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GROUND-REFLECTED RADIATION AND ALBEDO

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Abstract—The diffuse radiation incident on an inclined plane is composed of both the ground-reflected radiation and the sky diffuse radiation. The evaluation of the sky diffuse radiation has already been described in many references. In this paper we focus on the ground-reflected radiation, its relation to insolation conditions and its evaluation by means of models. We used six data banks from the following four countries: Switzerland, France, The Netherlands, and the U.S.A. We investigated how the albedo depends on the amount and the composition of the incident radiation, on geometrical parameters such as the height and/or the azimuth of the sun and on meteorological parameters such as the humidity. We did not find any notable dependence. We also tested different models evaluating the ground-reflected radiation on tilted planes with corresponding measurements on an inverse horizontal plane (facing the ground) and on inclined planes. We came to the conservative conclusion that the best results are obtained when using a constant averaged measured albedo, for transposition to tilted surfaces, when assuming the ground-reflected radiation to be isotropic.

1. INTRODUCTION

In order to correctly evaluate the diffuse radiation incident on an inclined plane of any orientation and of any tilt angle, we need to know separately the sky diffuse radiation as well as the ground-reflected radiation. References [1] and [2] deal with the transposition of the solar radiation from the horizontal plane to any plane; they are based on international collaborations and they recommend the use of the model developed by Perez [3,4] for the evaluation of the sky diffuse radiation incident on an inclined plane. In this paper we are going to focus on the ground-reflected radiation which is also significant and which can sometimes reach values of the order of 100 W/m^2 for a vertical plane. Let us remember that the albedo is defined here as the ratio between the ground-reflected radiation and the global radiation incident on the ground. It has already been previously found, but based on restricted data, that using an albedo value measured on the site and considered as constant leads to satisfactory results [5]. We now test a few models for the evaluation of the ground-reflected radiation by using six data banks corresponding to measurements performed in Geneva and Lausanne in Switzerland, Albany in the United States, Cabauw in The Netherlands, Trappes and Carpentras in France. In the next sections, we describe, in more detail, the data, models, tests and the conclusions involved in this study of the ground-reflected radiation. All radiations and quantities are defined in the Nomenclature at the end of this paper.

2. DATA

We mention here only the data selected in the data banks and relevant for this study.

For evaluating the models we need data on the three components of the solar radiation incident at the earth surface, these are G_h (global), D_h (diffuse), B (direct normal).

We also need data for the ground-reflected radiation measured on a reverse horizontal plane (R_h) and on inclined planes (R_i).

The measurement of R_h involves a pyranometer mounted horizontally and facing downwards at a few meters from the ground. For the measurement of R_i the pyranometer is protected against sky radiation by a black horizontal cover mounted above the pyranometer.

Although unimportant, but for simplicity and symmetry reasons, all data we used refer to the solar time rather than to the legal time. We also restrict ourselves to data covering hourly periods only.

All hourly periods retained for this study satisfy the following quality control criteria:

$$G_h > 5$$

$$D_h < 1.05 \cdot G_h$$

$$B < 1360$$

$$|B_h - (G_h - D_h)| < 10 \quad \text{for} \quad 5 < B_h < 50$$

$$|B_h - (G_h - D_h)| < 15 \quad \text{for} \quad 50 < B_h < 100$$

$$|B_h - (G_h - D_h)| < .15 \cdot B_h \quad \text{for} \quad 100 < B_h < 1360$$

where $B_h = B \cdot \sin h$, and the radiation unit is Wh/m^2 h.

For all sites but Lausanne, all data involve accurate pyrheliometers and pyranometers (Eppley PSP and NIP, Kipp + Zonen CM10). Such devices were carefully calibrated by comparison with standards and substandards.

When possible, we also eliminated data corresponding to snow conditions by using reports from nearby meteorological stations. Note that the effects of such conditions on the albedo are described in other studies [8–11].

Authors are ISES members.

2.1 *Site's description*

Geneva (Switzerland). The measurements were performed on the roof of a building of the University (Sciences II) within the city of Geneva (elevation: 380 m; latitude: 46.2°N; longitude: 6.1°E) for a one-year period from June 1, 1986 to May 31, 1987.

The measured radiation components retained for this study are the following: G_h, D_h, B, R_h, R_N, R_S, R_E, R_W, R_{30}, R_{45}, R_{60}. D_h was measured by the use of a small moving disk. In such a case there was no need for a geometrical correction.

B was measured by means of a Normal Incidence Pyrheliometer (NIP) from Eppley. All other components were measured with CM 10 pyranometers from Kipp and Zonen. Measurements were taken every minute, mean values were recorded every six minutes, and hourly values were computed on this basis. 3200 hourly periods were retained for this study.

Lausanne (Switzerland). Data were obtained at the Ecole Polytechnique Fédérale de Lausanne (elevation: 410 m; latitude: 46.5°N; longitude: 6.6°E[2]) over a three-year period from 1980 to 1982. Twenty-two hundred hourly periods were retained for this study. They correspond to the following measurements: G_h, D_h, R_h. D_h was measured by use of a shadow band. The geometrical correction is based on isotropy. All measurements were performed with CM 5 pyranometers from Kipp and Zonen. Measurements were performed every 30 seconds, mean values were recorded every 30 minutes from which hourly values were obtained.

Albany (New York, U.S.A.). The measurements were performed on the roof of the Atmospheric Sciences Research Center building in Albany (elevation: 80 m; latitude: 42.7°N; longitude: 73.8°W) from April 1987 to February 1988 with a break in August 1987 for the calibration of the measuring devices. Six hundred hourly periods were retained for this study. Measurements are as follows: G_h, D_h, B, R_N, R_S, R_E, R_W. D_h was measured by use of a shadow band from Eppley. The geometrical correction is based on isotropy. B was measured by means of a Normal Incidence Pyrheliometer (NIP) from Eppley.

All other components were measured with PSP pyranometers from Eppley. Hourly values were obtained by summing measurements already integrated over fifteen minute periods.

Cabauw (The Netherlands). The measurements were performed at Cabauw (latitude: 52.0°N; longitude: 4.9°E) from 1979 to 1982. Data were provided by the Technisch Physische Dienst at Delft[6]. Twenty-seven hundred hourly periods were retained for this study. Measurements are G_h, D_h, B, R_h. D_h was measured by use of a shadow band with a geometrical correction based on isotropy. The instruments used were a NIP and PSP's from Eppley. Hourly values were derived from mean values corresponding to six-minute periods.

Trappes and Carpentras (France). The data came from measurements performed in 1981 at Trappes (latitude: 48.7°N; longitude: 2.0°E) and Carpentras (latitude: 44.0°N longitude: 5.0°E[7]. We retained for this study 1400 hourly periods for Trappes and 2500 hourly periods for Carpentras. The measured components are as follows: G_h, D_h, B, R_N, R_S. The data were provided directly for hourly periods.

We have data on R_h for only three sites. For the other sites, we evaluate R_h from data on R_i (more precisely from R_N and R_S) and we consider these values as indirect measurements of R_h. These can be compared to other measurements or to model predictions.

2.2 *Evaluation of the albedo*

For each site, we computed a mean albedo ρ from the data corresponding to all retained hourly periods:

$$\rho = \Sigma R_n / \Sigma G_h.$$

We also determined for each site the separate mean albedos ρ_b and ρ_d for the beam and diffuse radiation components in the following way.

By selecting hourly periods for which there is no beam radiation at all, we deduce the albedo for the diffuse radiation as usual:

$$B_h = 0 \quad R_h = R_{dh} \quad G_h = D_h$$

$$\rho_d = \Sigma R_{dh} / \Sigma D_h = \rho = \Sigma R_h / \Sigma G_h.$$

The albedo for the beam radiation ρ_b is obtained by selecting hourly periods corresponding to clear sky conditions, i.e., $D_h < 150$ Wh/m^2 h and $B_h > 500$ Wh/m^2 h, and by using the previous evaluation of the diffuse albedo ρ_d:

$$R_{bh} = R_h - R_{dh} = R_h - \rho_d \cdot D_h$$

$$\rho_b = \Sigma R_{bh} / \Sigma B_h.$$

The values of the albedo for the global, beam, and diffuse radiation components and for each site are presented in Table 1.

3. MODELS

We now consider the models for the evaluation of the ground-reflected radiation on any plane. The reverse horizontal plane is a particular case related to the albedo, which we are going to treat separately.

3.1 *Albedo models*

Many albedo measurements have already been performed for different ground vegetation, in various

Table 1. Albedo for global (ρ), diffuse (ρ_d) and beam (ρ_b) solar radiations on the horizontal plane (See Section 2)

Site	Area	ρ	ρ_d	ρ_b
Geneva	semi-urban	0.133	0.132	0.132
Albany	semi-urban	0.137	0.135	0.143
Lausanne	cultivation	0.220	0.171	0.261
Cabauw	Meadow	0.233	0.219	0.254
Trappes		0.220	0.198	0.265
Carpentras	dry meadow	0.154	0.143	0.166

seasons, for snow cover and for other conditions[8–11]. We are now going to describe and test a few simple models dealing with the albedo or the ground-reflected radiation on the reverse horizontal plane.

Liu and Jordan's Assumption[12]. The first evaluations of the ground-reflected radiation were achieved by Liu and Jordan. Their conclusion was that a constant albedo $\rho = 0.2$ can be applied to the global radiation incident on the horizontal plane:

$$R_h = 0.2 \cdot G_h.$$

Mean measured albedo[5]. Preliminary albedo measurements have previously shown that satisfactory results can be obtained when applying a constant albedo value but measured or evaluated on the considered site, to the global radiation on the horizontal plane:

$$R_h = \rho\,(\text{site}) \cdot G_h.$$

Gueymard's model[13]. A parametrization of the albedo was achieved by Gueymard who fitted published data concerning albedo measurements in North America to a polynome where the latitude φ is the main variable. Gueymard got the following expressions for two ranges in latitude:

$$\rho = -18 + 2.4 \cdot \varphi - 0.04 \cdot \varphi^2 \qquad 20° < \varphi \leq 30°$$

$$\rho = a_0 + a_1 \cdot \varphi + a_2 \cdot \varphi^2 + a_3 \cdot \varphi^3 \qquad 30° < \varphi \leq 60°$$

where ρ is expressed in % and φ in degree.

The coefficients a_i are determined once a month and daily values can be deduced by interpolation. These are not fitted for any site under investigation here.

Nkemdirim's model[14,15]. In this model, the albedo depends on the height h of the sun:

$$\rho = \rho_o \cdot \exp(b \cdot (90 - h))$$

where h is in degree and where b is positive. This albedo applies to G_h as usual.

In this study, the coefficients ρ_o and b were determined, for each site, by fits through the data. Obviously, these coefficients are site-dependent.

Beam/diffuse model. In a previous study[16] it was found that the albedo depends significantly on the beam radiation B_h. Therefore, it makes sense to consider separate albedos for the beam and diffuse components on the horizontal plane:

$$R_h = R_{bh} + R_{dh} = \rho_b \cdot B_h + \rho_d \cdot D_h.$$

Here again, albedos are site dependent and obtained separately at each site by measurement.

3.2 *Models for the evaluation of the ground-reflected radiation on any plane*

We considered two models: isotropy assumption; and Temps and Coulson's model[17].

Isotropy assumption. If the ground-reflected radiation is isotropic, its contribution to an inclined plane is given by

$$R_i = \rho \cdot G_h \cdot \tfrac{1}{2}(1 - \cos s)$$

where s is the tilt angle of the inclined plane with respect to the horizontal plane.

Temps and Coulson's model[17]. Measurements achieved by Coulson *et al.*[18] on the reflection coefficients for different matters, real and artificial, led to an expression where the albedo depends on the height and the azimuth of the sun and on the azimuth of the inclined plane under consideration:

$$\rho = \rho_1 \cdot [1 + \sin^2(\tfrac{1}{2} \cdot (90 - h))] \cdot |\cos \alpha|$$

where h is expressed in degree, where ρ_1 is a parameter depending on the site and where α is the azimuth difference between the sun and the inclined plane (or more precisely, the horizontal projection of the angle between the sun ray and the normal to the inclined plane).

Let us point out that the angle α is not defined when the sun is at the zenith and/or when dealing with the reverse horizontal plane. Consequently, the model cannot be applied in such cases.

4. EXPERIMENTAL OBSERVATIONS

4.1. *Horizontal albedo*

The albedo or the ground-reflected radiation on a reverse horizontal plane can depend on parameters such as latitude, height of the sun, the season, the nature of the incident radiation (beam or diffuse), as already seen in the models, but also on some other geometrical or meteorological parameters. We investigated such possible variations of the albedo by scanning all data, parameter by parameter, site by site, or globally. In order to compare or to mix different sites corresponding to different mean albedo values, we normalize for each site all individual albedo values ρ_i to its mean value ρ_{site}. Therefore, we define a relative albedo or a normalized albedo ρ_n by

$$\rho_n = \rho_i / \rho_{\text{site}}.$$

Figure 1 shows how the relative albedo may depend on nine parameters considered one by one, all sites being considered at once. All data are plotted versus the considered parameter. For each bin in abscissa we represent the mean value and the standard deviation of the corresponding data. The larger the standard deviation, the larger the scattering of the data around the mean value. In some cases, low level radiations correspond to larger relative fluctuations and to a larger scattering of the data. Let us now discuss the different features of Fig. 1.

In Fig. 1(a), the albedo depends slightly on the height h of the sun[19–20] and, in particular, the albedo is larger for low h values such as $h < 15°$. We fitted a function $f(h)$ through these data. Let us point

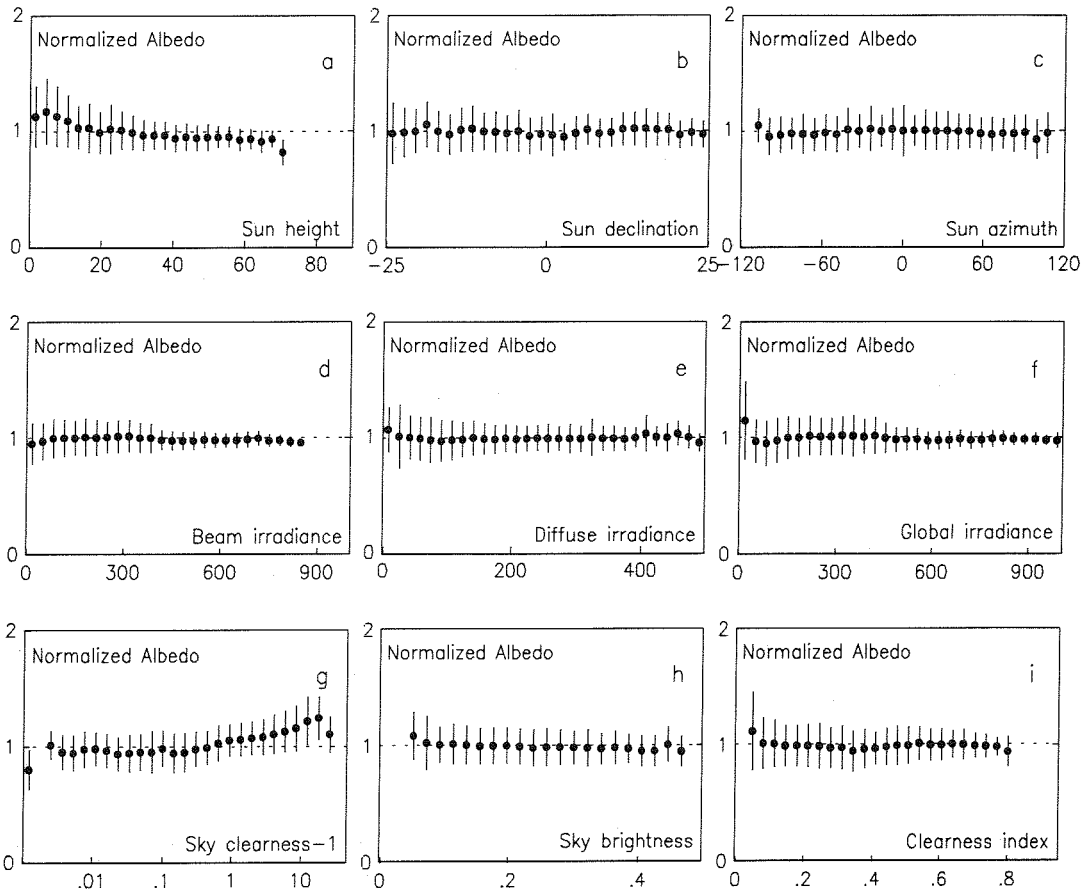

Fig. 1. Albedo variation with data from all sites under consideration. Variations of the albedo with the sun height (a) and with the sky clearness (g) are factorized and extracted for the other graphs (b, c, d, e, f, h, i). (See Section 4.)

out that the range $h < 15°$ not only correponds to low radiation values (sunrise and sunset conditions), but that it includes less than 5% of the hourly periods. Consequently, the range $h < 15°$ plays a very small role when considering whole day behaviours or values, at least for latitudes below 50°. Let us also note that the standard deviation (i.e., the scattering of the measurements) is of the same order of magnitude as the observed deviation of the relative albedo from unity.

In Fig. 1(g), the albedo depends slightly on the sky clearness as defined by Perez[3]:

$$\epsilon = (B + D_h)/D_h.$$

Clear sky conditions correspond to larger albedo values. We fitted a function $g(\epsilon)$ through these data. Note that less than 5% of the hourly periods correspond to the range $(\epsilon - 1) > 10$ (or $B > 10 \cdot D_h$). Also the scattering of the observed values is significant.

We consider both albedo variations mentioned above, $f(h)$ and $g(\epsilon)$, as two independent variations. In order to look for other possible variations without being biased by correlations between parameters and eventual reflections of already observed effects, we recompute new relative albedo values ρ'_n by factorizing the variations already mentioned

$$\rho_n = \rho'_n \cdot f(h) \cdot g(\epsilon) \quad \text{or} \quad \rho'_n = \rho_n \cdot f^{-1}(h) \cdot g^{-1}(\epsilon).$$

Figures 1(b)–(f), (h) and (i) show that ρ'_n does not depend significantly on either one of the following parameters: sun declination (or the season), sun azimuth, amount of global or diffuse or beam radiation, clearness index K_t (or the weather) and sky brightness Δ as defined by Perez[3]:

$$\Delta = D_h \cdot m / I_o$$

where m is the air mass and I_o the solar constant (see Nomenclature).

We also investigated the possible influence of the humidity on the albedo. We have correlated measurements of the humidity (by means of dry and wet thermometers) only for Geneva. We could expect variations of the albedo when the ground is wet, i.e., when the relative humidity of the air is around 90–100% (rainy weather or fog), but we did not find any significant effect of this kind.

Altogether, we have seen that both the height of the

sun and the sky clearness do induce slight variations of the albedo, which is not the case of the other parameters considered. Nevertheless, both effects are small. If we consider the ground-reflected radiation, they induce variations below 10 Wh/m^2 h. They may be considered statistically and quantitatively as unimportant, if not negligible. In our opinion, it does not make sense to justify and introduce such complications, especially in a context where we are limited by crude models and rough and incomplete measurements to describe a rather complex situation. In addition, introducing empirically such effects into the model does not improve significantly their applicability or their accuracy (see Section 5).

4.2 *Oriented albedo and azimuth effects*

In order to investigate how the ground-reflected radiation behaves depending on the orientation of the observation plane, we used the data for the vertical planes considered in Geneva, Albany, Trappes, and Carpentras.

Oriented albedo coefficients ρ_i are defined by

$$\rho_i = [2/(1 - \cos s)] \cdot R_i/G_h$$

where $\cos s = 0$ for vertical planes and where the index i refers to North, South, East, and West vertical orientations.

Table 2 shows the values of the mean oriented albedo coefficients $\bar{\rho}_i$ for the four sites under consideration as well as the same quantities but differentiated for morning and afternoon periods.

Numerous particular effects can be observed but they are all variable depending on the site, its surrounding environment (for instance clear buildings may reflect the solar radiation especially for conditions close to normal incidence), orientation, season, time of the day, nature and amount of radiation as well as many other conditions.

We did not find any general property or dependence which could be factorized within the definition of the oriented albedo and which could consequently improve the applicability of the models previously described.

Such observations are not surprising. It just confirms that the situation is very complex and that we are still far from being able to describe accurately and coherently such a radiation context. Nevertheless, the ground-reflected radiation is small as compared to sky radiation and, as it will be shown in the next sections, simple models, even if not perfect, are able to reduce the reality with an accuracy of 10 Wh/m^2 h. The point we would like to make is that it will not be easy in the future to improve the models and that for the time being it is not justified in most cases to introduce unnecessary complications.

5. MODEL EVALUATION

5.1 *Models for determination of ground albedo*

The albedo models are applied for the evaluation of the ground-reflected radiation on the reverse horizontal plane. The accuracy of the corresponding models can be deduced from the comparisons between the model predictions and the measured radiations. We define two indicators as follows:

- The mean bias difference (MBD or μ) is the average difference between computed and measured hourly values in radiation units. It gives some information on the long term bias or the systematic difference between model predictions and measurements.
- The root mean square difference (RMSD or σ) between computed and measured hourly values (also in radiation units) includes biases and fluctuations and is usually considered as a way to evaluate errors.

Both RMSD and MBD are presented in Table 3 for each model and site studied. Also included are the mean reflected irradiances in [Wh/m^2 h].

As it appears in Table 3, the best results are obtained when applying a *constant mean albedo* measured on each site. This very simple model has no bias because it is based on a measured albedo and its accuracy for all sites holds 8 Wh/m^2 h, or 14% if one refers to the corresponding mean reflected radiation of 57 Wh/m^2 h. The models which are not site-dependent are not satisfactory. Introducing an albedo depending on the height of the sun (Nkemdirim's model) or using two different albedos (ρ_d/ρ_b) for the beam and the diffuse component on the horizontal plane does not significantly improve the situation. Let us notice that the accuracy of the model may also vary from site to site.

The applicability of the model based on a mean measured albedo is shown in Fig. 2 for all sites (i.e., 12600 hourly periods). Computed values are plotted versus the measured ones. Each dot corresponds to an hourly period. For an ideal model, all dots should line up on a straight line at 45°. The differences between the model predictions and the measurements are described through the indicator C–M (computed–measured), also represented versus different parameters. The indicator C–M corresponds per bin of abscissa to

Table 2. Differentiated albedos for vertical planes and for morning (a.m.) and afternoon (p.m.) conditions (See Section 4)

Plane	north			south			east			west		
Site	mean	am	pm	mean	am	pm	mean	am	pm	mean	am	pm
Geneva	0.17	0.15	0.18	0.14	0.15	0.14	0.17	0.15	0.19	0.16	0.17	0.15
Albany	0.12	0.12	0.13	0.15	0.14	0.16	0.20	0.21	0.19	0.13	0.10	0.16
Trappes	0.19	0.18	0.19	0.26	0.25	0.26	-	-	-	-	-	-
Carpentras	0.17	0.17	0.18	0.14	0.13	0.15	-	-	-	-	-	-

Table 3. Applicability of the albedo models (See Section 5)

Site	Geneva		Albany		Lausanne		Cabauw		Carpentras		Trappes		All	
R_h [Wh/m²h]	50		49		69		51		67		58		57	
Model	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
ρ = 0.2	26	18	23	24	-6	12	-7	9	20	20	-5	12	5	20
ρ (site)	0	5	0	10	0	10	0	7	0	11	0	12	0	8
Gueymard	31	29	13	16	6	23	12	24	20	24	10	21	16	26
Nkemdirim	-2	6	0	6	-6	13	-4	7	-2	7	-5	12	-4	9
ρ_b / ρ_d	0	5	0	10	-2	8	1	8	2	12	2	13	0	9

R_h is the mean value of the ground-reflected radiation on the reverse horizontal plane.
μ and σ are the mean bias difference and the root mean square difference between model predictions and measurements.
Unit: Wh/m^2 h.

the combination MBD ± RMSD of the indicators already defined. No significant tendency can be observed, apart from the effects already discussed in Section 4 and related to high beam radiation conditions. Let us remark that introducing the functions $f(h)$ and $g(\epsilon)$ as defined in Section 4 does very little to improve the mean value of the indicators shown in Table 3.

Altogether, Fig. 2 and Table 3 show that the ground-reflected radiation on a reverse horizontal plane can be evaluated without significant bias by using a constant albedo measured on the considered site and with an accuracy of the order of 8 Wh/m^2 h.

5.2 *Models for transposition to inclined surfaces*

We tested different models by comparing their predictions to data for inclined planes. Our data correspond to 22400 hourly values in Geneva, 2400 in Albany, 500 at Carpentras, and 2800 at Trappes, with a total of 32600 hourly values for these four sites.

The models have already been presented in Section 3.2.

We have a different choice for the albedo and, consequently, different models based on isotropy. We tested the four following possibilities:

- a constant value of the albedo for any site (Liu and Jordan, $\rho = 0.2$);
- a unique and constant value of the albedo but measured on the site ($\rho = R_h/G_h$, see Table 1);
- a measured differentiated albedo for each orientation (NSEW, see Table 2);
- an albedo differentiated for each orientation and for morning and afternoon conditions (NSEW, a.m./p.m., see Table 2).

In addition, we have the nonisotropic model of Temps and Coulson.

Results are shown in Table 4 for these five models, the four considered sites both individually and as a whole. As in Section 4, we present the bias (μ) and the accuracy (σ) as well as the mean value of the considered radiation for the evaluation of relative effects.

The model of Temps and Coulson is the worst in this context. It is mainly due to the factor $|\cos \alpha|$ (see

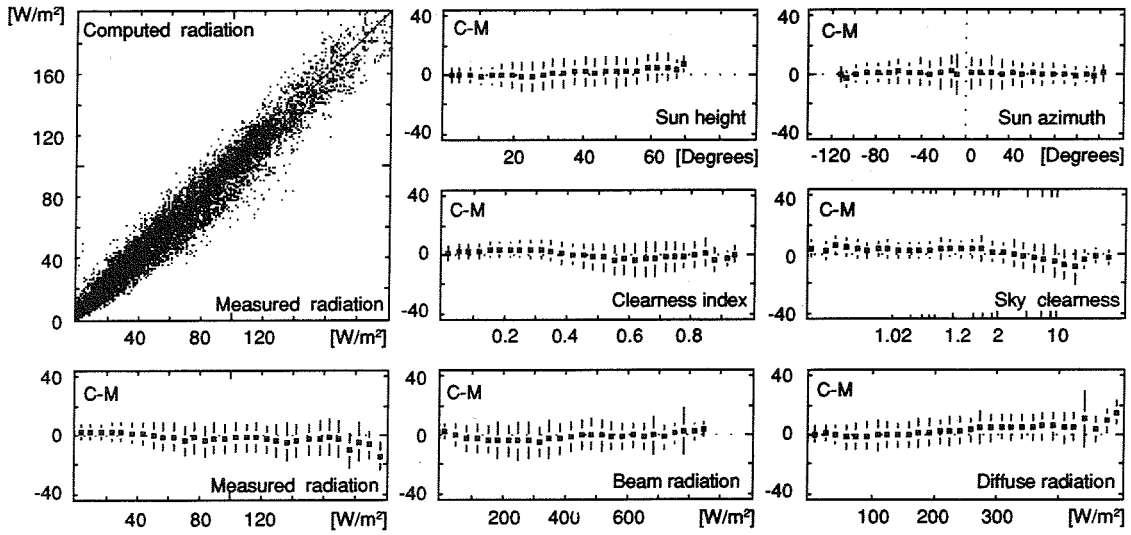

Fig. 2. Applicability of the model for the evaluation of the ground-reflected radiation on a reverse plane with the assumption of an albedo constant and site-dependent. Data include 12600 hourly periods for all sites. The indicator C–M illustrates comparisons between computed and measured values. (See Section 5.)

Table 4. Applicability of the models for the evaluation of the ground-reflected radiation on inclined planes (See Section 5)

Site	Geneva		Albany		Carpentras		Trappes		All	
R_i [Wh/m²h]	20		27		33		29		23	
Model	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
ρ = 0.2	6	9	9	14	10	12	-3	8	6	10
Temps & Coulson	-7	11	-9	15	-9	15	-5	13	-7	12
ρ (site)	-3	6	-3	10	0	8	0	8	-2	7
ρ (site, NSEW)	0	5	0	7	0	7	0	7	0	6
ρ (site, NSEW, am/pm)	0	5	0	7	0	7	0	7	0	6

R_i is the mean value of the corresponding radiation.
μ and σ are the mean bias difference and the root mean square difference between model predictions and measurements.
Unit: Wh/m^2 h.

Section 3.2) which induces unrealistically large variations of the albedo as well as under some geometric configurations, zero values, which were never observed. It is also confirmed that the hypothesis of Liu and Jordan ($\rho = 0.2$) is unsatisfactory. Actually, we treated this model as a reference for comparisons rather than a good candidate to be selected.

Table 4 shows that the use of differentiated albedos very slightly improves the situation as compared to the case of a unique albedo. Table 4 also shows that differentiating morning and afternoon albedos does not do any better. In our opinion, the mentioned improvement is too small to justify the corresponding complications.

Altogether, the isotropic model simply based on a constant mean albedo measured on the site is satisfactory. Its accuracy is of the order of 7 Wh/m^2 h. We did not extract from our data other general properties or tendencies which could be factorized in a simple way and which could significantly improve the situation.

6. CONCLUSIONS

The ground-reflected radiation on any inclined plane (including the reverse horizontal plane which corresponds to the usual definition of the albedo) can be evaluated with an accuracy better than 10 Wh/m^2 h by assuming that the ground-reflected radiation is isotropic and when knowing the albedo of the site under consideration. This may be obtained simply from a short measurement campaign.

Even if some anisotropic effects do exist (related to incidence angles, to the nature and the quantity of the radiation from the sky and to other conditions), they seem to strongly depend on the site, its environment and its peculiar characteristics. Consequently, they can not be fed into the models in a coherent and general way. We investigated many of these effects by using several good data banks, moreover, site-specific gains in performance were not found to be substantial, but we remain with the conclusion that, for the time being, the isotropic model with an albedo known for the site under consideration, is the model to be used and that the other complications which we could introduce are not justified in most cases.

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NOMENCLATURE

G_h, D_h, B_h global, diffuse, beam solar radiation on the horizontal plane
B beam normal solar radiation
R_h ground-reflected radiation on the reverse horizontal plane (facing the ground)
R_{bh}, R_{dh} same as above, but induced by the beam solar radiation only, or the diffuse solar radiation only
R_i ground-reflected radiation on an inclined plane
i = N, S, E, W for vertical plane facing North, South, East, West
i = 30, 45, 60 for a plane facing South and tilted by 30°, 45°, 60° from horizontal
I_o Solar constant [18] variable around the mean value 1367 [W/m^2]
K_t clearness index ($=G_h/(I_o \cdot \sin h)$)
h height of the sun (with respect to the horizontal plane)
a azimuth of the sun
s tilt angle (from horizontal) for an inclined plane
m air mass

Greek

φ latitude
ρ albedo for the global radiation (G_h)
ρ_b, ρ_d albedo for the beam (B_h), or the diffuse (D_h) solar radiation
ρ_n relative or normalized albedo (= ratio of an hourly value of albedo to its mean value for the site)
ϵ sky clearness = $(B + D_h)/D_h$
Δ sky brightness = $D_h \cdot m/I_o$

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