Abstract: Physic-geographical features and climatic conditions that are characteristic to Braşov area make necessary the determination of a mathematical model to simulate in a satisfactory manner the variation of the solar radiation. The present paper proposes the solar radiation simulation (direct, diffuse and consequently the global solar radiation) for Braşov urban area in clear sky condition using Linke turbidity factor (\(T_L\)). Turbidity factor values were modelled based on direct solar radiation measurements. MBE and RMSE statistic indicators were used to validate the solar radiation models proposed.

Key words: Beam radiation, Diffuse radiation, Linke turbidity factor, MBE, RMSE

1 General Considerations
The solar potential of an area is determined and influenced by the climatic and physic-geographical parameters in aiding with the pollution level. Thus it is essential to know the amount of solar radiation available on earth with the purpose to develop solar energy systems and to estimate their efficiency. Therefore, it is essential the study of radiation attenuation by the atmosphere. An accurate approximation for the absorption and scattering phenomena suffered by solar radiation in clear sky conditions may be provided by Linke turbidity factor.

Braşov, is a medium-sized industrial city situated in a mountainous basin, experiencing some specific weather phenomena (thermal inversion, fog, mist, early and late frosts [6]), that have a great impact on the radiative potential of the region.

In this respect the present paper proposes the direct, diffuse and global solar radiation simulation in clear sky conditions Braşov urban area, according to modelled values of Linke turbidity factor; to test the degree of accuracy of the simulations the MBE and RMSE errors are calculated.

2 Direct Solar Radiation Simulation
Direct solar radiation is the most often used solar radiation component as input data in the renewable energy systems design; therefore it is necessary to determinate a mathematical model to simulate its variation precisely.

The values of the \(T_L\) factor were obtained from direct solar radiation records at a 10 minutes interval, of a four-year database (global and diffuse solar radiation are measured by a solar sensor type BF3 - MU -1.0 in W/m²), applying relation (1), for the days that comply with the clear sky conditions (clear sky days were extracted from the four years data base [2]):

\[
T_L = -\left(\delta_R \cdot m\right)^{-1} \cdot \ln\left(\frac{I_0 \cdot \varepsilon \cdot \sin(\alpha)}{B_h}\right). \tag{1}
\]

As shown in relation (1), \(T_L\) factor depends on the extraterrestrial radiation \(I_0\) corrected by the eccentricity factor \(\varepsilon\), altitudinal angle \(\alpha\) and direct radiation \(B_h\) (all known terms). Two other terms intervene: relative air mass \(m\) and optical air depth \(\delta_R\), for their calculation Kasten-Young equations [5], [6] were used. It was ascertained, these equations approximates in a precise manner the meteorological phenomena that occur frequently for high values of the air mass.

For the \(T_L\) factor determination this paper proposes its modelling depending on month. It is also taken into consideration that \(T_L\) factor has a descending variation during a day [2]. At noon when the highest values for solar radiations are registered the \(T_L\) factor value is smaller than the daily mean.

Figure 1 presents the variation curves for the calculated \(T_L\) values (blue curve) and the proposed values (green curve) with monthly equation [2]. \(T_L\) values depend on the factors outlined above as well as meteorological parameters that determine the season; as for the warm season higher values are observed then the ones for the cold season and also a
more pronounced downward slope.

Figure 2 presents the measured and simulated values of direct solar radiation for the considered days. The turbidity modelling depending on solar time leads to a very good approximation for solar radiation values under 750 W/m²; for higher values a slightly under-estimation is observed.

The variation curves of solar radiation (real and simulated values) for several clear sky days are presented in Fig. 3.

Because of weather phenomena, the real curve of solar radiation has a certain "delay" in increasing intensity during the period before noon and a slow decrease during sunset. Also, the asymmetry phenomenon towards 12 solar hours of real curve can be observed (the estimation models offered by literature leads to symmetrical curves [7]).

Variation curves generated using modelled TL values offer an accurate simulation for clear sky conditions, both quantitatively and qualitatively.
3 Diffuse Solar Radiation Simulation

Diffuse solar radiation represents a fraction from the radiative flux, and has a particularly increase variation in the early morning, it maintains an appreciatively constant value at noon, then before sunset it starts to decrease.

Because of this variation pattern it was considered that the simulation with constant TL factor values is the most appropriate.

The monthly mean values of TL factor are presented in Fig. 4. It can be observed that for the warm season months the TL factor values are higher than those for the cold months.

Figure 5 presents the values of the diffuse radiation, measured and simulated values with mean monthly values of TL. It can be observed that the simulated values are close to those real for diffuse radiations lower than 175 W/m²; for higher diffuse radiation values a slightly underestimation it was recorded.

Figure 6 presents the variation curves for diffuse radiation (measured and simulated values) during a day. Simulated curves overestimate the real values during solar noon and sunrise and at sunset an underestimation is recorded.

Figure 7 presents the variation curves (real and simulated data) for all radiation components, with high solar potential.
4 Mean Bias Errors (MBE) and Root Mean Square Errors (RMSE)

To determine the level of performance of the proposed models (for solar radiation simulation) both long-term and short-term type errors MBE and RMSE were calculated [1], [3].

In order to have a more detailed analysis over the proposed models behaviour the errors will be calculated in kWh/m².

Figure 8 presents the monthly MBE and RMSE errors calculated for the direct radiation.

It can be seen the MBE values are between -0.2 and 0.1 kWh/m² and RMSE between 0.1 and 0.3 kWh/m².

Figure 9 presents the MBE and RMSE errors for diffuse solar radiation. It can be observed the monthly errors are about 0.1 – 0.4 kWh/m² for RMSE and ±0.2 kWh/m² for MBE.

The MBE and RMSE errors for global solar radiation are presented in Figure 10. It can be observed that the monthly errors are between 0.1 - 0.2 kWh/m² for RMSE and for MBE between -0.1 kWh/m² and 0.2 kWh/m²; this confirms a good accuracy of the proposed model.

5 Conclusions

More accurate modelling of Linke turbidity factor leads to a better simulation of the direct and diffuse radiation and consequently of the global radiation. The statistical performed analysis validates the proposed model.

Acknowledgement:
This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S.

References: