An Assessment of the ASHRAE Clear Sky Model for Irradiance Prediction in Thailand Nuntiya

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Abstract: In Thailand, the ASHRAE clear sky model is commonly used as a basic tool for solar heat load calculation of air conditioning systems and building designs, in the engineering and the architectural communities. Unfortunately, this model was developed for the atmospheric condition in USA, which was quite different from the condition in Thailand. Joeijoo and Sorapipatana assessed the accuracy of the ASHRAE model in the northern part of Thailand. They found that the model considerable over estimated for global and direct solar radiation, and under estimated for diffuse solar radiation. In this study, an attempt was made in order to improve the accuracy of the model by revising all parameters of the ASHRAE model under the atmospheric condition of Thailand.

The five-year data of the solar radiation recorded by Silpakorn University's network in Chiang Mai, Ubon Ratchatani, Nakorn Pathom and Songkhla, , during year 1996-2000, were sorted out for clear sky days. The data of the sorted clear sky days were then used to revise the parameters of the ASHRAE model. Later, two-year data of the clear sky condition, during year 2001-2002, observed by the same network, were used to assess the accuracy and the suitability of the revised ASHRAE model. The comparisons between the revised and the unrevised one were also done.

From the study, it found that the predicted solar radiation obtained from the revised ASHRAE model was much more accurate than the unrevised one. The root mean square error (RMSE) of the revised model for global, direct and diffuse radiation, at those stations in the upper part of Thailand (excluded Songkhla) were 5.982%, 13.592% and 28.430%, respectively, and the corresponding mean bias error (MBE) found to be -0.136%, -2.816% and 9.222%, respectively. As compared to the RMSE of the unrevised ASHRAE model for global, direct and diffuse solar radiation were 15.382%, 37.485% and 64.399%, respectively, and the corresponding mean bias error (MBE) were 13.808%, 34.092% and -57.032% , respectively.

The root mean square error (RMSE) of the revised model for global, direct and diffuse radiation**,** at the station in the lower part of Thailand (Songkhla) were 6.096%, 12.101% and 35.792%, respectively, and the corresponding mean bias error (MBE) found to be -1.021%, -5.231% and 18.003%, respectively. As compared to the RMSE of the unrevised ASHRAE model for global, direct and diffuse solar radiation were 6.568%, 18.581% and 60.308%, respectively, and the corresponding mean bias error (MBE) were 2.749%, 14.132% and -48.680% , respectively.

Although the RMSE of the prediction of the revised model for the diffuse radiation were still considerable large, the accuracies of it have significantly been improved, as compared to those results of the unrevised one.

Keywords: Clear Sky Model, ASHRAE Model, Solar Radiation, Solar Heat Load Calculation, Thailand

Introduction

The ASHRAE clear sky model [1] is commonly used as a basic tool for solar heat load calculation of air conditioning systems and building designs among the engineering and the architectural communities in Thailand. Recently, Joeijoo and Sorapipatana[2] assessed the accuracy of the ASHRAE model in the northern part of Thailand. They found that the ASHRAE model is considerable over estimation for direct radiation, and under estimation for diffuse radiation. The reason for large errors in the prediction of the ASHRAE model stemmed from the assumptions of the standard atmospheric condition used in the model itself, which was hypothesized the clear sky as for a typical nonindustrial midlatitude atmospheric condition in USA.[3]. As a result, it gives large deviations for predictions in the tropical climate as in Thailand. In this study, an attempt was made in order to improve the accuracy of the model for the prediction of solar radiation in clear sky for Thailand by revising new parameters of the ASHRAE model.

The Ashrae Clear sky model
The ASHRAE clear sky model was originally developed by Moon (1940)[4], and later was modified by Threlkeld and Jordan (1958)[5] and Stephenson (1967)[6] . The ASHRAE model is shown in simple expressions as follows:

   (a) Direct normal solar radiation

The direct normal solar radiation on the surface normal to the

Sun's ray, $\dot{I}_{bn}$, is represented by:

$$\dot{I}_{bn} = A\exp(-B\sec\theta_z),$$ (1)

Where A = apparent solar irradiation
        B = atmospheric extinction coefficient
        θ_z = zenith angle.

Monthly variations of the constants A and B are listed in Table 1.
   (b) Diffuse solar radiation
The diffuse solar radiation on horizontal surface is given by:

$$\dot{I}_d = C\,\dot{I}_{bn},$$ (2)

Where C=the diffuse radiation factor and the values of C are also listed in Table 1.

Table 1 The constant parameters A,B,C and related parameters of the ASHRAE model for clear sky days on the twenty-first day of each month [1]

Month	Io W/m^2	Equation of time, min.	Declination, deg.	A W/m^2	B (Dimensionless ratio)	C (Dimensionless ratio)
Jan	1416	-11.2	-20.0	1209	0.142	0.058
Feb	1404	-13.9	-10.8	1193	0.144	0.060
Mar	1383	-7.5	0.0	1164	0.156	0.071
Apr	1360	1.1	11.6	1115	0.180	0.097
May	1339	3.3	20.0	1084	0.196	0.121
Jun	1330	-1.4	23.45	1069	0.205	0.134
Jul	1328	-6.2	20.6	1166	0.207	0.136
Aug	1343	-2.4	12.3	1088	0.201	0.122
Sep	1364	7.5	0.0	1131	0.177	0.092
Oct	1386	15.4	-10.5	1172	0.160	0.073
Nov	1408	13.8	-19.8	1199	0.149	0.063
Dec	1417	1.6	-23.45	1212	0.142	0.057

Data Sources

The data used in this study were obtained from the solar radiation measurement sites of Silpakorn University's network in Chiang Mai, Ubon Ratchatani, Nakorn Pathom and Songkhla. Their locations in Thailand are shown in Figure 1. These data consist of: 1) five-year data of global and diffuse solar radiation during 1996-2000. The global solar radiation was measured by Kipp and Zonen pyranometer, model CM21, and the diffuse solar radiation was measured by Kipp and Zonen pyranometer with a shade ring, model CM11&CM121. The output data of these measurements were recorded by the Yogokawa chart recorder, Model LR 4000. After year 1997, they were recorded by the Campbell data logger, Model XL 21. 2) two-year data of global and diffuse solar radiation in the clear sky days during 2001-2002. The data were observed and measured at the same sites and the same network.

Methods

The Geography of Thailand
Thailand is divided into four main regions: the northern, the northeastern, the central and the southern region. The northern region is partly mountainous areas. The northeastern region is a plateau with mountains in the west and the south. The central region is mainly flat areas with mountains in the west and the Gulf of Thailand in the south, respectively. The southern part of Thailand is a peninsula, and is flanked by Andaman Sea in the west and the Gulf of Thailand in the east

The climate of Thailand
The climate of Thailand is dominated by the Asian monsoon: the southwest or the summer monsoon and the northeast or the winter monsoon. The southwest monsoon prevails during May to October from the India Ocean to the inland country. It causes rainfalls and cloudy sky in the whole country. This is the wet season in Thailand. The northeast monsoon previals from the central Asia to this country during November to February. This monsoon generally brings relatively cool and dry air mass to the country, with partly clear sky days.
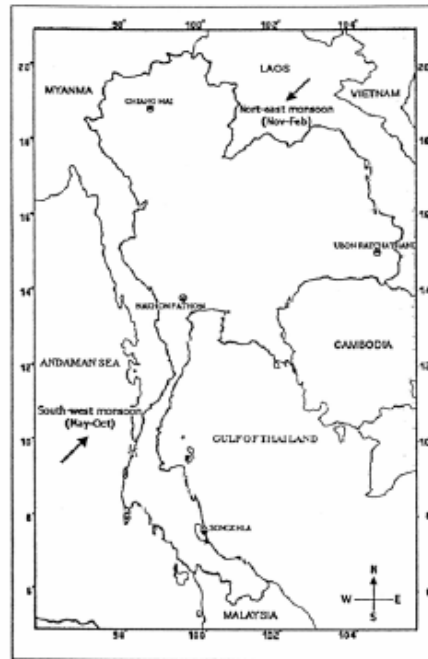
Fig. 1 A map of Thailand

At the point of view of Thailand's climate, the southern part of Thailand is moderate different from the rests of the country, as it always rains almost the year round. During the summer, the southwest monsoon prevails over the sea to the country. The air masses absorb high moisture water content and causes heavy rainfall and cloudy sky as it passes over the inland of Thailand. All regions have the rainfalls in this season. In contrast, during the winter, the northwest monsoon normally brings relatively cool and dry air masses to the country as it originates from the inland of the central Asia's land mass. However, as it travels across the Gulf of Thailand to the southern part of Thailand, the air masses absorb moisture from the sea and causes heavy rainfall as it passes over the peninsula. Consequently, the wet season in the southern peninsula has not yet been over, whilst the rests of the country are the dry season in the winter.

Since the climate in the southern part of Thailand is typical, as comparing to other regions. Therefore, in this study, the parameters of the ASHRAE model were analyzed and revised into two categories:
(a) The clear model for the upper part of Thailand, which excludes the southern part of Thailand. The observation data were pooled and collected from three main stations located on Chiang Mai, Ubon Ratchatani and Nakorn Pathom.
(b) The clear model for the lower part of Thailand, which is represented by Songkhla station

The sorting of the observed hourly clear sky radiation data
The unrevised model of the ASHRAE method was developed by using the data obtained from the clear sky of whole days. Unfortunately, it is very hard to obtain such data for the whole days' clear sky in Thailand. Very few days in the five years data were clear throughout a day and this happened only in a few months of the winter.

In order to obtain the data of the clear sky for each month in a year, a technique to identify solar radiation data of the clear sky condition was adopted. We specified the limits of the possible maximum and minimum hourly transmittance in each month as follows:
    (a) The first step is to sort out the data of the clear sky for the whole day.

The clear sky days for the whole days were sorted from the set of data mentioned above. The sorted data were selected from the days of which had a ratio of the duration of bright sunshine hours and the total possible bright sunshinehours greater than 0.85. A clear sky day can be identified by observing the symmetry of the amount of a half day global solar radiation, before and after the solar noon during a day. We specified that the difference of them in a clear sky day must be no more than 5%. In addition, a coefficient of determination (R^2) of a plot between the natural logarithm of the direct normal hourly radiation ($\dot{I}_{bn}$) and the corresponding hourly secant of θz on a clear sky day must not less than 0.95.

(b) The second step is to set up the limit of the possible minimum hourly transmittance in each month
The hourly transmittances of these sorted clear sky days, which have the minimum transmittance of each hour, during 8 am. To 4 pm., were regarded as the possible minimum hourly transmittance of a clear day. The comparisons of the mentioned hourly transmittance were done on a monthly basis, at the same hourly zenith angle θ_z in each month.

However, it was found that it was hardly to find any clear day during the summer monsoon season. To overcome this problem, we adopted the minimum hourly transmittance of the year as the possible minimum hourly transmittance value for the clear sky hours in the wet season. This could be done because, the turbidity of the clear sky days in the wet season in Thailand is lower than the turbidity in the dry season[7], which in turn it would give higher hourly transmittance in the wet season than that in the dry season.

(c) The third step is to set up the limit of the possible maximum hourly transmittance in each month
The possible maximum hourly clear sky transmittance of each hour in a month was determined by the ASHRAE model. This could be done because the result of the ASHRAE is likely to be over estimated due to its assumption of the relatively non-turbid atmosphere, as compared to Thailand's condition.

(d) The fourth step is to sort out the observed data of hourly solar radiation during the five year period, 1996-2000. An hourly solar radiation of the observed data was regarded as a clear sky hour, if its value of the hourly transmittance was in between the possible maximum and the possible minimum hourly transmittance. The results o f this sorting were then used for revision of the ASHRAE model.

The revision of parameters of the ASHRAE model
A plot between the natural logarithm of the monthly averaged direct normal radiation ($\dot{i}_{bn}$) and the corresponding hourly secant of zenith angle θz of the clear sky data were used to derive the parameters of the ASHRAE model as shown below.

$$\dot{I}_{bn} = A.\exp(-B.\text{Sec}.\theta_Z). \tag{3}$$

By taking the natural logarithm of equation (3), the result is:

In $\dot{I}_{bn}$ = In A + In exp(-B.Sec.θ_Z),

In $\dot{I}_{bn}$ = In A + (-B.Sec.θ_Z),

$$\text{In } \dot{I}_{bn} = \text{In } A - B.\text{Sec}.\theta_Z. \tag{4}$$

A plot of this expression between In $\dot{I}_{bn}$ versus secant of θ_z should be resulted in a straight line, with

A, the intercept of the vertical logarithmic axis of $\dot{I}_{bn}$ and B, the slope of this line.

The last parameter of C, the diffuse radiation factor wich is given in equation (2), was determined by averaging the ratio of the diffuse irradiance $\dot{I}_d$ to the direct normal irradiance $\dot{I}_{bn}$ at each mid hour angle in each month, when that mid hour angle had the zenith angle similar to the zenith angle in each hour of the 21st date of each month. The result of the revision of the ASHRAE model in this study will be discussed later in section 5.

Evaluation of errors
The revision of the ASHRAE model of this study was verified for its accuracy of predications. The obtained parameters of A, B and C were then used to predict solar radiation under clear sky days, during year 2001 to 2002. The results of the prediction were compared with the actual observations in the same period. The accuracy of the revised model was determined for root mean square error (RMSE) and mean bias error (MBE).

Results

From the methodologies mentioned above, the revised parameters of the ASHRAE model, evaluation of the errors of the unrevised ASHRAE model and the revised ASHRAE model were compared for the regions in Thailand as the follows:

Revised Parameters of the ASHRAE model
As mentioned before, we classified the climate of Thailand into two regions for the solar radiation's prediction. The revised parameters of the ASHRAE model in each region are shown as follows:

Table 2 The revised ASHRAE parameters for twenty-first day of each month for Chiang Mai, Ubon Ratchatani and Nakorn Pathom

Month	A W/m^2	B (Dimensionless ratio)	C (Dimensionless ratio)
Jan	1091	0.286	0.206
Feb	1084	0.341	0.248
Mar	1144	0.438	0.230
Apr	1169	0.469	0.307
May	1113	0.437	0.305
Jun	1163	0.394	0.281
Jul	1003	0.360	0.292
Aug	1024	0.381	0.310
Sep	1051	0.356	0.296
Oct	992	0.276	0.274
Nov	1126	0.296	0.208
Dec	1140	0.297	0.203

Table 3 The revised ASHRAE parameters for twenty-first day of each month for Songkhla

Month	A W/m²	B (Dimensionless ratio)	C (Dimensionless ratio)
Jan	1381	0.411	0.217
Feb	1115	0.265	0.223
Mar	1216	0.349	0.22
Apr	1085	0.313	0.254
May	1002	0.257	0.235
Jun	1087	0.318	0.228
Jul	1145	0.324	0.221
Aug	1049	0.258	0.197
Sep	1107	0.301	0.235
Oct	1139	0.282	0.212
Nov	1280	0.334	0.196
Dec	1238	0.332	0.228

E valuation of errors of the unrevised ASHRAE model
An evaluation of the errors between the prediction of the unrevised ASHRAE model and the actual measurement for the clear sky in Thailand, at Chiang Mai, Ubon Ratchatani and Nakorn Pathom, and at Songkhla are shown in Table 4, and 5, respectively.

Table 4 Comparisons of RMSE and MBE between measured and predicted results of the unrevised ASHRAE model, at Chiang Mai, Ubon Ratchatani and Nakorn Pathom

	Global radiation (MJ/m²h)	Direct radiation (MJ/m²h)	Diffuse radiation (MJ/m²h)
No. of observations	1082	1082	1082
Mean	2.263	1.759	0.504
RMSE	0.348	0.659	0.324
MBE	0.313	0.600	-0.287
% error of RMSE	15.382	37.485	64.399
% error of MBE	13.808	34.092	-57.032

Table 5 Comparisons of RMSE and MBE between the measured and the predicted results of the unrevised ASHRAE model, at SongKhla

	Global radiation (MJ/m²h)	Direct radiation (MJ/m²h)	Diffuse radiation (MJ/m²h)
No. of observations	294	294	294
Mean	2.901	2.375	0.526
RMSE	0.191	0.441	0.317
MBE	0.080	0.336	-0.256
% error of RMSE	6.568	18.581	60.308
% error of MBE	2.749	14.132	-48.680

Evaluation of errors of the revised ASHRAE model
Table 6 and 7 show an evaluation of the errors between the prediction of the revised ASHRAE model and the actual measurements for the clear sky in Thailand, at Chiang Mai, Ubon Ratchatani and Nakorn Pathom, and at Songkhla, respectively.

Table 6 Comparisons of RMSE and MBE between the measured and the predicted results of the revised ASHRAE model, at Chiang Mai, Ubon Ratchatani and Nakorn Pathom

	Global radiation (MJ/m²h)	Direct radiation (MJ/m²h)	Diffuse radiation (MJ/m²h)
No. of observations	1082	1082	1082
Mean	2.263	1.759	0.504
RMSE	0.135	0.239	0.143
MBE	-0.003	-0.050	0.047
% error of RMSE	5.982	13.592	28.430
% error of MBE	-0.136	-2.816	9.222

Table 7 Comparisons of RMSE and MBE between the measured and the predicted results of the revised ASHRAE model, at Songkhla

	Global radiation (MJ/m²h)	Direct radiation (MJ/m²h)	Diffuse radiation (MJ/m²h)
No. of observations	294	294	294
Mean	2.901	2.375	0.526
RMSE	0.177	0.287	0.188
MBE	-0.030	-0.124	0.095
% error of RMSE	6.096	12.101	35.792
% error of MBE	-1.021	-5.231	18.003

Discussion and Conclusions

The results in section 5 showed that both the unrevised and the revised ASHRAE model give small to large error for the predictions for global, direct and diffuse radiation, respectively.

The magnitudes of % error of the root mean square error (RMSE) of the unrevised ASHRAE model range from about 64%, 37% and 15% of the means for diffuse, direct and global radiation, respectively, for observations at those stations in the upper part of Thailand. And range from 60%, 19% and 7% of the means for diffuse, direct and global radiation, respectively, for observations at the station of the lower part of Thailand (Songkhla).

The comparison of % error of RMSE between the diffuse, direct and global solar radiation of the revised model are similarly to those of the unrevised one, but with much smaller magnitudes of error, about one half to one third of the previous ones. The % error of RMSE range from about 28%, 14% and 6% of the means for diffuse, direct and global radiation, respectively, for observations at those stations in the upper part of Thailand. And range from 36%, 12% and 6% of the means for diffuse, direct and global radiation, respectively, for observations at the station of the lower part of Thailand (Songkhla).

The percentages of mean bias error (MBE) in Table 4, 5, 6 and 7 clearly show that the unrevised ASHRAE mode tends to overestimate for both global and direct radiation and underestimate for diffuse radiation in the long term. Whilst, in our study, the revised model tends to underestimate for both global and direct radiation and overestimated for diffuse radiation. In addition, the revised model in this study gives much smaller error than the unrevised one, ranging from less than 1% to 18%. Whilst, the unrevised one has the error ranging from 3% to 57%.

The lowest percentage of error in the prediction of both models for the solar global radiation is because the underestimated diffuse radiation are generally compensated by the overestimated counter part of the direct radiation, or vice versa. However, the considerable relatively high values of error of the predication by the unrevised ASHRAE model were caused by the inpropriate assumption of the relatively clear atmospheric conditions of a typical mid latitude clear sky in the model, as compared to the actual of conditions in the high turbid tropics' clear sky. Two basic influent parameters affecting to deviations of the model are:

(a) high moisture contents in the mass of air and (b) no aerosols were included into the unrevised model [3]. The overestimation of global and direct radiation of the unrevised ASRAE model are caused by a low water content used in the model and negligence of the effects of aerosols. Thus, the errors are large when the effects of the aerosols are dominant. As one can see that the error of the prediction for the upper part of Thailand, in table 4 and 5, are much higher than the result of the prediction at the lower part of Thailand, because the turbidity of aerosols in Songkhla is generally lower than other parts of the country as they are washed out due to high rainfalls all year round [7].

In this study, the revision of the ASHRAE model has tremendously improved for its accuracy for the prediction in Thailand. Nevertheless, the relative errors of the prediction for the diffused radiation are still considerable high, and underestimation for the global and the direct solar radiation. The problems come from the unavailability of observed data of solar radiation in the clear sky days in the wet season in Thailand. In this study, we have to adopt the possible minimum solar radiation data in the dry season as the reference value to identify the data of the clear sky condition for the wet season. By this practice, the adopted values to identify the clear sky condition would be too low. Thus, it is likely that some data of the partly cloudy sky condition would infiltrate, and resulted in the regression parameters of which give low predictions of direct radiation, whilst it gives high overestimation of diffusion radiation.

Although the relative % of RMS error of the diffuse radiation of the revised model' predictions seems to be very high, in the absolute term, this value of the error is not large, since the diffuse radiation generally amounts for only a small fraction of the total solar radiation in a clear sky day.

In summary, the revised model has considerably improved the accuracy of the prediction for solar radiation for the clear sky days, and reducing amounts of errors for one half and one third of the previous errors. Some rooms for improvement could still be done, provided that a longer observation data of the clear sky condition is obtained, particular for the data of the wet season.

Acknowledgements

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