Study of the Potential for the Solar Concentrating Sector in Burkina Faso

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Abstract: The results of atmospheric effect characterization on the town of Ouagadougou in Burkina Faso are presented and the link with the availability of the direct component of solar radiation is discussed. Experimental meteorological data are treated to set a system of constant references which are used to extrapolate the likely atmospheric effect given by the other experimental meteorological data from 1976 to 2006. As results the periods of strong monthly attenuation of the solar potential are pointed out.

Key words: Solar radiation, direct component, solar potential, Burkina Faso, experimental data.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_t$</td>
<td>Average monthly coefficient of transmission</td>
</tr>
<tr>
<td>$P_{atm}$</td>
<td>Atmospheric pressure in millibar (mB)</td>
</tr>
<tr>
<td>$\delta_s$</td>
<td>Sun declination according to earth equator</td>
</tr>
<tr>
<td>$\theta_H$</td>
<td>Incidence angle on horizontal plane</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Geographical latitude</td>
</tr>
<tr>
<td>$\psi_0$</td>
<td>Solar constant = 1,366.1 W·m$^{-2}$</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Hour angle</td>
</tr>
<tr>
<td>$\omega_s$</td>
<td>Duration of the insolation</td>
</tr>
<tr>
<td>$f_{atm}$</td>
<td>Direct sun rays transmittivity factor or attenuation factor</td>
</tr>
<tr>
<td>$H$</td>
<td>Elevation angle</td>
</tr>
<tr>
<td>$Z$</td>
<td>Zenithal distance</td>
</tr>
<tr>
<td>$\psi_{th,gl}$</td>
<td>Theoretical instantaneous radiation</td>
</tr>
<tr>
<td>$N_{ir}$</td>
<td>Day number in the calendar from 1 to 365</td>
</tr>
<tr>
<td>$\vec{i}$</td>
<td>Unit vector carrying the direction of the sun</td>
</tr>
</tbody>
</table>

1. Introduction

According to Benard, Menguy, and Schwartz [1], during the year and out of the atmosphere, it is the equator which receives the maximum of energy (10 kWh/(m²·Jr)); while moving away from the equator, the decrease is initially slow (so that at a latitude of 30°, it measures 8.8 kWh/(m²·Jr)); the decrease is faster between 30° and 50° (with around 5.9 kWh/(m²·Jr) at 50°), then it becomes brutal (with 4.8 kWh/(m²·Jr) at the polar circle, where energy reaches hardly half of that of the equator). Burkina Faso localized between 11° and 13° of latitude receives on the ground an average solar energy of 5.5 kWh/(m²·Jr) with a period of insolation around 3,000 to 3,500 h/year. One can understand that there is a strong decrease of energy even if Burkina Faso is perceived as an appropriate geographical situation to benefit from a good solar radiation. Besides, for concentration technology application, only the direct component of the solar radiation can be concentrated. This component is not only related to the latitude, but takes into account the effects of atmospheric disturbance [2].

We share the point of view of Kalogirou [3]. A saying states that any investigation in solar concentration requires knowledge on the real characteristics of solar energy in the locality. Therefore, our study relates to the evaluation of the effective and recurring availability of the direct solar radiation through the characterization of the atmospheric
disturbance. The present study will be undertaken for the main town of Burkina Faso where solar technology use is in full emergence.

2. Methodology for the Evaluation of Atmospheric Disturbance

In order to determine the characteristics of atmospheric obscuration for solar energy, we can calculate the average monthly coefficient of solar transmission called, $K_t$. That is the ratio between the monthly insolation at ground’s horizontal plane, $\hat{H}$, which is usually experimental data, on the monthly insolation of the atmosphere over a supposed horizontal plane, $\hat{H}_0$ [1, 3]:

$$K_t = \frac{\hat{H}}{\hat{H}_0} \quad (1)$$

For this study we use experimental data about the town of Ouagadougou registered by the meteorological station of “Meteo” localized at 12.36° N. These data are about the monthly average of solar global radiation on horizontal plane from 1986 to 2006 [4]. However, this station does not register the direct and diffuse component of solar radiation. On the other hand, we have data from MeteoNorm [5], with direct and diffuse average hourly irradiations over a horizontal plane, used in the PhD work of COULIBALY (2011) and used also in commercial software such as TRANSYS Wolf [6].

We considered the 3 levels of atmospheric disturbance proposed by M. Daguenet in 1985, in Table 1, in order to establish 3 corresponding border curves of coefficient transmission according to the month, so that, on the basis of the 3 references, we situate the conditions sustained by the town of Ouagadougou from 1986 to 2006. Whatever the source of data the coefficient $K_t$ is calculated by Eq. (1), where:

- $\hat{H}$, is experimental data from Meteo about the monthly insolation over an horizontal plane;
- $\hat{H}_0$, is theoretical data obtained by a triangular integration from sunrise to sunset of global radiation out of the atmosphere on a horizontal plane, given by Kalogirou [3]:

$$\hat{H}_0 = \frac{12 \times 3600}{\pi} \psi_0 \left[ 1 + 0.033 \cos \left( \frac{360}{365} N_{fr} \right) \right] \times \left[ \cos \phi \cos \delta_s \sin \omega_s + \frac{\pi \omega_s}{180} \sin \phi \sin \delta_s \right] \quad (2)$$

where

$$\delta_s = 23.45 \sin \left( \frac{360}{365} (284 + N_{fr}) \right)$$

and

$$\omega_s = \frac{2}{15} \cos^{-1} [-\tan \phi \tan \delta_s] \quad (3)$$

$$\psi_{th, glo} = \psi_0 \left[ 1 + 0.33 \cos \left( \frac{360}{365} N_{fr} \right) \right] \times f_{atm} \cos \theta_H$$

The three standard values, set as basis in order to appreciate the town atmospheric conditions are determined by calculating a theoretical monthly average coefficient of transmission at the same latitude, always using Eq. (1) where now:

- $\hat{H}$, is still calculated as in the previous case using Eq. (2).
- $\hat{H}_0$, is theoretical data about monthly average insolation, calculated by triangular integration of extrapolated instantaneous radiation. The extrapolated radiation is given by Eq. (3) [1, 7]:

$$\theta_H = \frac{\pi}{2} - h = \frac{\pi}{2} - \sin^{-1} [\sin \phi \sin \delta_s + \cos \delta_s \cos \omega]$$

and $f_{atm}$ is the instantaneous atmospheric attenuation of direct radiation. It is a factor defined in accordance with Daguenet (1985) and predetermined by two constants $A$ & $B$ which are chosen to establish the sky criteria according to Table 1.

$$f_{atm} = A \exp(-B \times m_h) \quad (4)$$

with

$$m_h = \frac{P_{atm}}{1000 \sin(h)}$$
Instantaneous radiations on horizontal plane are calculated with a gap of 36 s. Over the year, the daily insolation is obtained by means of numerical integrations from sunrise to sunset by the formula of the trapezoids. And the approximation of monthly insolation is done by holding a plurality of daily insolation according to the number of days in each given month.

3. Results

Fig. 1a confirms a best fit bordering line of our estimations of the daily direct radiation on horizontal plane for the case of clear sky and the experimental data, from “MeteoNorm”, about daily global radiation on horizontal plane. In the same figure, the layouts of direct and diffuse components prove that the real composition of daily global radiation is far from being direct radiations. That is the means of this work, which is to study direct solar energy availability through the level of atmospheric attenuation.

Fig. 1b shows the evolution of the monthly average coefficient of transmission $K_t$, while Fig. 1c shows at the same time the percentage of direct insolation compared to the global monthly insolation out of the atmosphere. In Fig. 1b, 3 border curves correspond to M. Daguenet’s criteria.

By comparative analysis of diagram bars in Figs. 1b and 1c we can point out that the rates of variation are similar through the month. These results were expected to note a strong correlation between the monthly average transmission coefficient, $K_t$, and the direct component of solar energy received on the ground.

There seems to be an order of magnitude between $K_t$ and the direct component of solar energy. In the better case where equal 0.68 for the month of February the higher percentage of 72% is obtained for direct radiation. On the contrary, in the last case where turns around 0.52 in August, the contribution in direct solar energy is only 40%.

On the basis of the layout of standard values of $K_t$ over the 12 months in Fig. 1a, we established the theoretical border value of $0.67 \pm 0.03; 0.59 \pm 0.03$; and $0.49 \pm 0.04$, to respectively identify the limits of clear sky, normal sky, and of industrial zone. In later consideration we are going to use these standard values as reference.

Fig. 2 shows the results of processing with the data of “Meteo”. It is a gradual color diagram which situates the values of $K_t$ according to the month and according to the year. We can observe that the progression is marked by a decrease. For a given month the variation is like teeth of saw, year after year. There is not a great constance in the same month, but from time to time the values are close to each other. On the other hand in a given year, we can notice the same propensity of variation from month to month, with a general decrease from January to August and increase from August to December.

Diagrams in Figs. 3a-3c, bring more precisions on previous results shown in Fig. 2. They highlight, by means of two color codes (red and blue), the months and the years for which the town of Ouagadougou, is under established conditions in accordance with the border of $K_t$ standard values.

There is a big gap between the period from 1976 to 1981 and the period from 1984 to 2006. From 1977 to 1980 there were not data because of government changes at that time. This period marks the first path of the city to a strong urbanization and the extension of infrastructures.
Fig. 1 (a) Results of the meteorological data processing; (b) average monthly transmission coefficient; (c) monthly average of the contribution from direct radiation to global radiation.
From 1984 to 2006 a tendency appears clearly in a given month. The city appears to be usually under conditions below those of an industrial zone, from July to September. That also occurred during the half of the years from April to June. From January to March and October to December the tendency is located between the conditions of an industrial zone and those of a normal zone. These results show that the periods of autumn and winter are the periods when we can expect a strong component of direct solar radiation (between 60% and 72%, related to the data of MeteoNorm). In the rest of the year, we can notice that the atmospheric conditions can worsen according to the year from April to June and worsen in an effective way from July to September.

Rainy seasons are particularly marked by cloudy sky with many dust and high wind. This situation creates a deposit of fine particles of sand. We assume that the raise of these particles in dry season explains the low level of $K_i$ from April to September each year. These various obstructions of the sky harm the transmission of direct solar energy and make the period between January and March and between October and December the most appropriate to benefit from a technology with concentration.

### 4. Conclusion

At the end of this study, we keep in mind that the periods from January to March and from October to December, are the periods when the component of direct radiation is statistically higher in the town of Ouagadougou, compared to the incident energy out of the atmosphere. There is a recurrent tendency in monthly evolution of the monthly average coefficient of transmission according to the year, marked by a decrease in a process of “teeth of saw”. So data from MeteoNorm source report a yearly progression of the atmospheric conditions in the town of Ouagadougou which tend to appear as in a sky of industrial area.

For the particular case of the town of Ouagadougou in Burkina Faso we suppose this observation is related to the amplification of urban activities without appropriate infrastructures, such as the number of roadways. In order to establish the real potentialities of the country, and make the best choice for solar concentrating technology installation zone, it would be necessary to reinforce the study of atmospheric disturbance all over the entire territory and it will be necessary to compare to each other the rates of energy produced per month. The number of ground meteorological stations must be increased to get more realistic experimental data rather than using approximations and correlations from over-viewed data given by satellites for which each pixel represents a large area.
Fig. 3  Grid according to the condition met by the city of Ouagadougou, according to the month and the year.
Red: the condition is fulfilled; blue: the condition is not fulfilled.
References


