FUNCTIONAL SOLAR ENERGY APPLICATIONS BASED ON AN IMPROVED INSOLATION MODEL

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INTRODUCTION

By considering the literature concerning solar-energy economics and preceding the recent oil crisis, as e.g. the study by Löf and Tybout (1), it is obvious that at that time everybody was convinced that solar energy would be competitive with the traditional energy sources when the latter had become more expensive, especially fuel. However at the present time, anyway as far as Belgium is concerned, this hope has not been fulfilled although oil prices have risen dramatically. It is evident that one has been biased by the cheap fuel prices and overlooked the intricate feed-back action of rising oil prices on our economies. In fact the price of devices, appliances and manpower simultaneously have risen considerably, perpetuating the unbalance between solar-energy and traditional sources in favour of the latter. It has been demonstrated that rising fuel prices are not making solar energy economies more attractive so as to provide a breakthrough for the latter. In fact it appeared that more attention should be given to the basic physics, to the right application and to an adequate management of solar energy.

Consequently, in this paper, attention will be focused on these important aspects of solar energy applications. First an improved direct solar radiation model will be proposed making it possible to compute more accurately the impinging solar energy on flat surfaces. Preliminary data will also be presented for vertical surfaces. Secondly, attention will be given to the management of the solar-energy by the simultaneous use of panels as shutters and concentrators. As a result of both innovations the output of traditional solar energy devices can be doubled in favourable circumstances.

IMPROVED RADIATION MODEL

After reviewing the available literature on radiation models, sometimes also called weather models, it must be concluded that most authors principally paid attention to the insolation on flat horizontal surfaces, thereby assuming a flat earth as shown in figure 1. As soon as data for insolation on vertical surfaces are presented, the weakness of this assumption appears. Generally, in order to obtain the data for vertical surfaces, authors as e.g. Chauliaguet et al (2), multiply the data for insolation on horizontal flat surfaces by sec θ_z, θ_z being the apparent zenith angle of the sun. Obviously it is impossible to compute the radiant energy carried at grazing or near grazing incidence by the solar radiation as represented by the line g in figure 1. As a result the data show sometimes incorrect results as in the case of those of Liu and Jordan (3) as was proven by Kusuda and Ishii (4). However in their model they neglect the energy contribution of the grazing rays. To improve our knowledge it has to be emphasized that the energy contribution of slanted rays cannot correctly be obtained by multiplying that of vertically incident radiation by a geometrical factor. One has to bear in mind two important facts : First, slanted rays are subjected to greater absorption by the atmosphere due to their longer path through the latter. Hence at their arrival at the earth's surface they are less energetic than orthogonal rays. In fact the correct atmospheric absorption processes should be accounted for. Secondly it implies the consideration of the real shape of the earth and its atmosphere as shown schematically in figure 2. More important, the relevant mathematics on which an accurate computation can be based are available. They have been developed by Chapman (5). He has shown that in order to account for the energy contribution by grazing rays one should replace sec θ_z by a more relevant function, known commonly as the Chapman function and defined as follows

$$\mathrm{Ch}\,(x,\,\theta_z) = \sec\theta_z - \int_0^{\theta_z} \exp\left\{x(1-\sin\theta_z\,\mathrm{cosec}\,\theta_i)\right\}\sec\theta_i\,\tan\theta_i\,d\theta_i \quad \ldots (1)$$

θ_z being the zenith angle, θ_i the angle of incidence and x a function of the earth's radius and the scale height of the atmosphere considered. For more detailed information on the latter parameter the reader is referred to textbooks on aeronomy, e.g. Nicolet (6).

Basically the second righthandside term of equation (1) offsets the endlessness of the first one and is applicable near sunset and sunrise and virtually during the whole day in the wintermonths in the higher mid-latitudes where the European countries are situated.

Considering the Chapman function and taking into account various parameters that could adversely affect the energy of impacting solar radiation, the following extended formula of Bouguer is proposed :

$$G_b = f\eta\, G_o\, p^m \quad \ldots\ldots\ldots (2)$$

where f is a correction factor taking into account the variability of the solar distance, G_o is the solar constant, η the reduction by the cloud cover,

$$p = e^{-\Sigma\alpha_i} \quad \ldots\ldots\ldots (3)$$

the α_i taking into account the various absorptions due to air turbulence, aerosols, etc, and

$$m = \mathrm{Ch}\,(x,\,\theta_z)\,P/P_o \quad \ldots\ldots (4)$$

where finally P is the pressure at the altitude considered and P_o the same at sea level. In these expressions the other symbols have the meanings proposed by Beckman et al. (7).

Starting from formulae (2)-(4) preliminary computations have been done for the beam irradiation H_b on vertical walls of various azimuths during both a cloudless typical winterday morning and a comparable full day at 50.8° latitude at sea level assuming x = 650 and $\Sigma\alpha_i$ = 0.33. H_b is defined as follows

$$H_b = \int_{t_o}^{t_1} G_b\cos\theta_i\,\cos(\gamma_s-\gamma)\,dt \quad \ldots (5)$$

where γ_s is the azimuth of the sun. The preliminary results of such calculations are shown in figures 3 and 4. Contrary to what would have been expected, the next striking result was that during the morning period and consequently also during the afternoon period a 15° - 20° offset wall receives more radiation than a due south wall. As a result, if a swivelling device could be made operational shifting at noon a vertical wall from an azimuth + 15° towards - 15° a gain of approximately 7.5% could be realized compared to a fixed vertical wall exposed to the south. This has been emphasized in figure 4 by adding point P.

From what is explained above it is evident that the radiation models published until now should be considered as first order approximations of equation (1). There is further opportunity to introduce second order corrections. Considering figure 2 it is obvious that at the earth's surface we see the sun only at an apparent position which differs from the real one. Due to the layered structure of the atmosphere with changing composition the ray paths starting at E are not straight, as depicted in figure 2 but curved. Mathematical formulae are available but computational models have not yet been developed.

INSOLATION MANAGEMENT

No intention is made to prescribe a management plan on national or institutional scale but only to present some ideas illustrating the principle that, with some simple devices and good sense, solar energy could be applied more efficiently at the family home or at the second residence. More particularly attention is drawn to the simultaneous use of concentrators as shutters and the beneficial effect of allowing for the dwelling habits of the owners. The proposed measures make sense only as long as they are not made obsolete by sophisticated technology applied on a large scale, providing cheap energy as yet beyond reach.

Concentrator-shutter

Generally ignored is the fact that for every calorie saved in winter by sophisticated insulation of the home, an equivalent one must be dispensed with in summer. As a result the application of solar energy to the family home may not be seen as a question of heating alone; there is the equally, if not more, important aspect of cooling during summer. In fact, houses especially built for saving energy in winter are quite inhabitable in summer. Heating and cooling should therefore be considered as an integrated effort. The most promising idea is therefore to invest in equipment with forced air coupled with a heat pump that provides additional heat in winter and cools in summer. However, it is possible to dispense with this device by making sensible use of shutters, which could be arranged such as to act as concentrators of solar energy appropriately. Therefore vertical walls should be recommended as supports for solar collectors as has been done by Trombe in Odeillo (France). A vertical collecting wall obviously does not present the best inclination for collecting solar energy, but offers a relatively fair cross section in winter and a poorer one in summer. Its performance is, in fact, relatively high in winter and low in summer; which was the aim. Its performance in winter can be enhanced in a simple way by adding plane specular reflectors. The use of such devices has already been recommended by many authors e.g. Tabor (8) and Souka and Safwat (9). The geometrical factors involved have been produced by Wijeysundera (10). However instead of limiting their action to a single function, a dual mode is proposed. Mounted either on vertical or horizontal spindles they could be positioned in such a way that their additional supply of radiative energy would be maximized. This has been illustrated in figures 5 and 6. The upper parts represent the profiles of the arrangements for vertical walls and respectively a perfectly or near horizontal mirror and a vertical one. These mirrors could be made of aluminum sheets polished on both slides and fixed on panels of insulating material. In winter at night and in summer during the day, these panels should be closed as shutters. Due to their construction they will reduce heat loss during winter nights and prevent the solar radiation from penetrating the home during hot summer days. In the lower parts of figures 5 and 6 the influence of the positioning of the concentrators on the illumination of the collector is shown. The hatched regions represent the portions of a vertical wall that could be double exposed. A computer program has been prepared in order to define the most efficient position of the concentrator which has been called concentrator-shutter for its double action as a shutter and a concentrator. From the drawings exhibited it is evident that with an apparent solar zenith angle of 45° a horizontal concentrator-shutter can double the output of a solar collector.

Dwelling habits

From a survey of the current literature it appears that practically no author has paid attention to the dwelling habits of the owners for which solar energy applications were conceived. When taken into consideration they could influence strongly the conception of the solar heating and cooling system, resulting in appropriate insulation management yielding accountable savings. In order to illustrate this statement let us consider a family home where the owners are absent during the day, a situation frequently encountered nowadays when both husband and wife are breadwinners. During their absence, their home captures a vast amount of solar energy that is subsequently squandered by ineffective energy management. Radiative energy entering profusively through windows and accumulated in walls and furniture during sunshine hours when the house is unoccupied could be succesfully tapped, stored and applied when the family is home instead of its subsequent loss after sunset. Therefore the use of heat pumps is recommended. During their absence such devices could take the room temperature even below the ambient one so that instead of losing heat by radiation and convection, the chilled house would become a real heat sink with all its inherent advantages. Simulation of this behaviour is in process.

CONCLUSION

A premium requirement to evaluate solar energy applications correctly is the use of a realistic radiation transfer function. Obviously, without extensive use of sophisticated technology, it is still possible to improve drastically the yield of a solar energy application system in a one family home, given an appropriate heating and cooling management system.

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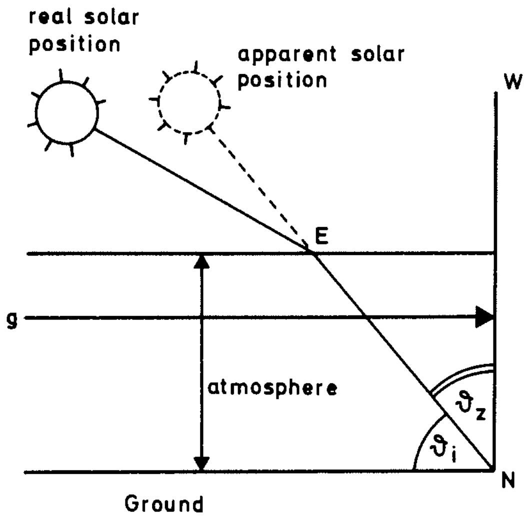


Figure 1 Schematic radiation geometry assuming a flat Earth.

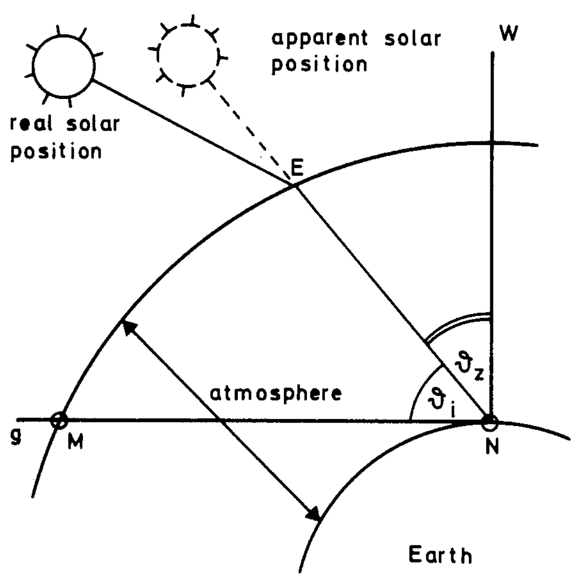


Figure 2 Schematic radiation geometry for a spherical Earth.

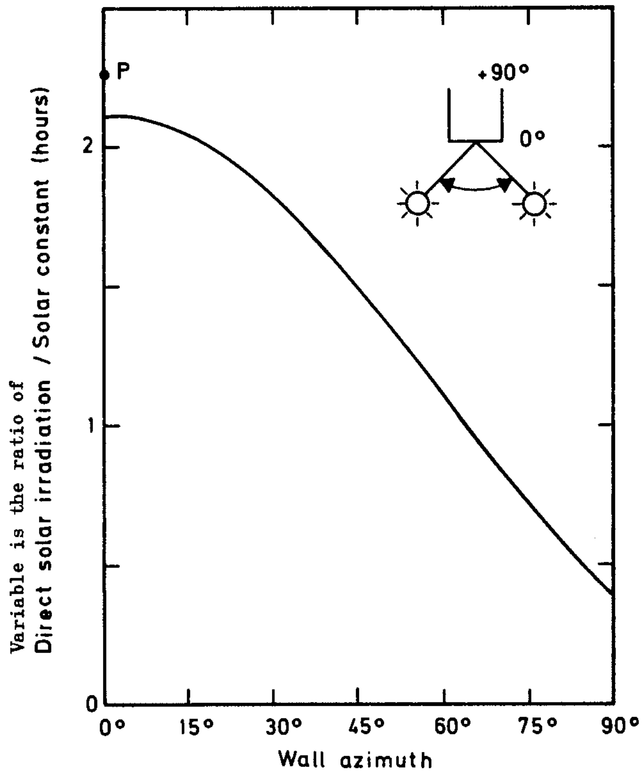


Figure 3 Daily beam irradiation (winter, clear sky).

Inset: relative position of the sun in horizontal plane.
Figures: asimuths of the walls 0^o = due South.

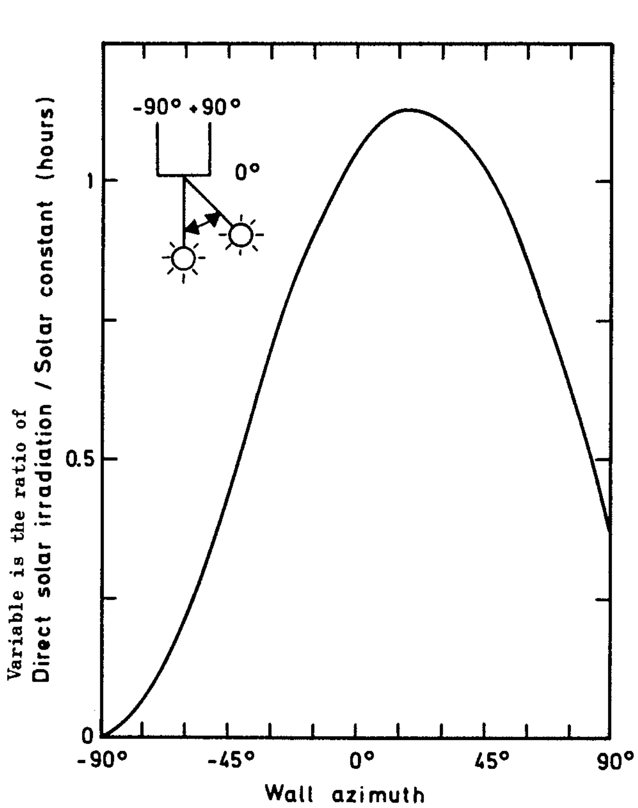


Figure 4 Beam irradiation in the morning (winter, clear sky).
Inset: relative position of the sun in horizontal plane.
Figures: asimuths of the walls 0° = due South.

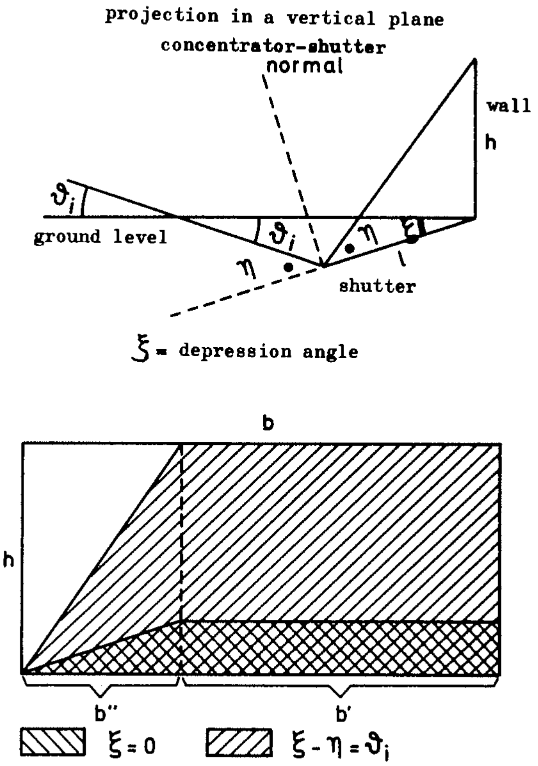
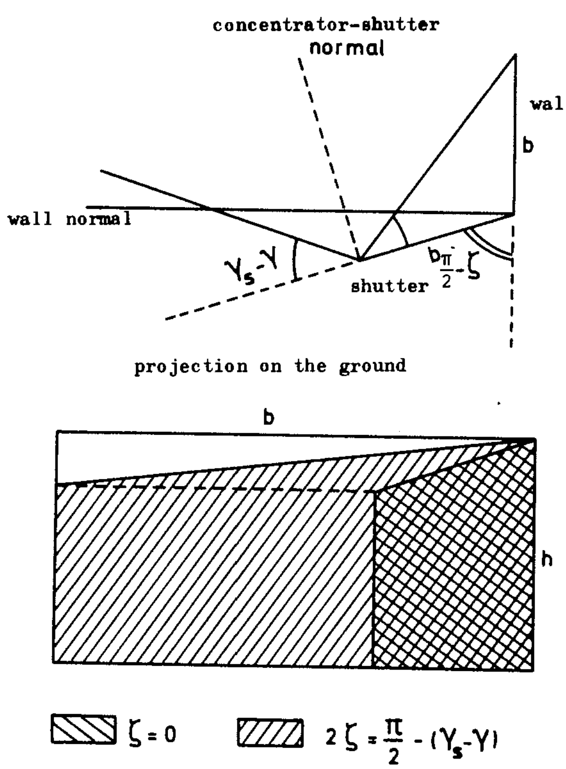
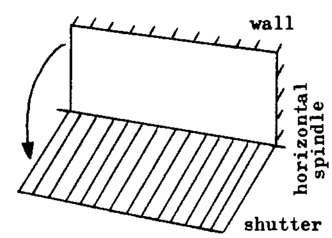


Figure 5 "Horizontal"*arrangement (top) and effect of a concentratorshutter (bottom).
*"Horizontal" means the shutter is operated as a hatch.





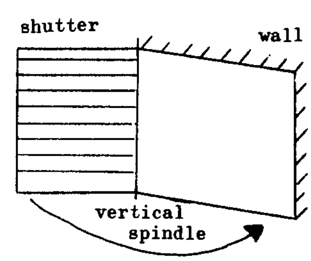


Figure 6 "Vertical"*arrangement (top) and effect of a concentratorshutter (bottom).
*Vertical means the shutter is operating as a classical shutter does.