{12}$$

It was found that the RMSE values for all equations were in the range from 0.65 to 4.28, as in Table-2, while the MBE values for all equations were in the range from -0.01 to -0.22, showing mostly underestimated measured values (H_m) by these equations.

However, most equations generally produced acceptable RMSE and MBE errors as seen in Figures 1-3 and 6-9, as compared to equations (4) and (5) which were not applicable for Baghdad city and showed overestimated predicted values. This is reflected in table 2 where RMSE and MBE values are very high, while R^2 values are above normal and unacceptable. As seen in Figures- 4 and 5, a high level of overestimation was observed throughout the months of the year and, therefore, they are considered as the lowest-efficient performance models in this work.

The new empirically developed equations 7 and 8, which were used in this work to estimate the monthly average daily global solar radiation on horizontal surface (H_c), can be successfully used for Baghdad city, as can be obviously observed in Fgures- 7 and 8 as well as in Table-2 for RMSE, MBE and R^2 values.

Based on the statistical indicators presented in Table-2, all equations showed a good estimation of monthly average daily global solar radiation on a horizontal surface (H_c) for Baghdad city. Equations (1) to (3) and equations (6) to (9) are recommended for predicting the calculated values (H_c) for Baghdad city (Figures- 1-3 and 6-9). They had the best overall results of consistently and a good estimate when applied to the monthly average daily data for all months in the year, as well as elsewhere with similar climatic conditions.

It is clear that Figures- 1-3 and 6-9 show a good matching between measured and predicted global solar radiation data for most months. Figures- 1-3 showed overestimated values in the months of April to September and underestimated values in the other months. Figures- 6-9 demonstrated overestimated values in the months April, June and August and underestimated values in the other months.

The best overall agreement and excellent matching are seen in Figures-(1 and 6), where RMSE, MBE and R^2 values are 0.75 & 0.65, -0.01&-0.03 and 99% for both, respectively. In addition, Figures- 8 and 9 show agreement and matching values for RMSE, MBE and R^2 values of 1.67 & 1.94, -0.08 & -0.10 and 99% for both, respectively. Next, Figures –(2and7), then the last is Figure-3, see Table-2.

However, equations -4- and -5- are not recommended for predicting values of H_c for Baghdad city, as seen in Figures-(4 and 5).

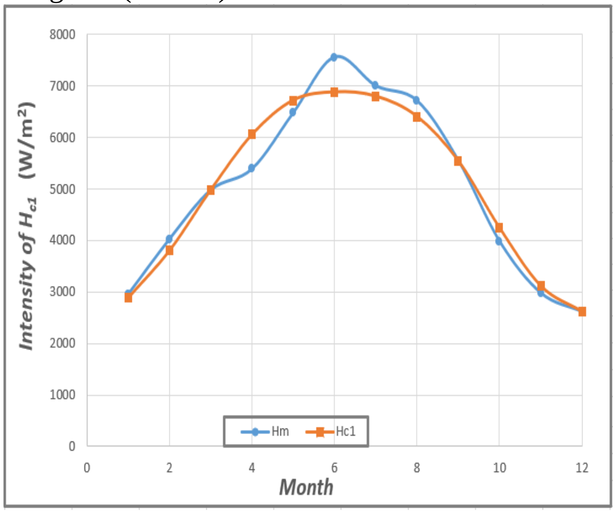

Figure 1-The monthly averages daily values of H_m, $H_{c1}$and H_{c2} for Baghdad city

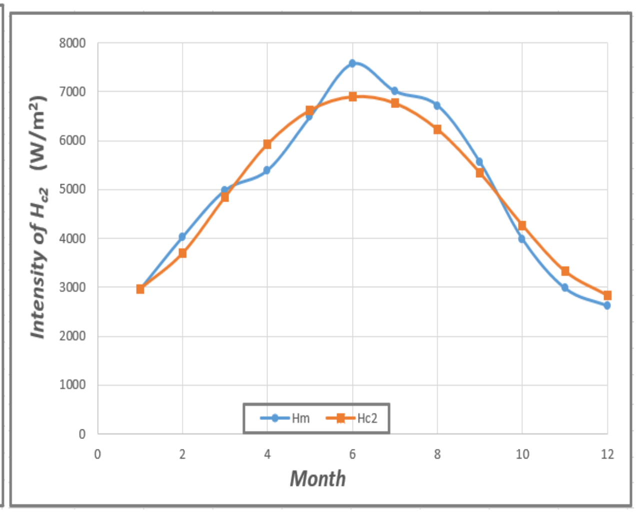

Figure 2-The monthly averages daily values of H_m, $H_{c1}$and H_{c2} for Baghdad city

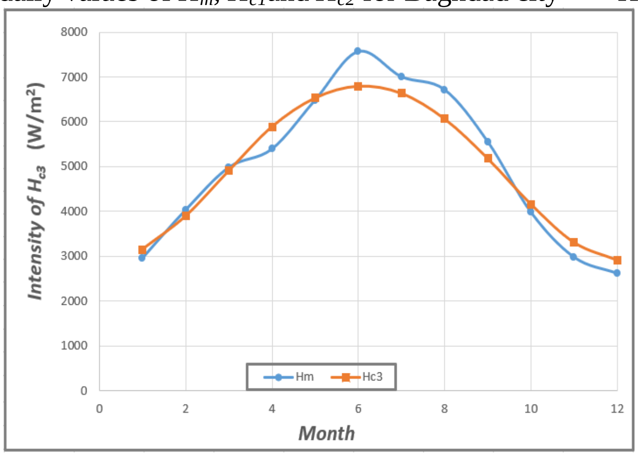

Figure 3-The monthly averages daily values of H_m, $H_{c3}$and H_{c4} for Baghdad city.

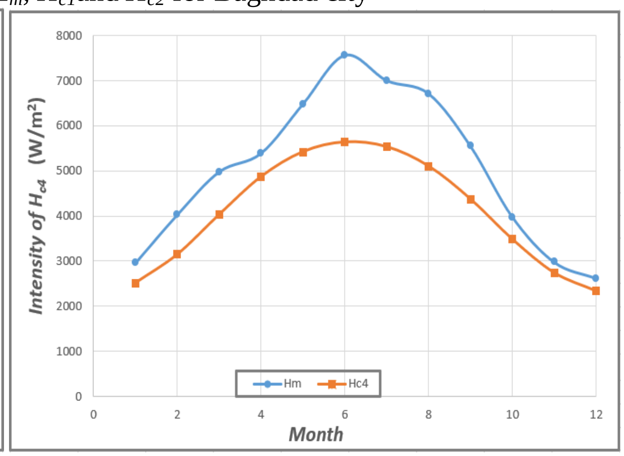

Figure 4-The monthly averages daily values of H_m, $H_{c3}$and H_{c4} for Baghdad city.

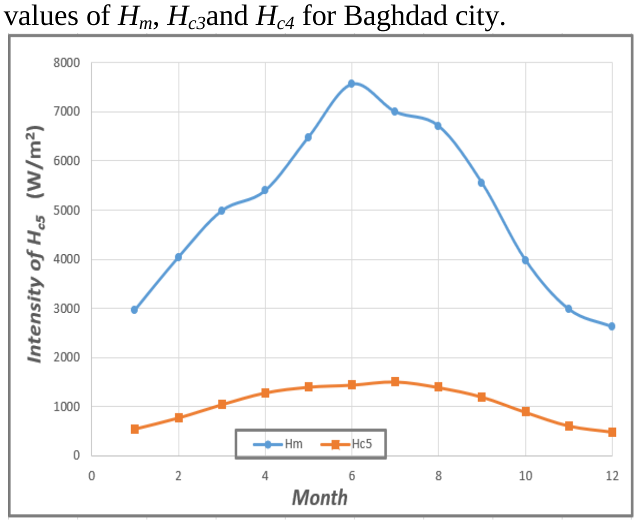

Figure 5-The monthly averages daily values of H_m, $H_{c5}$and H_{c6} for Baghdad city.

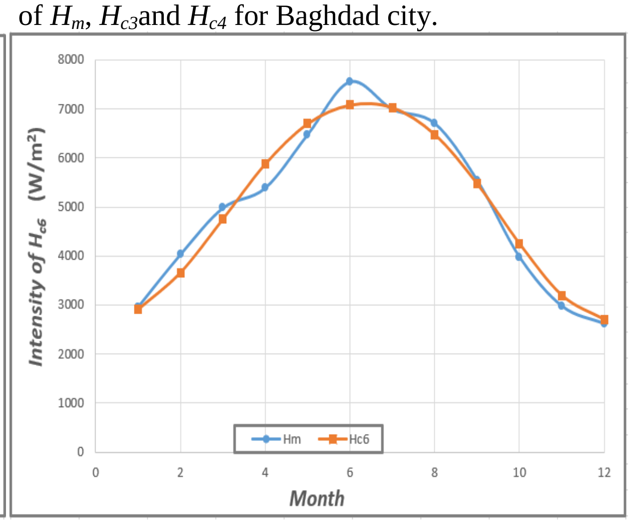

Figure 6-The monthly averages daily values of H_m, $H_{c5}$and H_{c6} for Baghdad city.

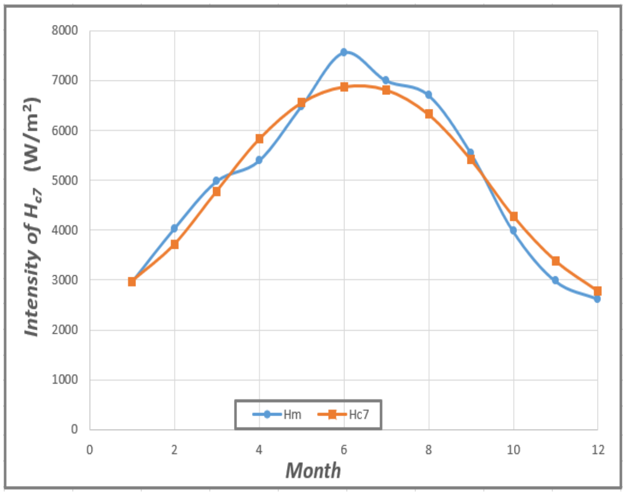

Figure 7- The monthly averages daily values of H_m, $H_{c7}$and H_{c8} for Baghdad city.

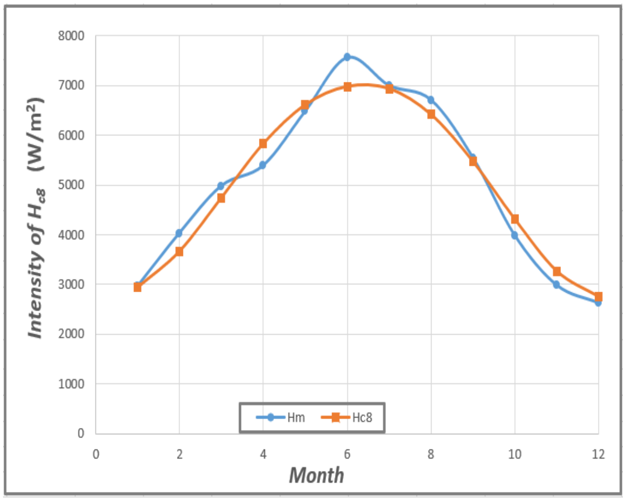

Figure 8- The monthly averages daily values of H_m $H_{c7}$and H_{c8} for Baghdad city.

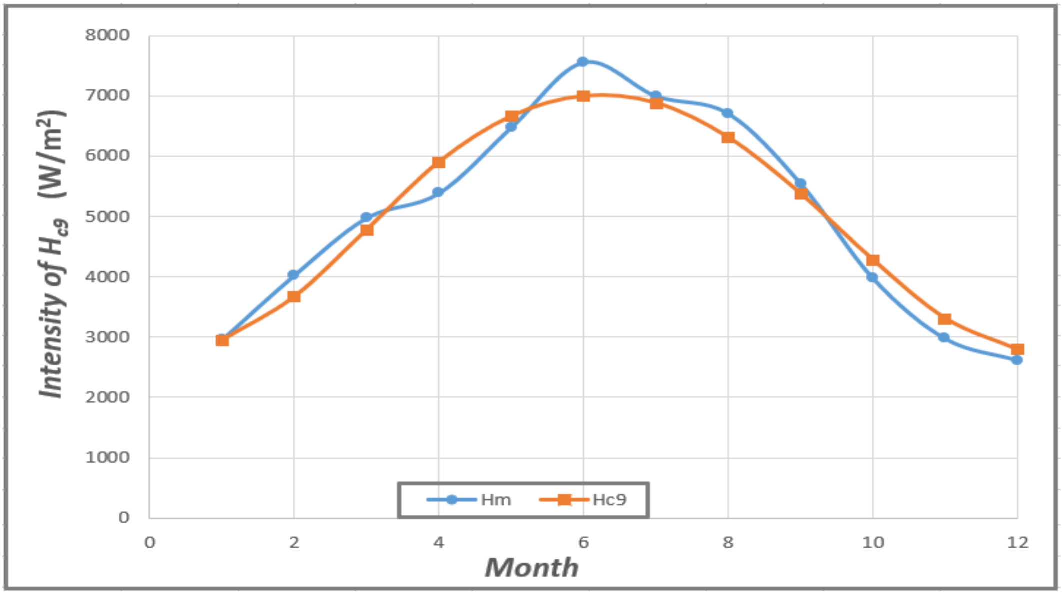

Figure 9-The monthly averages daily values of H_m and H_{c9} for Baghdad city.

CONCLUSIONS

The importance of meteorological data that are easily measured and obtained in Iraq is clear. Hence, temperature values used as a basis to estimate and predict the monthly average daily global solar radiation in Baghdad, using nine first-order Angstrom-type regression linear equations, are applicable and simple. The results show that the five models' equations as well as the tow developed equations have a good agreement between the measured and calculated values. Hence, we recommend applying these equations for cities that have same weather conditions, except for tow equations which showed worst results and, hence, are not recommended for Baghdad cityin particular.

The values of empirical coefficients of nine stated equations (*a* and *b*), as listed in Table- 1 were re-applied to calculate the predicted values. The comparison was made between measured and calculated values using well-known types of errors included in Table-2. Then the measured and calculated values were drawn in Figures-(1-9). Equations and their Figures-(1-3 and 6-9) provided a reasonable degree of best fitting between measured and predicted values for Baghdad city, but equations and their Figures-(4

,5) failed to show a good matching because they are applicable for cities of climate and weather conditions different from those of Baghdad. Therefore, they are not recommended for Baghdad city in particular. The scientific interest in the developed equations and their Figures-(7, 8), providing diversity in the use of temperature in various forms, can make use of the higher flexibility to use the mean temperature, thereby lowering the cost of data set by using the minimum temperature only. Thus, these equations can be adopted in the future for predicting global solar radiation as first-order Angstrom type regression linear equations.

The study was applied on data for 25 years (1990-2015), where the effect of weather changing is not sensible obviously.

The recommendation is to study the effects of global warming in climatological data as temperate and to calculate global solar radiation based on these climatological data.

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