SIMPLIFIED CALCULATION METHOD OF ANNUAL INCOMING SOLAR ENERGY ON TILTED AND ORIENTED SURFACES FOR THE CARPATHIAN BASIN

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The present paper aims at introducing a simplified method of manual calculation of annual incoming solar energy on any tilted and oriented surface using annual horizontal global radiation or sunshine duration hours as input. The proposed simplified formula is developed for the Carpathian basin and can be used in 8 countries with a total geographical area of 483 495 km^2*. In prospect, a similar formula can be determined for other regions applying the presented methodology.*

In our work we used the following: the open access CarpatClim database as input data, the Liu-Jordan model as detailed method that was validated with measurement data. The simplified method was developed and validated by use of various statistical approaches and methods.

Key words*: solar radiation models; annual solar radiation; Carpathian region; tilted, oriented surface; simplified calculation*

1. Introduction

In engineering practice there is a need for quick manual calculation methods of the annual incoming solar energy on any tilted and oriented surface. However, usually data is only available for horizontal surface [1]. It can be used for instance to support the design of passive or active solar systems particularly in the first design phase or when the energy potential for a larger area (city, country, region) has to be determined [2–4]. Such methods could also be used in building energy evaluation and certification. Present paper aims at introducing such simplified method developed for the Carpathian region covering parts of Croatia, Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia and Ukraine. In this region the access to detailed global radiation data is limited. The data is measured only at a small number of stations and sold at a high price. Furthermore, it is mostly measured only on horizontal surface and in some cases the accuracy of measured data is questionable.

Certainly there are several detailed methods available for architects and engineers, but such methods are so complex and time demanding that practically they cannot be used manually, only as software applications.

The proposed simplified method is based on sunshine duration data easily accessible for the analyzed region, which can be transferred to global radiation. There are several publications about the relationship between sunshine duration and global radiation. These publications are generally based on the idea of Angström [5]. In Angström's original model a daily clear sky radiation is used, however, later the change of this value to the daily extraterrestrial solar radiation was suggested by Prescott. This model became well known as the Angström–Prescott model [6] shown in Eq. (1).

$$\frac{G}{G_0} = a + b \cdot S. \tag{1}$$

Both of the mentioned models contain empirical constants which depend on the location, for which Jain later on derived a mathematical explanation [7]. The Angström–Prescott model was afterwards revised by Suehrcke [8,9]. However, in several present studies still the Angström–Prescott model is used. Several papers were published which aimed to determine the constants of the Angström–Prescott equations. Some of the recent papers were published for Malawi [10] and China [11]. Based on the station and satellite measurement data, Angström constants were calculated for Europe on a 25 x 25 km grid [12].

Based on the horizontal global radiation coming from the Angström–Prescott equation, there are several radiation calculation models to calculate global radiation for differently tilted and oriented surfaces, which have similarities between each other. In order to calculate the incoming radiation on tilted and oriented surfaces the ratio of global and diffuse radiation has to be determined. There are several papers dealing with this topic, however, a thorough review was made by Khorasanizadeh and Mohammadi [13]. They have evaluated a total of 35 diffuse fraction models. In their research they were grouping the models based on the required input parameters and the polynomial degree of the equations. In a widespread group the clearness index is used as input parameter, which can be also obtained from the Angström–Prescott equation, with a first grade polynomial [14,15].

The Liu–Jordan model [16], Temps–Coulson model [17], Hay model [18], Klucher model [19], Skartveit–Olseth model [20] and the Reindl et al. model [21] have the same approach to solar radiation calculation for differently tilted and oriented surfaces, however, each uses different way of diffuse radiation calculation. The beam radiation is calculated in each model as in Eq. (2) with the help of Eq. (3) and Eq. (4), and the reflected radiation is calculated as in Eq. (5).

$$I_t = (G - D) \cdot R_b. \tag{2}$$

where:

$$R_b = \frac{\cos\theta}{\sin\alpha_S}, \tag{3}$$

$$\theta = \cos^{-1}\begin{pmatrix} \sin\delta \cdot \sin\phi \cdot \cos\alpha_\mathrm{M} - \sin\delta \cdot \cos\phi \cdot \sin\alpha_\mathrm{M} \cdot \cos\gamma_\mathrm{M} \\ + \cos\delta \cdot \cos\phi \cdot \cos\alpha_\mathrm{M} \cdot \cos\omega \\ + \cos\delta \cdot \sin\phi \cdot \sin\alpha_\mathrm{M} \cdot \cos\gamma_\mathrm{M} \cdot \cos\omega \\ + \cos\delta \cdot \sin\alpha_\mathrm{M} \cdot \sin\gamma_\mathrm{M} \cdot \sin\omega \end{pmatrix}, \tag{4}$$

$$R_t = G \cdot A \cdot (1 - \cos\alpha_M) \cdot \frac{1}{2}. \tag{5}$$

The diffuse radiation is calculated in the Liu-Jordan model as in Eq. (6), in the Temps–Coulson model as in Eq. (7), in the Hay model as in Eq. (8), in the Klucher model as in Eq. (9), in the Skartveit–Olseth model as in Eq. (10) and in the Reindl et al. model as in Eq. (11). For the calculations the supplementary equations Eq. (12) – (15) need to be used.

$$D_t = D \cdot (1 + \cos\alpha_M) \cdot \frac{1}{2}. \tag{6}$$

$$D_t = D \cdot \cos^2\left(\frac{\alpha_M}{2}\right) \cdot \left[1 + \sin^3\left(\frac{\alpha_M}{2}\right)\right] \cdot [1 + \cos^2(\theta) \cdot \cos^3(\alpha_S)]. \tag{7}$$

$$D_t = D \cdot \left[(1 - A_i) \cdot (1 + \cos \alpha_M) \cdot \frac{1}{2} + A_i \cdot R_b\right]. \tag{8}$$

$$D_t = D \cdot \cos^2\left(\frac{\alpha_M}{2}\right) \cdot \left[1 + F \cdot \sin^3\left(\frac{\alpha_M}{2}\right)\right] \cdot [1 + F \cdot \cos^2(\theta) \cdot \cos^3(\alpha_S)]. \tag{9}$$

$$D_t = D \cdot \left[(1 - A_i - B) \cdot \cos^2\left(\frac{\alpha_M}{2}\right) + B \cdot \cos \alpha_M + A_i \cdot R_b\right]. \tag{10}$$

$$D_t = D \cdot \left\{(1 - A_i) \cdot (1 + \cos \alpha_M) \cdot \frac{1}{2} \cdot \left[1 + f \cdot \sin^3\left(\frac{\alpha_M}{2}\right)\right] + A_i \cdot R_b\right\}. \tag{11}$$

where:

$$A_i = \frac{G - D}{G_0}, \tag{12}$$

$$B = \max(0.3 - 2 \cdot A_i; 0), \tag{13}$$

$$f = \sqrt{\frac{G - D}{G}}, \tag{14}$$

$$F = 1 - \left(\frac{D}{G}\right)^2. \tag{15}$$

With the help of the equations above, the global radiation on a tilted plane can be calculated as follows:

$$G_t = I_t + D_t + R_t. \tag{16}$$

Several papers deal with comparing these models at geographically and meteorologically different locations. In papers [22] and [23] the Liu-Jordan, Hay and Klucher models were evaluated. In the paper of Ma and Iqbal [22] the data was measured in Woodbridge, Ontario. The measurements were made on south facing surfaces at three different tilt angles (30°, 60°, 90°). The statistical indicators for evaluation were the MBE and RMSE values. As a result it was concluded that both the Hay and Klucher models are performing better than the Liu-Jordan model. In the paper of Kudish and Ianetz [23] the data for evaluation was measured in Beer Sheva, Israel, on a 40° tilted, south oriented surface. The obtained results were similar to the results obtained by Ma and Iqbal. However, in this case only the results of the Hay model were acceptable on a monthly basis, though it was noted that on a yearly basis the Liu-Jordan model also gives acceptable results for a 40° tilt angle, south oriented surface. An extended statistical analysis was proposed and implemented for different regions of Canada [24]. In the paper, in addition to the MBE and RMSE values, the t-statistic analysis was added to the evaluation. Similar evaluation was made in Valladolid, Spain, where data from a south facing 42° tilted surface was studied and compared with results from 10 different diffuse calculation models [25]. Evseev and Kudish [26] tested 11 solar calculation models for different sky conditions: all, clear, partially cloudy and cloudy . The calculated data was compared to the data measured on a 40° tilted, south oriented surface. In a study Gueymard [27] compared 10 different models for all sky conditions. In this study the models were compared to measured data with optimal (direct, diffuse radiation and ground albedo measured) and suboptimal (only global radiation is measured) input parameters. It was found that with detailed input data the complex models performed better, however, with suboptimal input parameters less complex models performed better. A different model analysis was made in Belgium by Demain et al. [28] who were evaluating 14 different models with data measured at the Royal Meteorological Institute of Belgium. Regarding the best model selection a thorough paper was published by Badescu [29]. In this paper different statistical indicators were used and evaluated against each other. As a result it was concluded that the MBE and RMSE values accompanied by the slope of the best-fit line gives good indicator set, which was decided to be used in this paper as well.

2. Methodology overview

The methodology consists of two main parts. In the first part an 'average year' for daily global horizontal solar yield in the Carpathian basin is created and evaluated. It is based on the sunshine hours derived from the CarpatClim database. The sub-steps to determine the 'average year'are as follows:

1. The fundamental input data of the daily sunshine hours were derived from the free-to-use online CarpatClim database and was transferred to global radiation with the help of the Angström–Prescott model.
2. An average year of incoming solar energy for horizontal surface has been established with simple averaging of each geographic point's 30 years' daily data in the database grid.
3. The average year of incoming solar energy for horizontal surface has been statistically evaluated and the approximation has been proved to be accurate.

In the second part the simplified calculation method for yearly solar radiation calculation on tilted and oriented surfaces is proposed for the Carpathian basin using statistical methods. The results are validated with on-site measurements, detailed methods and statistical analysis. The sub-steps to determine the simplified calculation method are as follows:

1. The 'average year' of daily global horizontal solar yield determined in the previous part is used as input data.
2. Different detailed models (Liu–Jordan model [16], Temps–Coulson model [17], Hay model [18], Klucher model [19], Skartveit–Olseth model [20] and Reindl et al. model [21]) were selected from available literature and compared (see their formulas in Section 1.). The evaluation of the methods was based on on-site meteorological measurements carried out in the site of Budapest University of Technology.
3. With the detailed calculation method for the average year the yearly incoming energy was calculated for every azimuth angle (from 0° to 359°) and tilt angle (from 0° to 90°) in 1° steps.
4. A simplified calculation formula of annual incoming solar energy has been elaborated via applying fitting polynomials with the principle of least squares on the curves calculated from the detailed method.
5. Finally the simplified calculation formula has been statistically evaluated and its goodness has been justified.

In the research different methods were used: the open access CarpatClim database as input data, 6 radiation models as detailed methods, which were validated with on-site measured data. The simplified method was developed and validated by using fully statistical approaches and methods. Only general statistical indicators were used in the paper: mean bias error (MBE), root mean square error (RMSE), correlation coefficient, slope of the best-fit line, sum squared errors (SSE), and t-statistic. All calculations were made in Matlab software, where both the linear and non-linear least squares methods were used for curve fittings.

2.1. The CarpatClim database

For the creation of the average solar radiation year CarpatClim database was used. The database's time frame is 1961 – 2010, and it contains daily data of several meteorological parameters, such as daily mean temperature, relative humidity, precipitation, sunshine duration, etc. The climatological grids of the database cover the area between latitudes 44° – 50° N, and longitudes 17° – 27° E, and resolution of the grids is 0.1° x 0.1°. In total it consist of 5895 grid points. The grid data was created from measurement data from 8 countries, the number of meteorological stations and covered area of each country are presented in Table 1.

Table 1. Area and number of stations in each participating country

Country	Area [km^2] covered by CarpatClim	Area	Nr. of stations	Ratio of stations to total number
Croatia	14663	3.0%	26	4.4%
Czech Republic	12571	2.6%	23	3.9%
Hungary	86966	18.0%	165	28.2%
Poland	19794	4.1%	35	6.0%
Romania	184435	38.1%	158	27.0%
Serbia	45015	9.3%	63	10.8%
Slovakia	48520	10.0%	85	14.5%
Ukraine	71531	14.8%	30*	5.1%
Total	483495	100.0%	585*	100.0%

* *incomplete list*

The data from all stations was filtered and homogenized. The method used for homogenization and data quality was 'Multiple Analysis of Series for Homogenization' (MASH). The interpolation and gridding were made according to 'Meteorological Interpolation based on Surface Homogenized Database' (MISH) [30].

The homogenization and interpolation were made for several meteorological parameters, such as temperature, humidity, sunshine duration, solar radiation, etc. The data of solar radiation is available at the CarpatClim database, however, it was derived from the sunshine duration, that's why, in order to develop the average solar radiation year, the sunshine duration dataset was used.

2.2. Creation of the average year of solar radiation for horizontal surface

In order to determine the average year of solar radiation for a horizontal surface in the Carpathian basin, daily data of sunshine duration, which has a linear correlation with horizontal radiation, was evaluated. The time period of evaluation was from 1981 to 2010 which in total means 10956 daily values for each of the 5895 geological points in the CarpatClim database. The data was averaged both for each day and also for all of the geological points.

The calculated average year values were compared to the average years of each geological point to determine its goodness and applicability for the further calculations. In order to make this comparison, the daily values were normalized by the yearly total sunshine duration. Furthermore, in order to fully evaluate relationship between the two datasets, the Bland–Altman method was used [31]. This method was used to compare different measurement devices with each other. As it will be explained in Section 3 it was concluded that simply to use the correlation coefficient value can be misleading and instead of it a new graphic evaluation method was proposed.

2.3. Selecting the best performing radiation model

Based on the literature review in Section 1, it can be concluded, that so far no evaluation was made at Central European locations, however, it is necessary for this paper. For this purpose a preliminary research was made and it was concluded that for Budapest, Hungary, the best fitting model for 45° tilted south facing surface is the Liu-Jordan model [32]. However, since that paper was published, new measurements were made and the number of evaluated models was increased. As an addition to the previous research instead of just three models (Liu-Jordan, Hay and Reindl et al.) three other models were also evaluated (Temps–Coulson, Klucher, Skartveit–Olseth). The measurements took place at the Budapest University of Technology and Economics in the Renewable Energy Laboratory, from 6th June 2015 to 2nd February 2016. Horizontal global radiation, diffuse radiation and global radiation on a 45° inclined, south facing surface were measured in a laboratory. Data was registered every 10 minutes, which means a total of 34848 data points (including the night periods). Afterwards, registered data was filtered with application of the following constraints:

- measured radiation is over 1200 W/m^2
- measured radiation is under 5 W/m^2
- height of the Sun is under 5°

With consideration of the above mentioned constraints there were still 8282 data points remaining, which included sufficient data from all sky conditions and thus was applicable to select the best performing model.

2.4. Simplified calculation method for annual solar yield on tilted and oriented surfaces

The average solar radiation year for horizontal surface was created for the Carpathian basin. However, in most cases for energy output calculations of solar collectors and PV panels radiation data is required for tilted and oriented surfaces, which is very complex to calculate. For this reason a simplified method is proposed in this paper which was elaborated through the following steps:

- As a first step with the detailed calculation method (Liu-Jordan model, Eq. (2) – (6) and Eq. (16) for the previously defined average year the yearly incoming energy was calculated for every azimuth angle (from 0° to 359°) and tilt angle (from 0° to 90°) in 1° steps. The calculated data was normalized with the horizontal data in order to have dimensionless values which can be compared.
- In the second step, 4 polynomials (from 1st to 4th degree) were fit for every azimuth angle with the principle of least squares [33]. The fitted polynomials are covering for every azimuth angle all slopes from 0 to 90°.
- The third step was to select the best performing polynomial and determine the constant values of the polynomial, thus create the equations.
- The fourth step was the model evaluation. In order to evaluate the simplified method, again the correlation coefficient and the Bland-Altman method were used as it was described in Section 1.

3. Results and discussion

3.1. Average year of solar radiation for horizontal surfaces

The created average year of solar radiation for horizontal surfaces is presented in Figure 1. The comparative analysis of the created average year to the average years of each geological point proved that, for 99.37% of the locations the calculated correlation coefficients between the values were over 0.9 which determines proximity to linear connection between the two datasets. The Bland–Altman method to compare different measurement devices with each other showed that simply to use the correlation coefficient value can be misleading and instead of it a new method was proposed. This method presents a graphical evaluation of two datasets. On the ‘x’ axis the average of two datasets is presented and on the ‘y’ axis the difference of two datasets. The diagram also includes an average difference line and two limits which are the average difference ±2 times the calculated standard deviation. The created diagram is shown in Figure 2. The graphic interpretation may be misleading, because several points on the figure seem to be out of the above mentioned bounds. However, in total 95.05% of the points are within the bounds. The method is stating that, if the differences are Normally distributed (they have a Gaussian distribution), then 95% of differences will lie between these limits [31]. Therefore, it can be stated that the points show a Gaussian distribution and the average year can be a statistically acceptable simplification for further calculations. The calculated average of the points is close to zero, and the standard deviation is $2.89 \cdot 10^{-04}$. With these values the t-statistic value is $-2.41 \cdot 10^{-13}$ which is significantly lower than the limit value for 95% significance level ($t_{95\%}$= 1.960 [33]). Thus, the assumed average year can be applied for further calculations as input data.

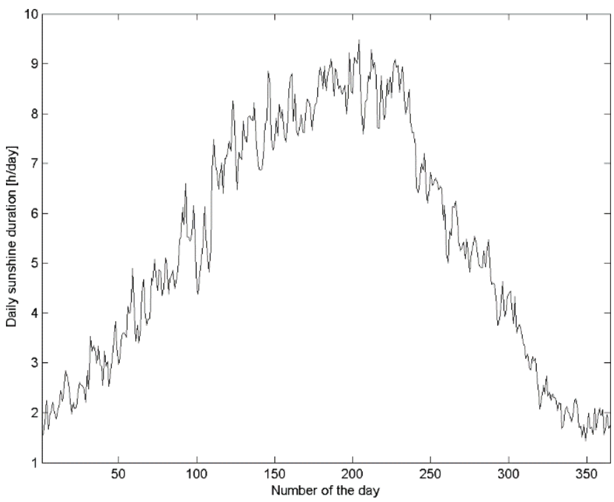

Figure 1. Daily sunshine duration chart of the average year for the Carpathian basin

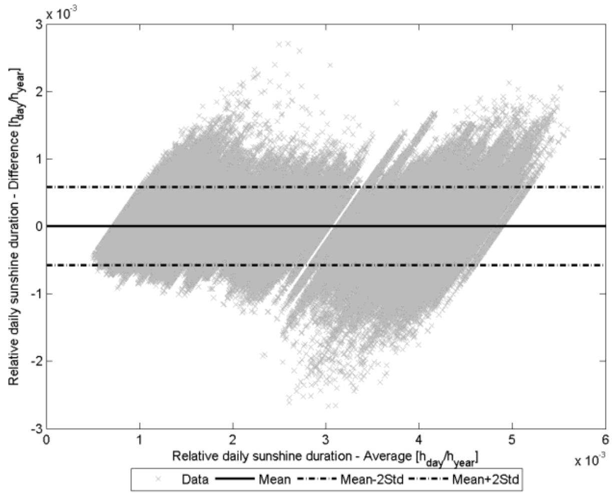

Figure 2. The comparison of relative daily sunshine duration of the average year and the CarpatClim database’s geographical location’s average year

The locations with lower than 0.9 correlation coefficient were checked on Google Maps, from which it was concluded, that the points with low correlation coefficients are usually located on sites with high elevation in the Carpathians, thus they have small significance in energy calculations.

3.2. Results of solar radiation data analysis and model evaluation

As discribed before 6 different solar radiation models were compared to find the best performing one. The results of the model comparison are summarized in Table 2.

Table 2. Results of evaluation of different solar radiation models

Models	Liu-Jordan	Hay	Reindl et al.	Temps-Coulson	Klucher	Skartveit-Olseth
Average radiation [W/m^2]	302.2	313.5	315.4	332.8	318.2	389.6
MBE [W/m^2]	-5.3 (-1.7%)	6.0 (1.9%)	7.9 (2.5%)	25.2 (7.6%)	10.7 (3.4%)	82.1 (21.1%)
RMSE [W/m^2]	75.8 (25.1%)	73.8 (23.5%)	74.0 (23.5%)	81.3 (24.4%)	75.1 (23.6%)	137.5 (35.3%)
Slope of the best-fit line	1.02	0.97	0.97	0.99	0.97	1.15
Correlation coefficient	0.965	0.967	0.967	0.963	0.966	0.931

From Table 2 it can be concluded that all models have very high correlation coefficients with the measured data, also in most cases the best-fit line's slope is close to 1, which indicates a good relation between the measured and calculated values. The MBE values indicate that apart from the Liu-Jordan model all others overestimate the measured values, while the calculated RMSE values show that the Hay model performs the best. As for the slope of the best fit line the Temps-Coulson model has the closest value to 1, however, in other indicators it is performing worse than other models. All in all it was concluded that the Liu-Jordan, Hay and Reindl et al. models performed good, while the other models performed relatively bad. From the three good performing models, the Liu-Jordan model was selected for further calculations, since it performed the best according to two of the indicators, and it has a relatively good performance regardless of the orientation of the receiving surface.

The constants for the diffuse fraction equation were derived from the measured data as well. As it was mentioned in Section 1 a linear equation was formulated as in Eq. (17), which has a 0.935 correlation with the measured values.

$$\frac{\mathrm{D}}{\mathrm{G}} = \left\{ \begin{array}{cc} 0{,}85 & for\ \frac{\mathrm{G}}{\mathrm{G_0}} \leq 0{,}27 \\ 1{,}251 - 1{,}488 \cdot \frac{\mathrm{G}}{\mathrm{G_0}} & for\ 0{,}27 < \frac{\mathrm{G}}{\mathrm{G_0}} < 0{,}71 \\ 0{,}195 & for\ \frac{\mathrm{G}}{\mathrm{G_0}} \geq 0{,}71 \end{array} \right\} \tag{17}$$

3.3. Simplified calculation method for annual solar yield on tilted and oriented surfaces

The calculated average year in function of the yearly incoming energy for every azimuth angle (from 0° to 359°) and tilt angle (from 0° to 90°) is presented in Figure 3.

From the comparison of the 4 polynomials (from 1st to 4th degree) with the calculated correlation coefficients and the sum of squared errors, the 2nd degree polynomial was accepted as it is simpler than the 3rd and 4th degree polynomials and gives significantly better values than the 1st degree polynomials. The next step was to fit curves on the 'a' and 'b' constants of the 2nd degree polynomial, while the 'c' constant value was set as 1, which appeared to be a sufficient approximation. For the 'a' and 'b' constants the curves were determined in an iterative process, during which Eq. (18) and Eq. (19) were found. The calculated correlation coefficient value for the 'a' constant was 0.9993, and for the 'b' constant was 0.9998. The SSE values were $3.788 \cdot 10^{-10}$ and $1.764 \cdot 10^{-06}$ respectively. In case of the 'a' constant the SSE value is at least four orders of magnitude smaller than the actual values, this difference for the 'b' constant is three orders of magnitude. From the calculated indicators it can be concluded that the obtained equations are acceptable.

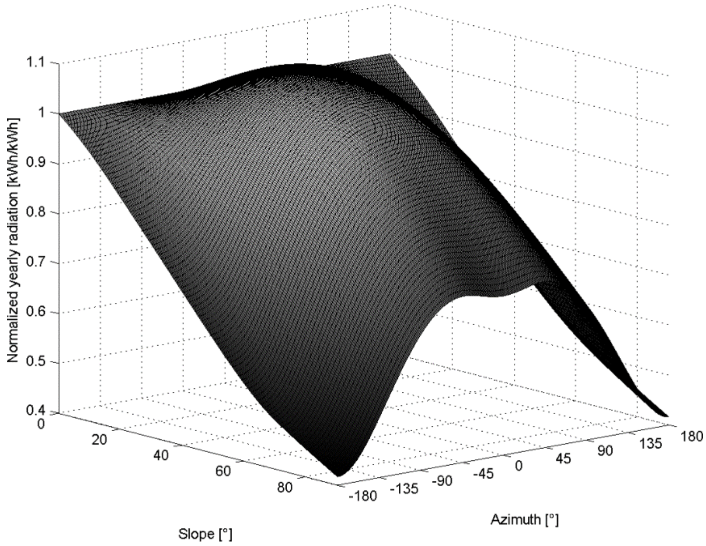

Figure 3. The normalized yearly radiation for different azimuth and slope angles

$$a = \alpha_a \cdot \cos(x) + \beta_a \tag{18}$$

$$b = \alpha_b \cdot \cos(x) + \beta_b + \gamma_b \cdot \cos(2 \cdot x) \tag{19}$$

The calculated values of simplified and detailed method are presented in Figure 4. From the figure it can be stated that the simplified method has a good linear correlation with the detailed method. The calculated correlation coefficient was 0.997. However, when the calculated values are examined with the Bland-Altman method the result can be seen in Figure 5. From the figure it is visible that the several calculated values are out of the bounds, however, altogether 94.6% are within. In this case it can be concluded that the calculated differences show close to normal distribution.

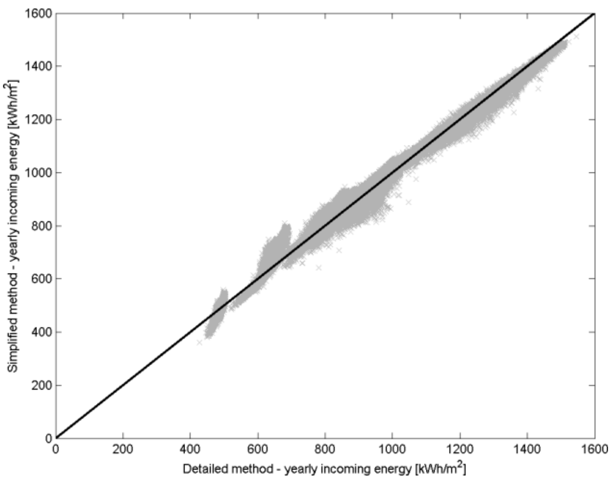

Figure 4. Results of the simplified and detailed calculation method

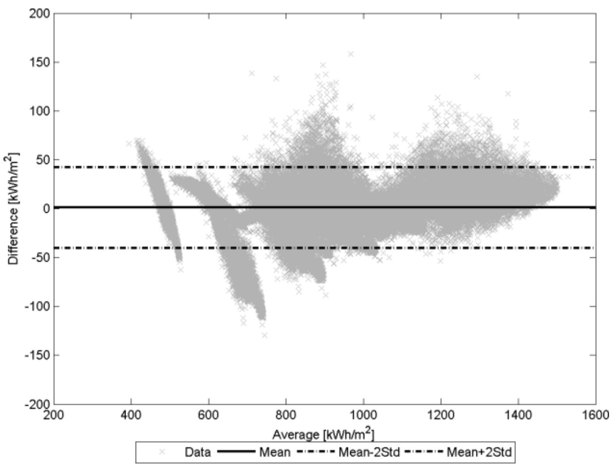

Figure 5. Bland-Altman test of the simplified and detailed calculation method

From the above described steps the following simplified equation is proposed for simplified solar radiation calculations for the Carpathian basin:

$$G_{t,y} = \begin{Bmatrix} [\alpha_a \cdot \cos(\gamma_M) + \beta_a] \cdot \alpha_M^2 \\ +[\alpha_b \cdot \cos(\gamma_M) + \beta_b + \gamma_b \cdot \cos(2 \cdot \gamma_M)] \cdot \alpha_M \\ +1 \end{Bmatrix} \cdot G_y \tag{20}$$

The proposed constants for the equation above are presented in Table 3.

Table 3. Calculated constants for the Carpathian basin

Constant	α_a	β_a	α_b	β_b	γ_b
Value	$-5.369 \cdot 10^{-05}$	$-3.983 \cdot 10^{-05}$	$6.546\ 10^{-03}$	$-6.965 \cdot 10^{-04}$	$-7.148 \cdot 10^{-04}$

With the proposed calculation method it is possible to calculate yearly solar radiation for a tilted and oriented surface using just tilt angle and azimuth angle of the surface and the global radiation on a horizontal surface. The input horizontal global radiation data can be taken from the open access CarpatClim database or can be calculated manually e.g. from the daily sunshine hours as explained in Section 1 or can be taken from radiation measurements. The proposed method has an average of 1 kWh/m^{2}year difference to the reference calculated values for the 5895 points of the CarpatClim database. In total the average error of the proposed method is 0.014%.

4. Conclusion

In the paper a simplified model has been proposed to calculate annual incoming solar energy on surfaces with any tilted angle and azimuth. The simple formula Eq. (20) has been validated for any geographical position in the Carpathian basin except for some rarely inhabited spots with high elevation in the mountains. The significance of this limitation is negligible. The only necessary input data are the annual horizontal global radiation and the surface orientation and angle. The calculations can be carried out quickly and manually without any software support. The annual horizontal global radiation or daily sunshine hours can be taken from the open access CarpatClim database by simply inserting the coordinates, but certainly any other reliable datasets can be applied.

The proposed formula has been developed for the Carpathian basin and can be used in 8 countries with a geographical area of 483 495 km^2. In prospect a similar formula can be determined for other regions by applying the proposed methodology. A precondition in this case should be to have an access to long-term daily sunshine hours or daily horizontal global radiation datasets for a recommended period of minimum 10 years. If such data exists, the simplified formula can be developed and validated by applying purely statistical methods.

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Nomenclature

A	– albedo value [–]
D	– diffuse radiation on a horizontal plane [kW/m^2]
D_t	– diffuse radiation on a tilted plane [kW/m^2]
G	– global radiation on a horizontal plane [kW/m^2]
G_t	– global radiation on a tilted plane [kW/m^2]
$G_{t,y}$	– yearly global radiation on a tilted plane [kWh/m^2]
G_y	– yearly global radiation on a horizontal plane [kWh/m^2]

G_0 – extraterrestrial radiation [kW/m^2]

R_b – ratio of beam radiation on a tilted plane to the horizontal plane [kW/kW]

R_t – reflected radiation on a tilted plane [kW/m^2]

S – relative sunshine duration [h/h]

a,b – Angström constants of the Angstöm-Prescott equation [–]

Acronyms

LCR – Larger Carpathian Region

MBE – Mean Bias Error

MASH – Multiple Analysis of Series for Homogenization

MISH – Meteorological Interpolation based on Surface Homogenized Database

RMSE – Root Mean Square Error

SSE – Sum Squared Errors

Greek symbols

α_M – tilt angle of the tilted plane [°]

α_S – height of the Sun [°]

γ_M – azimuth angle of the tilted plane [°]

δ – declination [°]

θ – angle of incidence [°]

ω – hour angle [°]

ϕ – latitude [°]

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