Prediction of the intensity of direct solar irradiation

MARTINA SVĚTINSKÁ, LUBOMÍR VAŠEK
Faculty of Applied Informatics, 760 05 Zlín, Nad Stráněmi 4511
Tomas Bata University in Zlín
760 01 Zlín, nám. T. G. Masaryka 5555
CZECH REPUBLIC
svetinska@fai.utb.cz http://www.svetinska.cz

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:

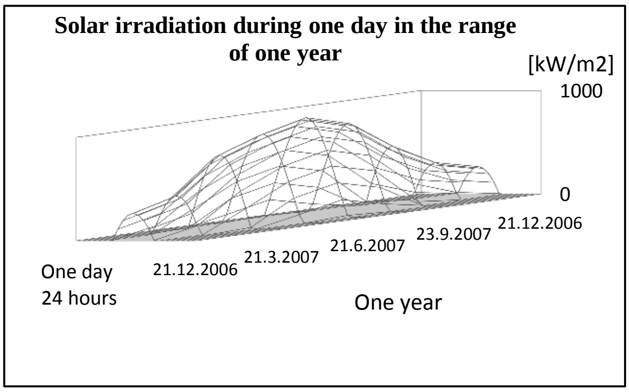

Fig.1. - Course of maximum intensity of solar irradiation in one year for all days

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:

$I_{rr}(date) = k_{y1}*\sin(k_{x1}*date-k_{x1}*k_{x2})+k_{y2}[W/m^2]$ (1)

Where:

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

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

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

… sinus shift in time (date);

$k_{y2} = [\ R_{MAX}\ (\ June\ 21\ ) + R_{MAX}(December\ 21)]/2$ (4)

… average daily max irradiation during a year;

$k_{y1} = R_{MAX}(June\ 21) – k_{y2}$ (5)

… half of the difference between the maximum and minimum value of the function R_{MAX} (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):

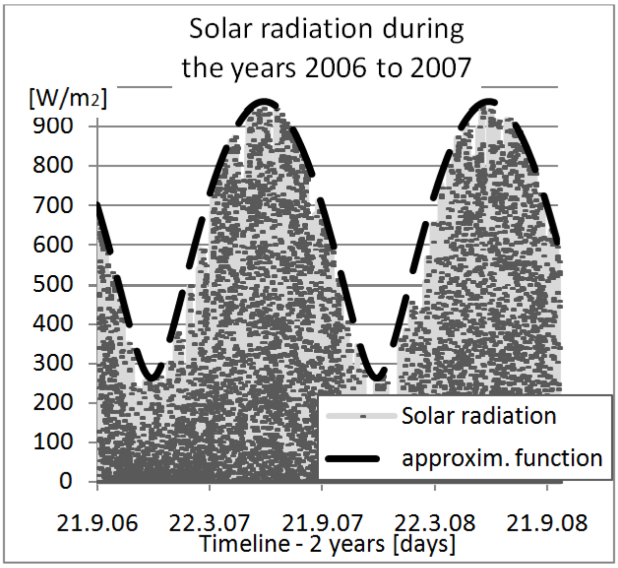

Fig.2. - Course of maximum intensity of solar irradiation in two years for all days

Parameters to the function been obtained to the area under the curve was calculated as the smallest and all measurements were lower than the calculated values. For the location of the town Zlín is a specific function form of:

$I_{rr}(date) = 342{,}5*\sin(2\pi/365*date-2\pi/365*80)+617{,}5\ [W/m^2]$ (6)

2.2 Sunrise time

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

$t_{sr}\ (date) = k_{y1}*\sin(k_{x1}*date-k_{x1}*k_{x2})+k_{y2}\ [minute]$ (7)

Where:

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

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

$k_{x2} = (September\ 23) = 266\ (or\ 267)\ [days]$ (9)

… sinus shift in time (date);

$k_{y2} = [t_{sunrise}(June\ 21) + t_{sunrise}\ (December\ 21)]/2$ (10)

… average daily maximum time of sunrise for a year;

$k_{y1} = t_{sunrise}(June\ 21) – k_{y2}$ (11)

… half of the diference between the maximum and minimum value of $t_{sunrise}$(date) during a year;

2.3 Sunset time

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

$t_{ss}(date) = k_{y1}*\sin(k_{x1}*date-k_{x1}*k_{x2})+k_{y2}[minute]$ (12)

Where:

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

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

$k_{x2} = (March\ 21) = 80\ (or\ 81)\ [days]$ (14)

… sinus shift in time (date);

$k_{y2} = [t_{sunset}(June\ 21) + t_{sunset}(December\ 21)]/2$ (15)

… average daily maximum time of sunset for a year;

$k_{y1} = t_{sunset}(December\ 21) – k_{y2}$ (16)

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

The following plot shows the changing times of sunrise and sunset during a year:

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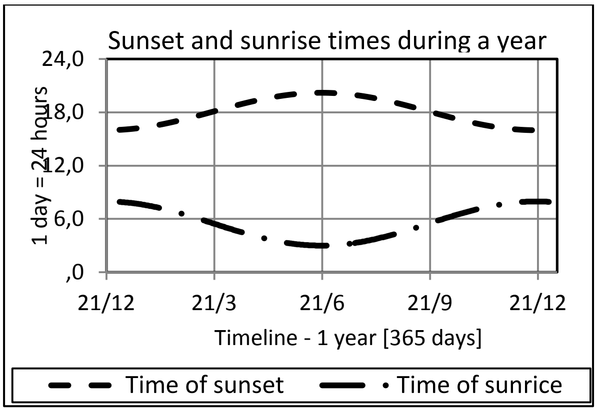

Fig.3. – Changing times for sunrise and sunset during a year

The length of sun exposure in one calendar day is equally long for the place the 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:

$$I_{rr}(t) = [k_{y1}*\sin(k_{x1}*date-k_{x1}*k_{x2})+k_{y2}] \cap I_{rr}(t) \geq 0 \ [W/m^2] \quad (17)$$

Where:

$$k_{x1} = const. = 2\pi/1440 \ [minutes^{-1}] \quad (18)$$

… conversion of sinus function period to 24 hours;

$$k_{x2} = t_{MAX}(date) - ¼*1440 \ [minutes] \quad (19)$$

… shift of sinus function in the time;

$$t_{MAX}(date) = [t_{sunrise}(date) + t_{sunset}(date)]/2 \ [minutes] \quad (20)$$

… time period with maximum sun exposure;
$t_{sunrise}(date)$ [minutes] … beginning of exposure time,
$t_{sunset}(date)$ [minutes] … end of exposure time, sunset time;

$$k_{y1} = Irr_{MAX}(date)/[1 - \sin(k_{x1}*t_{sunrise}(date) - k_{x1}*k_{x2})] \ [W/m^2]; \quad (21)$$

$Irr_{MAX}(date)$ [W/m^2] … the value of maximum solar irradiation during the calendar day on a clear cloudless sky;

$$k_{y2} = R_{MAX}(date) - k_{y1} \ [W/m^2] \quad (22)$$

k_{y2}[W/m^2] … 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.

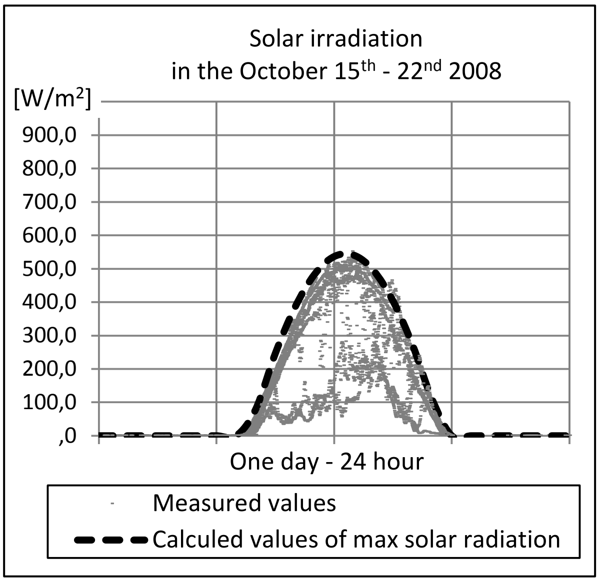

Fig.4. - Course of maximum intensity of solar irradiation in four days

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:

$$I_{rr}(t) = 730*\sin(0{,}0043633[*t-395])-185[W/m^2] \cap I_{rr}(t) \geq 0 \ [W/m^2] \quad (23)$$

The maximum intensity of irradiation during 15th October 2008:

$$Irr_{MAX}(October\ 15^{th}) = k_{y1} + k_{y2} = 730 + (-185) = 545 \ [W/m^2] \quad (24)$$

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

$$t_{sunrice}(October\ 15^{th}) = 454 \ [minutes] = 7{:}34 \ [hours] \quad (25)$$

Time of sunset (the end of exposure to solar irradiation) for given day:

$$t_{sunset}(\text{October } 15^{th} \text{ 2008}) = 1056 \text{ [minutes]} = 17{:}36 \text{ [hours]} \quad (26)$$

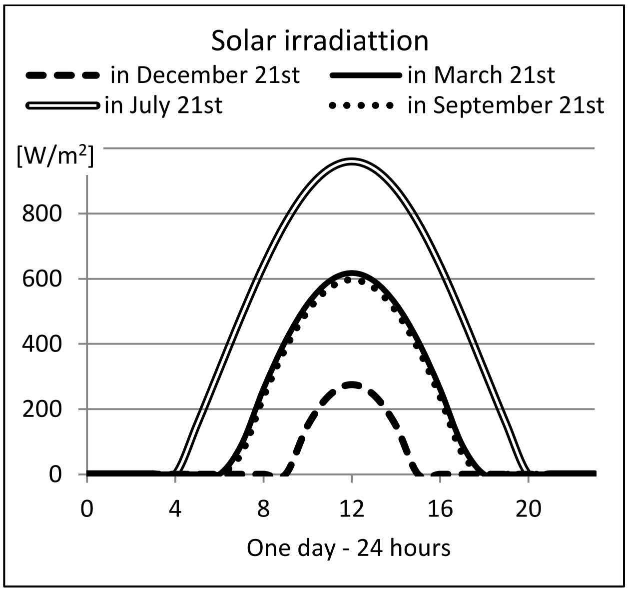

Fig.5. - Course of maximum intensity of solar irradiation in four days

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

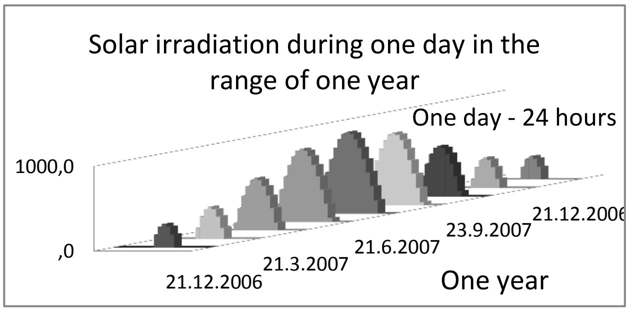

Fig.6. - Course of maximum intensity of solar irradiation in several days during year

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.

6 Acknowledgements

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