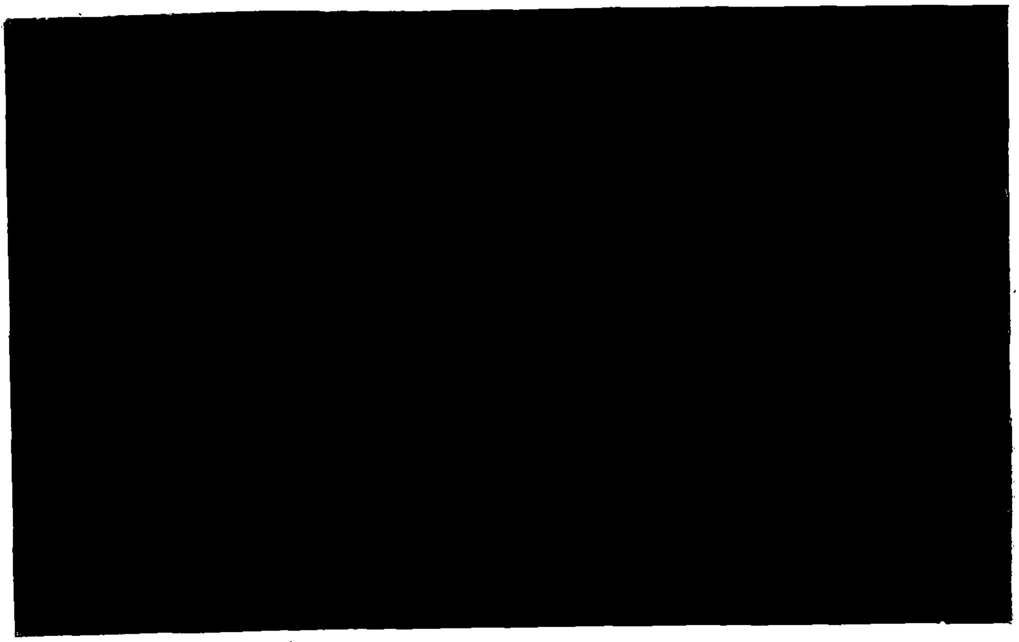

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SHORT WAVE IRRADIATION OF CYLINDRICAL AND RECTANGULAR BODIES

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by

Dr. Peter Valko

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Summary

Customary horizontal surface solarimeter data are of limited value only,when the instantaneous irradiation of three-dimensional objects is considered. However, many problems of architecture and engineering, but also those with respect to plants, animals and man can be solved only, if the structure of both the direct and diffuse radiation fields are sufficiently known. On the irradiation of horizontal and vertical surfaces of different orientation, the necessary empirical knowledge is now available [2,4]. On this basis, separately the direct, the diffuse and the global radiation loads on rectangular prisms and straight circular cylinders were computed. The effect of geometry on irradiation conditions was studied by varying the shape parameters (side-length ratios and the ratio of height to the radius of the basic circle resp.) through several orders of magnitude, but keeping constant the total exposed surface. All sets of these radiation load data were computed for five different values of atmospheric turbidity, for every 5th degree of the solar height between 10 and 70 degrees and for every 10th degree of azimuthal orientation respective to the sun's direction.

Zusammenfassung

Die momentane Bestrahlung von dreidimensionalen Objekten kann aus üblichen Solarimeter-Angaben der Horizontalflächen-Globalstrahlung kaum hergeleitet werden. Viele Probleme der Technik und Architektur sowie auch solche im Zusammenhang mit Pflanzen, Tieren und dem Menschen, können jedoch nur dann gelöst werden, wenn die Struktur

sowohl des direkten als auch des diffusen Strahlungsfeldes bekannt ist. In bezug auf die Horizontale und auf Vertikalflächen verschiedener Orientierung liegt das notwendige empirische Wissen zur Zeit vor [2,4].

Auf dieser Grundlage wurde die direkte und getrennt die diffuse und globale Strahlungslast von rechtwinkligen Quadern und geraden Kreiszylindern berechnet. Indem die Formparameter (Kantenverhältnisse sowie das Verhältnis der Höhe zum Kreishalbmesser) über mehrere Grössenordnungen variiert, die gesamte bestrahlte Hüllfläche jedoch konstant gehalten wurden, konnte der Einfluss der Geometrie auf die Bestrahlungsbedingungen untersucht werden. Alle Daten der Strahlungslast wurden für fünf verschiedene Werte der atmosphärischen Trübung, für alle fünf Grad Sonnenhöhen zwischen 10 und 70 Grad sowie alle 10^{o} Azimutwinkel - bezogen auf den Sonnenazimut - errechnet.

Résumé

Le rayonnement reçu à un moment précis par un objet à trois dimensions ne peut pour ainsi dire pas être déterminé en partant du rayonnement global mesuré sur une surface horizontale par un solarimètre. Bien des problèmes découlant de la technique et de l'architecture ainsi que de ceux se rapportant aux plantes, aux animaux et à l'homme ne pourront cependant être résolus que lorsque la structure du champ des rayonnements aussi bien direct que diffus sera connue. Les données empiriques se rapportant à des surfaces horizontales ou verticales de différentes expositions existent actuellement [2,4].

Partant de ces données, on a calculé l'importance des rayonnements direct, diffus et global tombant sur des parallélipipèdes rectangles et des cylindres d'axes verticaux. En faisant varier notablement les formes extérieures des solides (rapports des arrêtes et rapport entre la hauteur et le rayon de la base) tout en maintenant leur surface constante, on a pu étudier l'influence de leur géométrie sur les conditions de rayonnement. On a calculé tous les apports d'énergie dûs au rayonnement pour 5 valeurs du trouble atmosphérique, pour des hauteurs du soleil comprises entre 10 et 70^{o} et cela par tranches de 5^{o}, ainsi que pour tous les azimuts - par rapport à l'azimut du soleil - par tranches de 10^{o}.

Short wave irradiation of cylindrical and rectangular bodies

1. Introduction

Engineers and architects require information on the natural irradiation of the outer walls of a building one by one, and also of the building as a whole. Similar problems may arise with respect to plants, animals, or with regard to human physiology too.

A competent answer to such questions is possible only, if a detailed knowledge of the structure of the short wave radiation field, both as to the direct sun and the diffuse components, is available. In fact, one should know at any given time and location the direct and the diffuse radiation fluxes separately, and the sum of both - with respect to any given surface. That means, that functional relationships between these fluxes and quantities like solar height, atmospheric turbidity, azimuth between the sun and the surface's normal, as well as some further parameters should be known.

We may say that this basical knowledge is now available, at least in case of the horizontal surface and vertical surface of different orientation, as far as a cloudless sky is considered. Thus, conditions are given for computing the radiation load on three-dimensional bodies having horizontal and vertical outer surfaces. And that's the subject of the present paper.

2. Characteristic features of the short-wave radiation fluxes

Figure 1 gives a survey on the single radiation fluxes, received by horizontal and vertical surfaces, as well as on the derivation of these fluxes.

The direct sun radiation decisively contributes to the total irradiation; this part of the total flux is well known, both from theory and by measurements, therefore, its amount is available for arbitrary atmospheric conditions and positions of the sun. For the present computations direct intensity I_N received by a surface normal to the sunrays was considered as a function of the solar height angle h and the atmospheric turbidity coefficient B. Because of a stohastic relationship between turbidity and water vapour content of the air, determined numerically [1] this expression also takes into account a variable water vapour content. Arbitrary spatial components may then be computed by simple geometry.

The structure of the diffuse radiation field, on the other hand, is much more intricate, thus it can be computed only in case of simplified models. It is more realistic, therefore, to use directly measured radiation intensities as falling on horizontal and vertical surfaces. Radiation falling on the horizontal is a function of the solar height and turbidity, in case of vertical surfaces, however, it depends not only upon these two quantities, but also on the azimuth angle between the sun's direction and the surface's normal, furthermore on the albedo A of the terrain. Results concerning the diffuse radiation field, as considered for the present computations, were reported elsewhere [2,3,4]. They are valid for a mean albedo A=0,2.

According to figure 2, the diffuse radiation falling on the horizontal increases with growing solar height and also with turbidity. Diffuse radiation falling upon vertical surfaces (figure 3) does not only arrive from the sky vault, but also from the ground as reflected radiation. The figures show vertical diffuse intensity versus azimuth angle - surface orientation relative to the sun - for clean air ($10^3B = 50$), mean turbidity ($10^3B = 100$) and for a very hazy atmosphere ($10^3B = 200$). The curves were drawn for different solar heights. Without going into details it may be seen, that sun facing surfaces receive the most, shaded ones the least diffuse radiation, furthermore, that the values increase with turbidity. For surfaces turned away from the sun, radiation increases with the solar height, but sun facing surfaces show maximum irradiation at a certain threshold h-value; if the sun rises over this angle, the diffuse irradiation diminishes again.

3. Irradiation of three-dimensional objects

The direct, the diffuse and the global radiation were all computed separately for five different degrees of the turbidity coefficient

$$10^3 B = 50,\ 100,\ 150,\ 200 \text{ and } 250,$$

for every 5th degree of the solar height h between 10 and 70 degrees. The irradiation of all together 66 rectangular prisms of different shape (figure 4) was computed, by giving various values for the side-length-ratios x/y and z/y. These ratios extend over several orders of magnitude:

x/y = 1, 2, 5, 10, 100 and 1000,
z/y = 0,0001, 0,001, 0,01, 0,1, 0,2, 0,5, 1, 2, 5,10 and 100.

By turning the z-x surface of all these rectangular bodies first towards the sun, then 10, 20, and so on degrees away from the sun's direction, computations for 10 different positions were made. By these means, the three radiation fluxes were computed for 650 different conditions on all 66 rectangular bodies.

Computations for cylinders, if only circular cylinders are considered, are much simpler; here, only one shape characteristic has to be considered, the ratio of the height L to the radius R. In case of cylinders, the azimuth has no influence on the radiation load.

Lets consider a few graphs, plotted by using these data. Figure 5 is valid for average turbidity 100 and likewise for an average solar height of 30 degrees; $a = 0^{\circ}$ means, that the z-x surface of the rectangular prisms faces the sun. The figure shows radiation intensity versus the ratio z/y - this measures the relative height of the body - the upper part refers to the direct radiation, the lower to the diffuse one.

The ratio z/y covers four magnitudes in this picture. To get a better survey of the lapse of the curves, the diffuse radiation scale is ten times enlarged relative to the direct radiation scale. As parameter,the horizontal side-length-ratio x/y was chosen. For both parts, the curves x/y = 1, 2, 5, 10 and 100 were drawn. - It is apparent, that the influence of the height parameter z/y is just the opposite when the direct and diffuse radiation loads are compared. Obviously the horizontal characteristic has only a weak influence on flat objects, but for tall ones and for the direct component, the intensity varies between about 220 and 440 mcalories due to this parameter. It may be seen further, that likewise for tall objects, the diffuse component contributes almost with 50 % to the total radiation load.

Figure 6 compares direct and global radiation as falling on prisms in case of strong haze $10^3B = 200$, and at a solar height of 60 degrees. The curves were drawn again in the intensity versus ratio z/y-system. The left figure is valid when the z-x surface faces the sun, the one on the right, when turning it away by 90 degrees. - It may be seen, that at this solar height naturally the horizontal surface is favorised in comparison with the vertical surfaces; it is evident furthermore, that under such conditions the ratio of the horizontal edges has only a reduced influence on the radiation load. This latter effect is just the opposite for the two positions. Also in this case the contribution of the diffuse component - the vertical difference between the two bands of curves - is important, the more,the higher the body.

Figure 7 shows conditions of the diffuse component alone; the solar height amounts to 60 degrees again, the prism is facing the sun with its z-x surface ($a = 0^o$). The three bands of curves are drawn for the constant turbidities $10^3B = 50$, 100 and 200; as parameter, the horizontal ratio x/y was chosen as before. The considerable dependence of the diffuse irradiation on atmospheric turbidity turns out clearly. It can be seen too, that over a threshold value of the turbidity coefficient, somewhere between 100 and 200, the lapse of the curves changes: just at this turbidity value the shape of the body is of no importance.

As an example of the cylinder figure 8 shows, as before, the diffuse radiation load alone in function of the shape parameter L/R. Thin curves represent clean air (turbidity = 50), fat drawn curves strong turbidity ($10^3B = 200$). In both cases conditions at the solar heights 10, 30 and 60 degrees are illustrated. The similarity between the irradiation of cylindrical and rectangular bodies is, under certain conditions, very close.

Without entering here in further details,it may be summarized, that the three catalogues of data, containing all results of direct, diffuse and global irradiation, might give engineers and architects some hints concerning the shape and orientation of buildings, especially with respect to air conditioning and daylight design.

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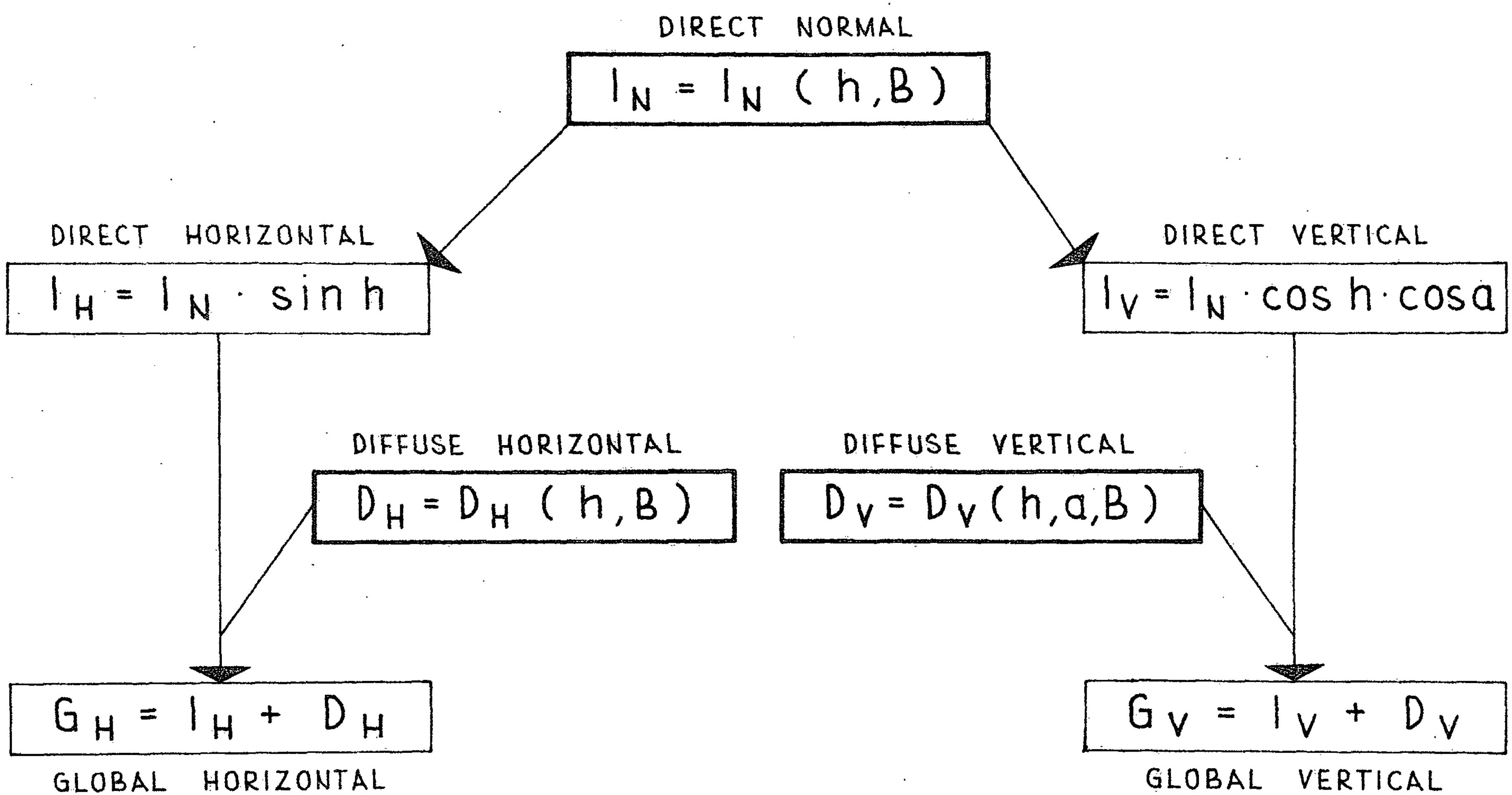


Figure 1 - Survey on the short wave radiation components received by horizontal and vertical surfaces

Figure 2 - Horizontal-surface diffuse irradiation depending on solar height and atmospheric turbidity

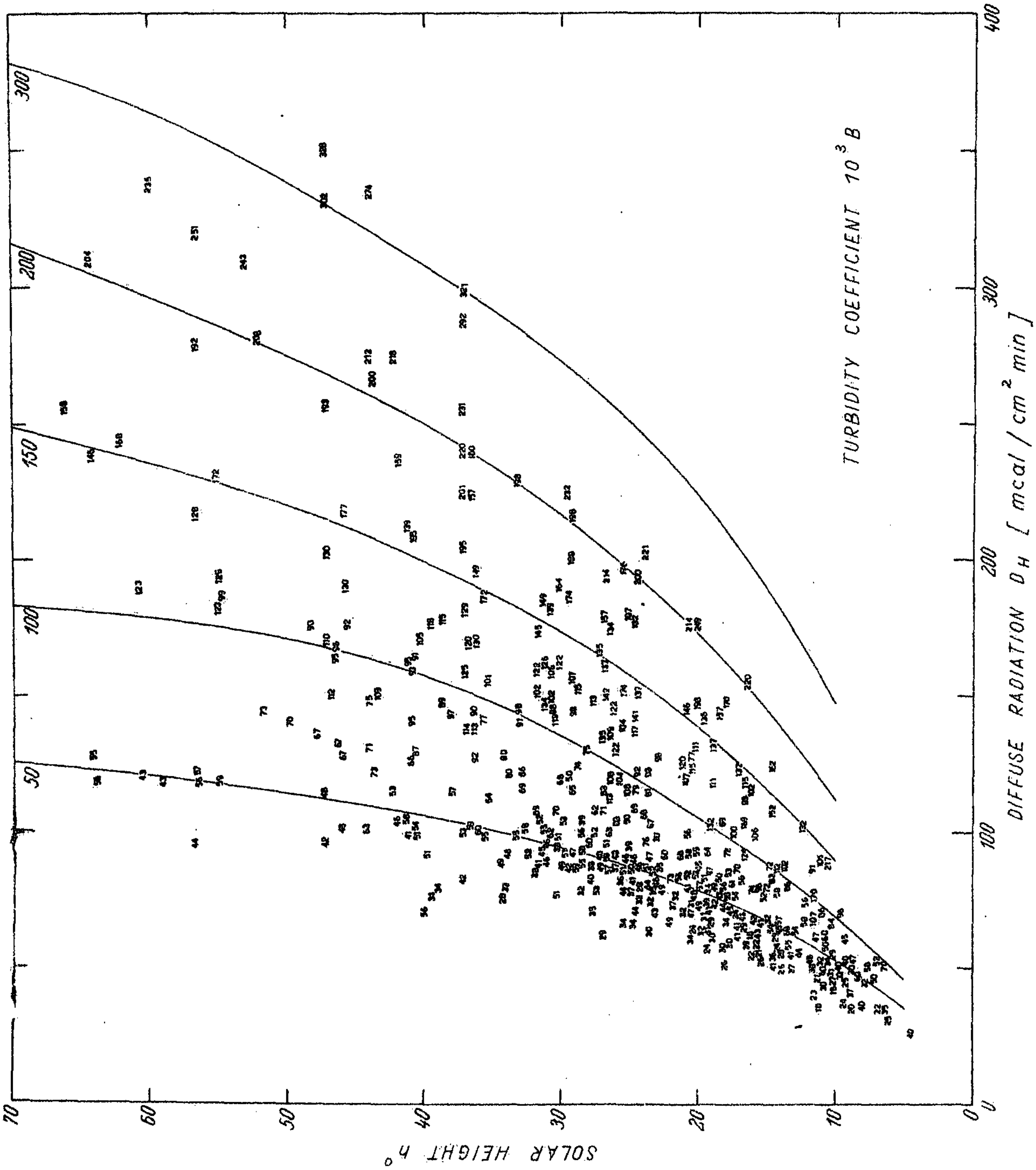
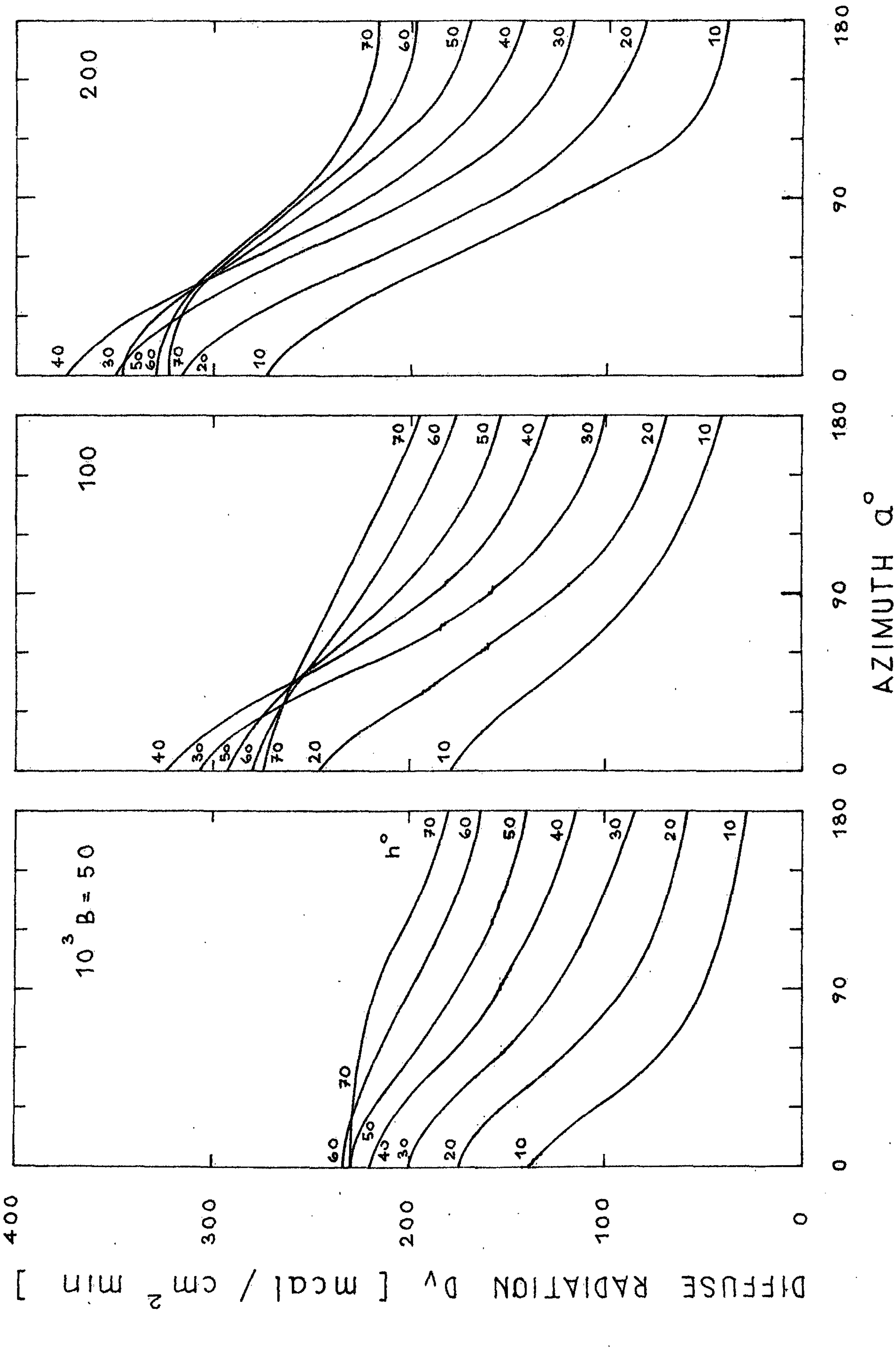


Figure 3 - Instantaneous diffuse radiation on vertical surfaces in function of the atmospheric turbidity coefficient, the wall-solar azimuth and the solar height



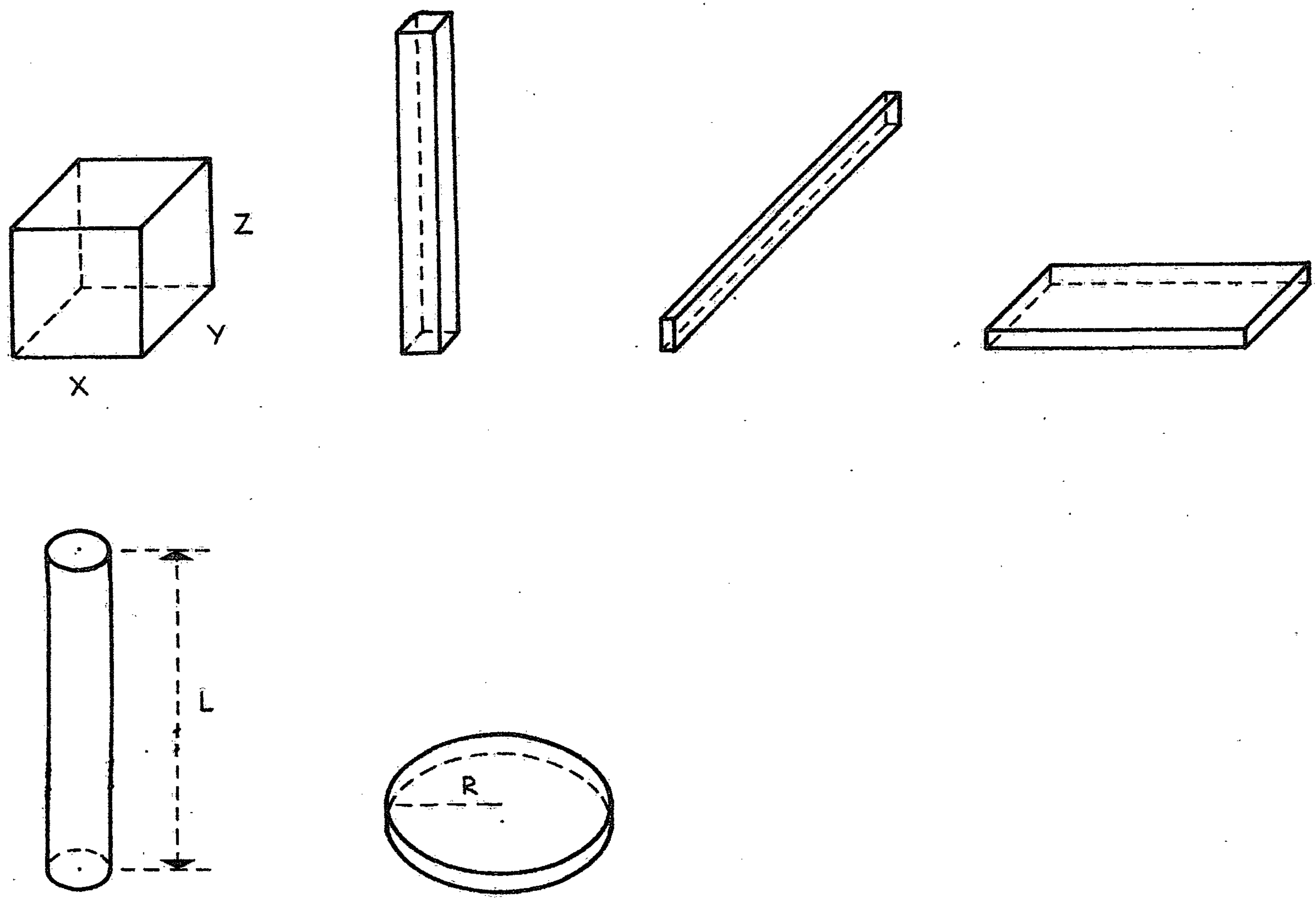
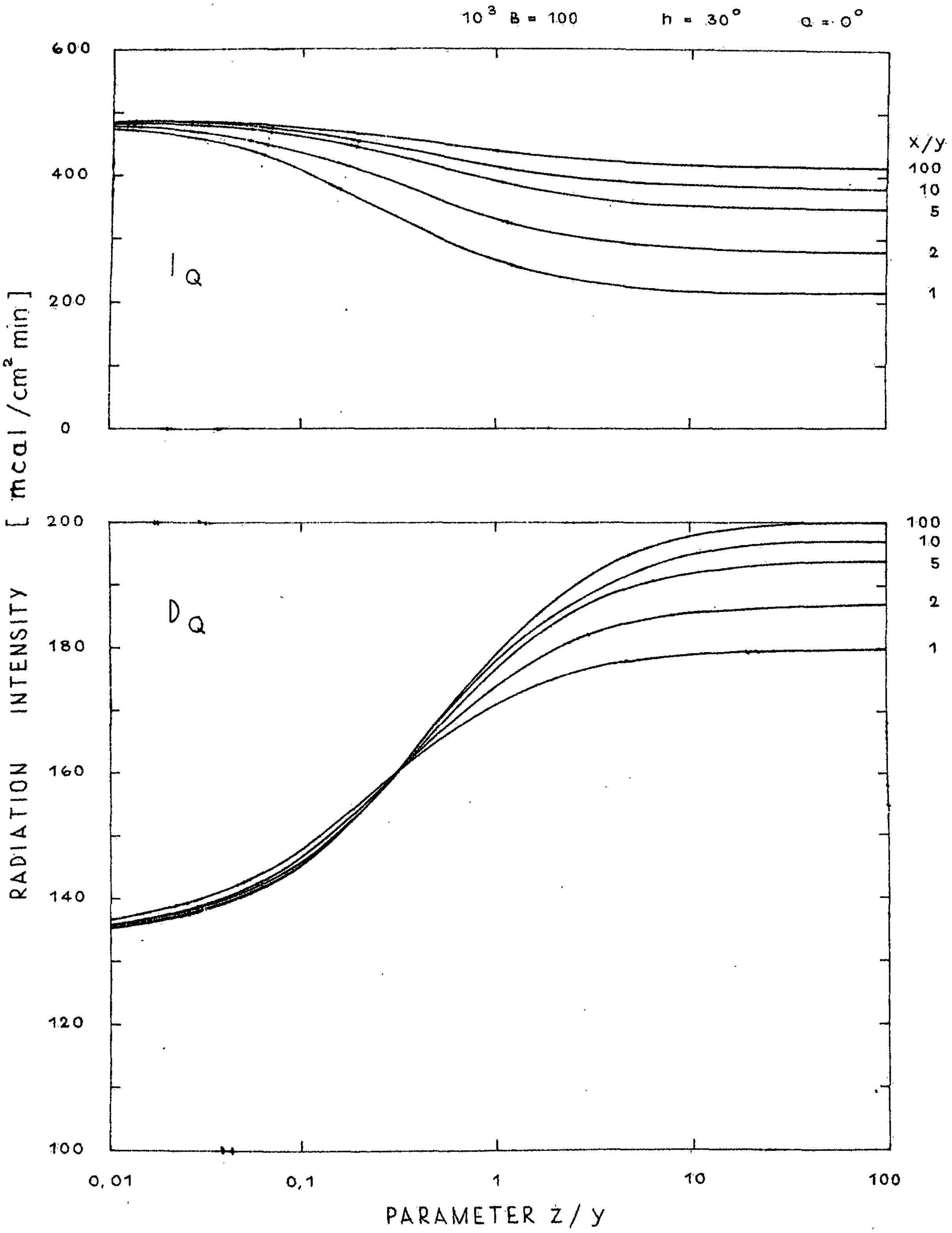


Figure 4 - Examples of rectangular prisms and straight circular cylinders, indicating the role of the shape parameters in computing the radiation load

Figure 5 - Direct (I_Q) and diffuse (D_Q) irradiation of rectangular prisms as depending on the side-length ratios z/y and x/y. Valid at a solar height h = 30°, wall-solar azimuth a = 0° ((z,x)-surface facing the sun) and turbidity 10^3B = 100



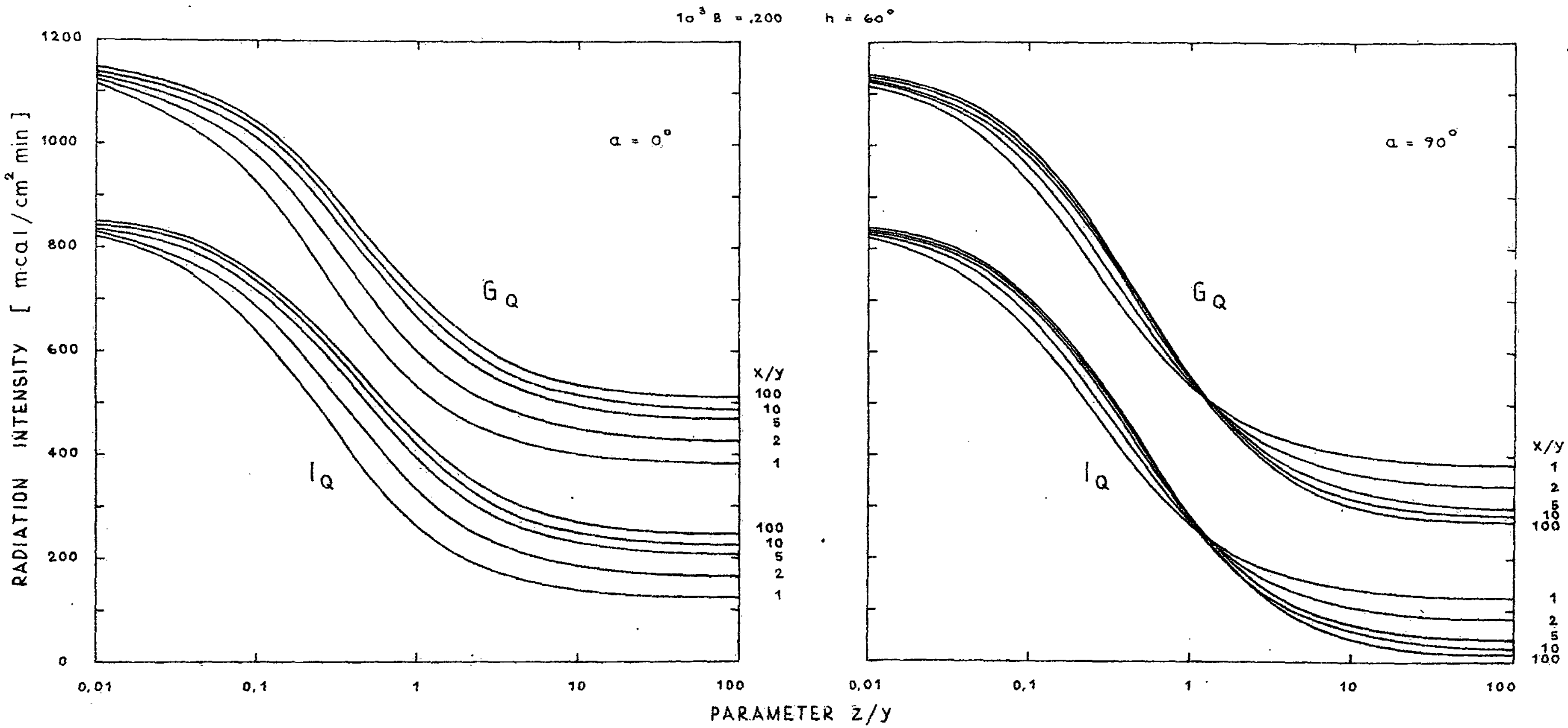


Figure 6 - Global (G_Q) and direct (I_Q) irradiation of rectangular prisms in function of their shape. Valid at a solar height h = 60° and turbidity 10^3B = 200. Patterns on the left : (z,x)-surface facing the sun; patterns on the right: (z,x)-surface turned away with 90° respective the solar azimuth

Figure 7 - Diffuse irradiation of rectangular prisms in function of their shape. Valid at a solar height h = 60° and wall-solar azimuth a = 0°. The three sets of curves were drawn for turbidities 10^3B = 200, 100 and 50 respectively

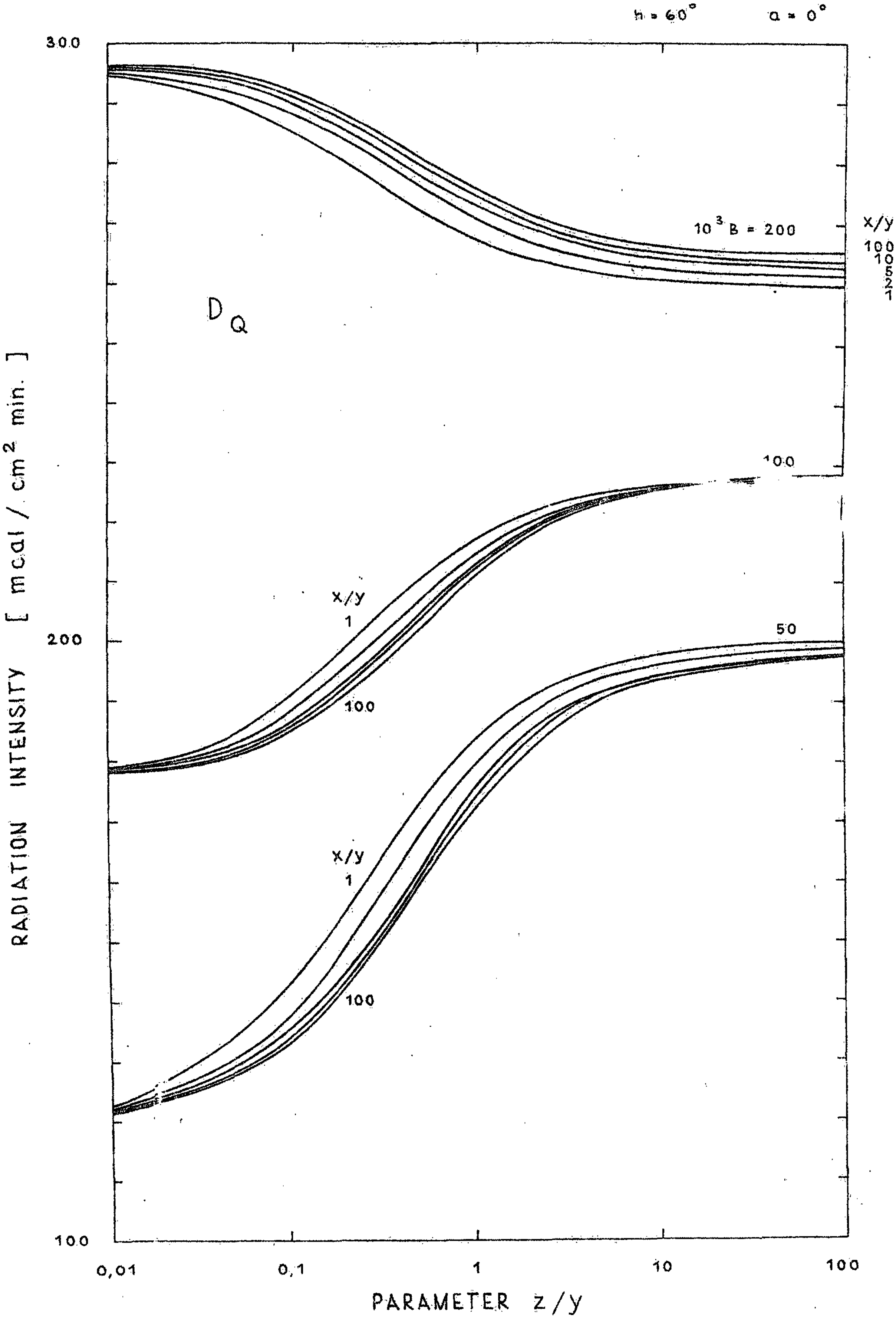


Figure 8 - Diffuse irradiation of straight circular cylinders of radius R and height L for turbidity $10^3 B = 50$ (thin curves) and 200 (fat curves) respectively. Valid for the solar heights 10°, 30° and 60° in both cases