Prediction of the intensity of direct solar irradiation

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Abstract: - This article contains instructions for calculating the maximum intensity of solar irradiation reaching Earth's surface every minute of the day throughout the year. This radiation can be measured and subsequently used for prediction of solar irradiation. But due to frequent occurrence of days with cloud cover are not the measured data complete. Therefore, to calculate the missing values using the appropriate functions to the measured values that could reach the solar irradiance in clear sky. Methods were necessary to clarify the effects of weather prediction for the optimal consumption of thermal energy for district heating in urban areas.

Key-Words: - Prediction, solar irradiation, energy, heating plant, heat, district heating, conurbation.

1 Introduction
The identification of thermal properties of buildings from the measured data of thermal energy consumption requires knowledge of all relevant external weather conditions. One of them is the solar energy falling on building surfaces and penetrating inside the envelope with which has to be reckoned. In the early prediction of a sunny day, along with identification of potential rate of heat input from solar irradiation into buildings can reduce the amount of energy produced to avoid the non-energy production.

2 Problem Formulation
The aim is to find the value of solar irradiation every minute of every day of the year, based on several measured parameters. It is a math function in which during the year can only enter the date and time, and which returns the maximum value of solar irradiance at that moment. Final result such a math function is typically graphic form:

This function has three parameters of varying values: The maximum attainable value of solar irradiation in the calendar day, time of sunrise and sunset time. Therefore, we determine the function with the following four steps.

2.1 Change in course of solar irradiation during the calendar year
Step 1 - Obtaining precise values of maximum solar irradiation intensity for every day of the year for a specific location can be fairly difficult because during the year are many days with clouds or overcast sky and the solar irradiance is below the maximum value.
The following function was selected for the calculation of missing values:

\[ I_{irr}(\text{date}) = k_y1 \cdot \sin(k_{x1} \cdot \text{date}-k_{x1} \cdot k_{x2})+k_y2 \,[\text{W/m}^2] \quad (1) \]

Where:

\[ k_{x1} = \text{const} = 2\pi/365 \ (366) \,[\text{days}^{-1}] \quad (2) \]

... conversion of sinus function period to 1 year;

\[ k_{x2} = (\text{March 21}) = 80 \ (81) \,[\text{days}] \quad (3) \]

... sinus shift in time (date);

\[ k_{y2} = \frac{R_{\text{MAX}}(\text{June 21}) + R_{\text{MAX}}(\text{December 21})}{2} \quad (4) \]

... average daily max irradiation during a year;

\[ k_{y1} = R_{\text{MAX}}(\text{June 21}) - k_{y2} \quad (5) \]

... half of the difference between the maximum and minimum value of the function \( R_{\text{MAX}}(\text{date}) \) for a period of 1 year;

Absence measured data are available, sufficient knowledge of the extreme values for the determination of this function.

Comparison of the measured values of the intensity of solar irradiation during the year with the calculated waveform is shown in the following chart (2):

\[ I_{irr}(\text{date}) = 342.5 \cdot \sin(2\pi/365 \cdot \text{date}-2\pi/365 \cdot 80)+617.5 \,[\text{W/m}^2] \quad (6) \]

2.2 Sunrise time

Step 2 - Mathematical function for the changing times of sunrise can be calculated in a similar way:

\[ t_{sr}(\text{date}) = k_{y1} \cdot \sin(k_{x1} \cdot \text{date}-k_{x1} \cdot k_{x2})+k_{y2} \,[\text{minute}] \quad (7) \]

Where:

\[ k_{x1} = \text{const} = 2\pi/365 \ (366) \,[\text{days}^{-1}] \quad (8) \]

... conversion of sinus function period to 1 year;

\[ k_{x2} = (\text{September 23}) = 266 \ (267) \,[\text{days}] \quad (9) \]

... sinus shift in time (date);

\[ k_{y2} = \frac{t_{\text{sunrise}}(\text{June 21}) + t_{\text{sunrise}}(\text{December 21})}{2} \quad (10) \]

... average daily maximum time of sunrise for a year;

\[ k_{y1} = t_{\text{sunrise}}(\text{June 21}) - k_{y2} \quad (11) \]

... half of the difference between the maximum and minimum value of \( t_{\text{sunrise}}(\text{date}) \) during a year;

2.3 Sunset time

Step 3 - The same function is applicable for sunset time:

\[ t_{ss}(\text{date}) = k_{y1} \cdot \sin(k_{x1} \cdot \text{date}-k_{x1} \cdot k_{x2})+k_{y2} \,[\text{minute}] \quad (12) \]

Where:

\[ k_{x1} = \text{const} = 2\pi/365 \ (366) \,[\text{days}^{-1}] \quad (13) \]

... conversion of sinus function period to 1 year;

\[ k_{x2} = (\text{March 21}) = 80 \ (81) \,[\text{days}] \quad (14) \]

... sinus shift in time (date);

\[ k_{y2} = \frac{t_{\text{sunset}}(\text{June 21}) + t_{\text{sunset}}(\text{December 21})}{2} \quad (15) \]

... average daily maximum time of sunset for a year;

\[ k_{y1} = t_{\text{sunset}}(\text{December 21}) - k_{y2} \quad (16) \]

... half of the difference between the maximum and minimum value of \( t_{\text{sunset}}(\text{date}) \) during a year;

The following plot shows the changing times of sunrise and sunset during a year:
The length of sun exposure in one calendar day is equally long for the place same latitude, but each locality has a different time shift caused by the difference in longitude.

### 2.4 Course of maximum intensity of solar irradiation during a day

Step 4 – In order to obtain an indication of the maximum solar irradiation during each day of the year is necessary to compare calculated and measured values collected during the same day in the history. If we have evidence at least for part of the year, then the remaining value can be calculated using a function that calculates the amount of solar irradiation throughout day at its maximum rate (on a clear cloudless sky). Example for calculating the known maximum and minimum values of function:

\[
I_{rr}(t) = [k_{y1}\sin(k_{x1}\cdot date-k_{x2})+k_{y2}] \cap I_{rr}(t) \geq 0 \quad \text{[W/m}^2]\]  

Where:

\[k_{x1} = \text{const.} = 2\pi/1440 \quad \text{[minutes}^{-1}]\]  
\[k_{x2} = t_{\text{MAX}}(\text{date}) - \frac{1}{4}\times 1440 \quad \text{[minutes]}\]  
\[t_{\text{MAX}}(\text{date}) = \frac{t_{\text{sunrise}}(\text{date}) + t_{\text{sunset}}(\text{date})}{2} \quad \text{[minutes]}\]  

… conversion of sinus function period to 24 hours;

…the shift of sinus function in the time;

…the time period with maximum sun exposure;

\[t_{\text{sunrise}}(\text{date}) \quad \text{[minutes]} \quad \text{… beginning of exposure time,}\]
\[t_{\text{sunset}}(\text{date}) \quad \text{[minutes]} \quad \text{… end of exposure time, sunset time};\]

\[k_{y1} = \frac{I_{r\text{MAX}}(\text{date})}{[1 - \sin(k_{x1}\cdot t_{\text{sunrise}}(\text{date}) - k_{x1}\cdot k_{x2})]} \quad \text{[W/m}^2]\]  

\[k_{y2} = R_{\text{MAX}}(\text{date}) - k_{y1} \quad \text{[W/m}^2]\]

\[k_{y2} \quad \text{[W/m}^2]\quad \text{… sinus shift in the direction of the y axis; date … number of the day.}\]

### 3 Problem Solution

The calculation function uses sinus function to obtain maximum values of solar irradiation during a day. Sinus was chosen as described for the purposes of sufficient similarity with the measured data, which can be clearly seen in Fig. 4 and Fig. 5.

This data represents measured intensities, using meteorological station located on the roof of a building at the Tomas Bata University in Zlín, and parameters of the curve are calculated by equation:

\[
I_{rr}(t) = 730\sin(0.0043633[\ast t-395])-185\quad \text{[W/m}^2]\]  
\[\cap I_{rr}(t) \geq 0 \quad \text{[W/m}^2]\]

The maximum intensity of irradiation during 15th October 2008:

\[I_{r\text{MAX}}(\text{October 15}^{th}) = k_{y1} + k_{y2} = 730 + (-185) = 545 \quad \text{[W/m}^2]\]

Time of sunrise (the beginning of exposure to solar irradiation) for given day:

\[t_{\text{sunrise}}(\text{October 15}^{th}) = 454 \quad \text{[minutes]} = 7:34 \quad \text{[hours]}\]
Time of sunset (the end of exposure to solar irradiation) for given day:

\[ t_{\text{sunset}}(\text{October 15}\text{th} \ 2008) = 1056 \text{ [minutes]} = 17:36 \text{ [hours]} \]  \hspace{1cm} (26)

Fig.5. - Course of maximum intensity of solar irradiation in four days

In a similar way it is possible to express any day of the year, as the following graph:

Fig.6. - Course of maximum intensity of solar irradiation in several days during year

4 Discussion

The Earth's movement around the Sun has been described in many articles such as [2] or [5]. The aim of this article was to simplify the calculation parameters of functions are easily verifiable for general majority of users while maintaining sufficient accuracy of calculation. Therefore, the method of calculation is based on the maximum and minimum values and verified using the measured data that each user is able to verify its exact location on Earth.

5 Conclusion

The Sun emits tremendous amount of energy in the form of electromagnetic irradiation, a fraction of this irradiation falls on human buildings, which are heated by energy generated a few hours before it is needed. Energy from the sun is not always part of the prediction, because its quantity is not easy to convert to the saved heat. [6, 7]

This article shows simplifying of the calculation of incident energy for other uses or precise calculations to predict the required heat energy.

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