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THE EFFECT OF SHAPE AND ORIENTATION ON THE RADIATION IMPACT ON BUILDINGS

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Summary

Building planning needs suitable information on radiation conditions, especially with respect to air-conditioning and daylight design. A survey on the origin and preparation of the data used is presented, furthermore the significance of the diffuse component of the total radiation impact is emphasized. The adaptation of the irradiation functions is demonstrated for summer and winter conditions at 0 m altitude (a. s. l.) for the geographic latitude of 47° N. Numerical examples in cases of rectangular and cylindrical buildings illustrate daily and hourly radiation load changes against variation of building shape and façade orientation.

Zusammenfassung

Die Bauplanung, insbesondere die klimatechnische- und die Tageslichtplanung, braucht geeignete Angaben über die Sonnenstrahlung. Ueber Herkunft und Aufbereitung der verwendeten Strahlungsdaten wird eine Uebersicht gegeben, hierbei wird die Bedeutung der diffusen Komponente der gesamten Strahlungsbelastung hervorgehoben. Die hergeleiteten Bestrahlungsfunktionen werden im Fall 0 m (Meereshöhe), 47° N geographische Breite unter Sommer- und Winterbedingungen angewendet. Rechenbeispiele für quader- und zylinderförmige Bauten zeigen, wie sich Tages- und Stundenwerte der Strahlungslast ändern, wenn Gebäudeform und Fassadenausrichtung verändert werden.

Résumé

L'industrie du bâtiment a besoin, en particulier pour l'élaboration de projets de climatisation et d'éclairage, de données appropriées sur le rayonnement solaire. On passe en revue l'origine et l'état des données du rayonnement utilisées ici en soulignant l'importance de la composante diffuse de la puissance radiative totale. Les fonctions d'irradiation sont adaptées pour l'altitude de 0 m (niveau de la mer), 47^{0} de latitude nord, pour des conditions estivales et hivernales. Des exemples numériques de constructions prismatiques et cylindriques mettent en évidence les changements de la puissance radiative horaire et journalière en fonction de la forme et de l'orientation des bâtiments.

Problems of planning

It is basically important to have a reliable survey on solar heat load conditions, when planning a building. The problem starts with the selection of a suitable site and the appropriate orientation of the façades. Heating and air-conditioning design requires the same information, both considering the capacity and the operation of the installations.

The optimum orientation should assure minimum heat loss in winter and minimum gain of heat during the hot summer period. Relying in the main on the sources compiled by Olgyay [1], Fig.1 may give a synopsis of the various solar orientation recommendations through the century. The most favourable building exposure should be somewhere between Southeast and Southwest, but, as it recently was also pointed out by Tonne [2], even nowadays no closer approach of the varying opinions is apparent.

These general proposals don't deal with the influence of the geometric shape on the orientation of a building. A quantitative treatment of this additional effect shows clearly (Olgyay [1,3], Buchberg and Naruishi [4]) that it has to be considered in any case.

Different methods and conceptions obviously lead to different solutions, but, on the other hand, the choice and the way of adaptation of available radiation data may also give rise to considerable uncertainties. In many cases the computation of the diffuse component of the total radiation load is not appropriate, or it is even ignored at all.

Available information

Table 1 should give a survey on the single radiation components and on the derivation of radiation impact data.

Initial data

All functional relationships in the presented form are valid for mean sun-earth distance and for constant air-pressure. The origin and the way of computation of the solar intensity I_N, as well as its reduction to different altitudes a.s.l., is described in [6]. Diagrams and the derivation of the diffuse fluxes D_H and D_V is given in [7] and [8]. These latter are gained empirically by using several years of solarimeter records and are valid for cloudless sky and for a mean terrain albedo of 0,2.

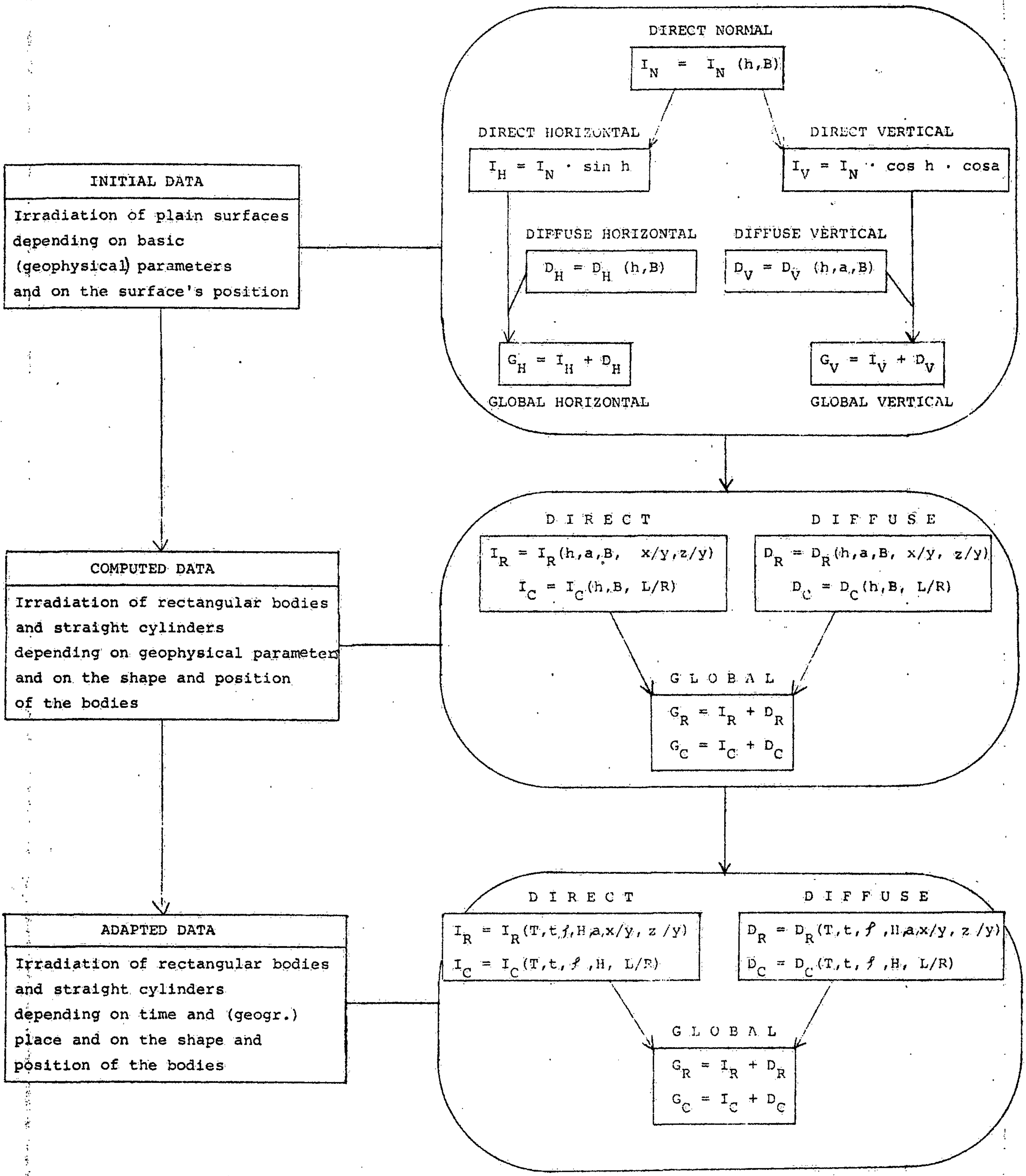

Table 1: Preparation of radiation data for planning use

a	azimuth between sun and surface's normal	T	calendar day
h	solar height	t	time of day
B	turbidity coefficient (see Schüepp [5])	f:	geogr. latitude
x,y,z	sides of a rectangular block (s.Fig.3)	H:	altitude a.s.l.
L,R	shape parameters of a cylinder (s.Fig.3)		

Computed data

The direct, diffuse and global irradiation were all computed separately for a big variety of rectangular blocks and straight circular cylinders, by varying the shape parameters x/y, z/y and L/R (s.Fig. 3), over several orders of magnitude. Also the other parameters a, B, and h were varied over a wide interval of values. The procedure and the behaviour of these functions are discusses in [9]. A catalogue of such data, valid for sea level air pressure (760 Torr), is at disposal.

Adapted data

For a given place, season and daytime the parameters a, h and B have to be determined numerically. The corresponding radiation impact values may then be taken from the computed data - catalogue. While the solar azimuth and the angular height h can be found by using common tables or graphs, B has to be determined carefully [6]. Correction for actual sun-earth distance has to be considered. An extended catalogue of such data for Zurich, Switzerland, is in preparation.

All computed and adapted data are related to bodies of 1 m^2 total exposed (without base) surface. This way, the effect of orientation on bodies of arbitrary shape (or the effect of shape on bodies of arbitrary orientation) may be studied by immediate comparison. All results are of general applicability.

Contribution of diffuse radiation to the total impact

The main feature of the results sketched in Table 1 is, that they include new diffuse radiation values, especially for the vertical surface irradiation function D_V, relying on an extensive empirical basis. These functions take into account the marked dependence on atmospheric turbidity and the inhomogeneous angular intensity distribution too. They may, therefore, differ considerably from data, derived on the base of the isotropic approximation or other simplifying assumptions [8]. In consequence, not merely the magnitude of the values, but also the daily and annual variations may be different. Furthermore, it is essential, that these deviations affect all conclusions concerning the dependence on shape and orientation of a structure.

By illustating the importance of the diffuse component, let's consider a straight circular cylinder, receiving natural radiation under cloudless sky conditions at 0 m altitude, at the latitude of 47^{o} North. Figure 2 shows the daily lapse (a.m. and p.m. values are symmetrical to noon) of the ratio of the diffuse to the global radiation loads, as computed for six different values of the parameter L/R (s. Fig. 3 later), both for the 15th of July and January respectively. The value 0,050 of the turbidity coefficient B represents clear cold air, B = 0,100 characterizes average beautiful summer weather, while B = 0,250 may occur under oppressively hot-humid conditions. The example of the circular cylinder was chosen, since, instead of two, only one shape parameter and no effect of orientation has to be considered. This simplifies computations, but facilitates the survey too. Nevertheless, radiation conditions are in many respect comparable with those of rectangular blocks.

The relative weight of the diffuse component is impressive, especially in case of tall bodies in July. Increasing turbidity increases the diffuse portion. Of course, to avoid a false impression, the absolute intensities should be considered simultaneously. Table 2 contains the corresponding figures of the global radiation.

It may be seen at once, that high D_C/D_G percentages coincide with relatively low global radiation. On the whole however, this example warns of an underestimation of the diffuse radiation component.

Case studies

To examine effects of shape and orientation, again 0 m altitude, 47^{o} latitude, the 15th of July with B = 0,100 and the 15th of January with B = 0,050 were chosen as examples. All cases sketched in Figure 3 were plaid through numerically for every full hours and for all orientations of the (z,x) surface ($x \geq y$) in steps of 15^{o}. The size of the bodies drawn in Figure 3 should indicate, that all of them have the same total exposed surface of unity. The numerical figures under the first row mean the ratio z/y, while x=z were chosen for all of these bodies (except of the cube of half height). For the bodies in the second row z/x was changed from 0 till 100 and x = y were kept constant. The third row shows two blocks of the geometry x/y = 5, z/y = 2 and x/y = 2, z/y = 5 respectively, furthermore the development of circular cylinders starting from L/R = 0 to L/R = 100.

Table 2: Global irradiation of cylinders. Complementary data to Fig. 2 in [Kcal/m^2 hour].

True solar time	July 15th											
	B = 0,250						B = 0,100					
	L/R						L/R					
	0,01	0,1	0,5	1	5	100	0,01	0,1	0,5	1	5	100
5	106	106	118	130	135	135	71	83	115	130	142	142
6	156	157	159	160	161	162	161	165	174	180	188	190
7	275	265	247	238	222	218	304	296	278	270	256	252
8	402	379	330	303	264	252	454	428	368	340	296	281
9	515	475	387	343	282	259	577	534	431	380	305	278
10	606	551	432	372	285	255	682	621	480	407	302	266
11	667	601	458	387	282	246	748	673	504	420	295	251
12^h	689	619	468	392	281	240	768	689	510	421	291	246
Total 1)	6143	5687	4730	4258	3543	3294	6762	6289	5210	4675	3859	3566

True solar time	January 15th, B = 0,050					
	L/R					
	0,01	0,1	0,5	1	5	100
5						
6						
7						
8	44	56	68	75	89	102
9	114	121	142	150	167	172
10	201	204	211	216	222	223
11	259	258	253	250	247	245
12^h	280	276	265	260	252	250
Total 1)	1516	1554	1613	1642	1702	1734

1) Total means the integral from sunrise to sunset in [Kcal/m^2 day].

By these means, the first row represents the successive transformation of buildings of dominantly "horizontal character" in those of dominantly "vertical character" and simultaneously the changeover from "no influence of orientation" to maximum influence of orientation". The second row shows another kind of transformation accompanied by a development "no influence - moderate influence - no influence of orientation".

The dependence of the radiation impact on all of these bodies on the parameters mentioned, were studied by drawing several kinds of suitable graphs. These show many instructive details, most of them being by far not trivial and hardly to find out without numerical experiment.

At this place only the daily totals in case of the first row blocks (Fig.3) may be presented. In Fig. 4 radiation load curves for seven different values of the z/y-ratio were plotted against the azimuth angle (South = 0^{o}). In consequence of the high sun path in summer, and the low sun path in winter, the z/y-ratio has an opposite effect respectively; differences due to this shape effect may be considerable for southern expositions, vanishing practically to 0 for about 75^{o} East/West in July and 45^{o} East/West in January.

In view of the intricate interaction of several effects, in most cases graphical trials are necessary.

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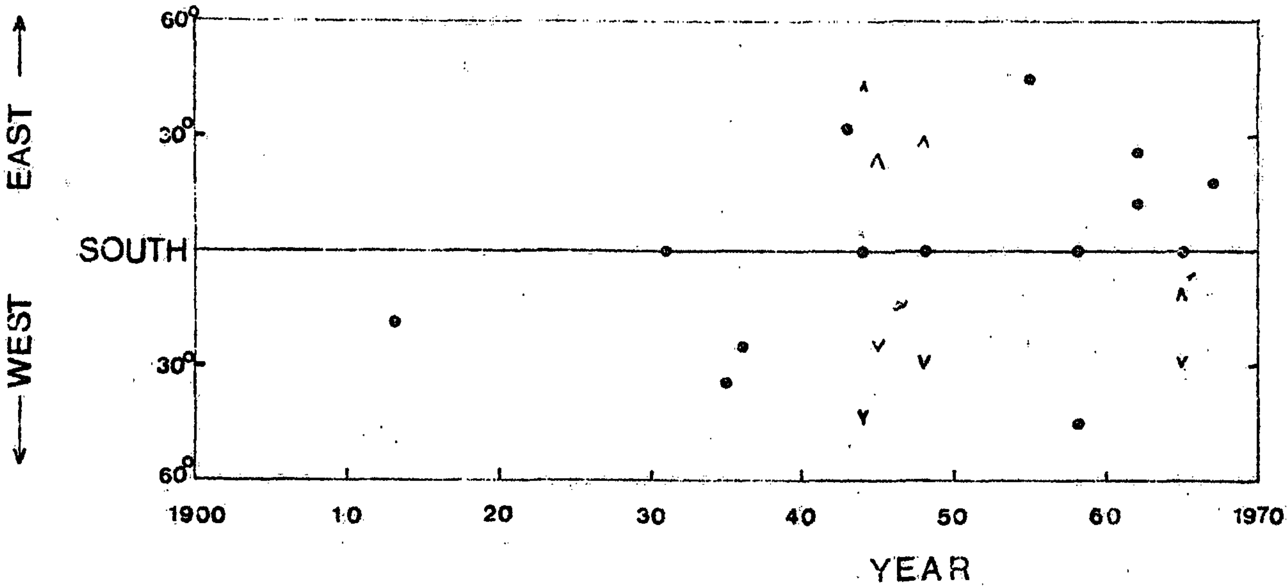
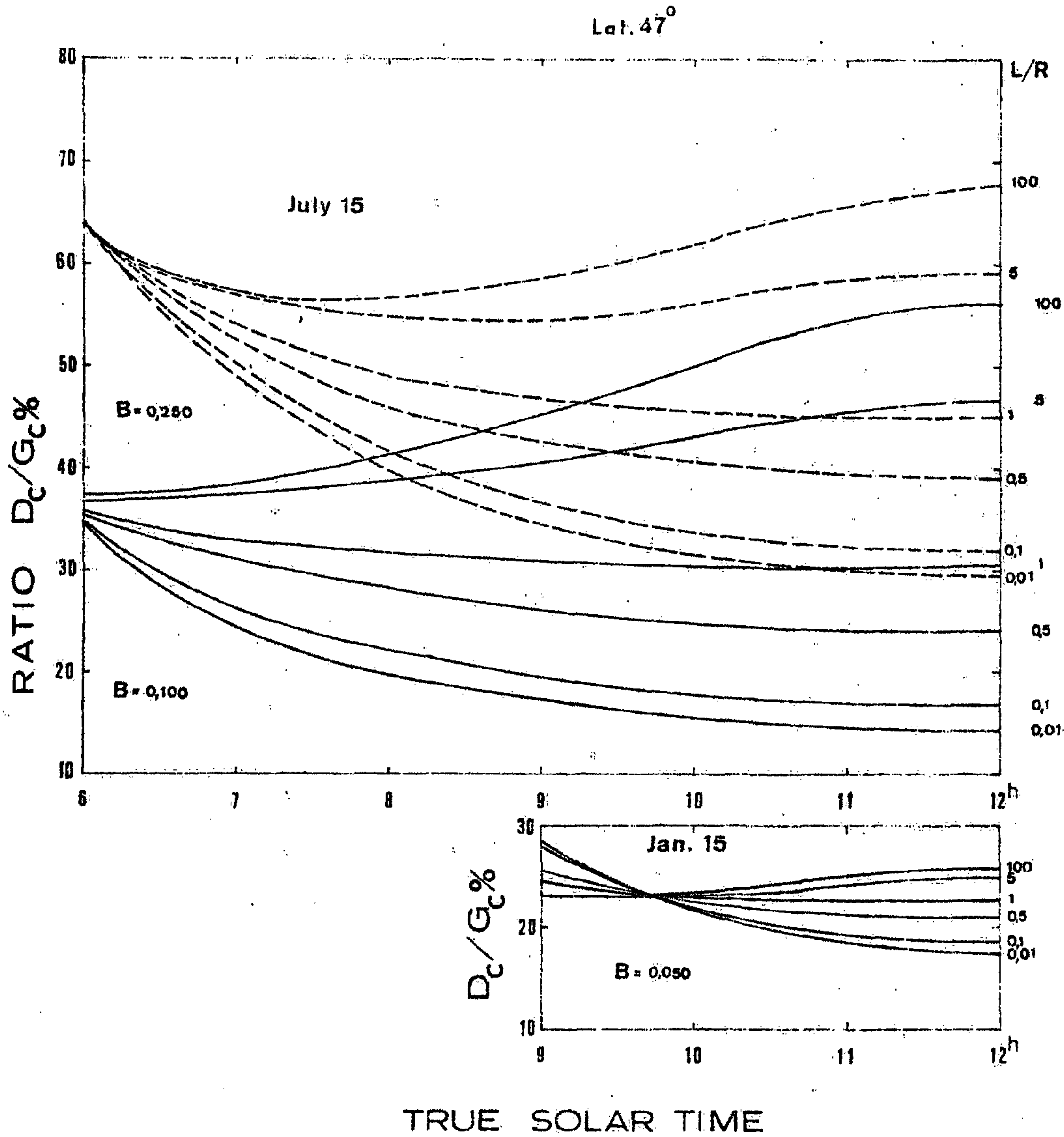


Fig. 1 Survey on recent recommendations on optimum building orientation (moderate latitudes).
• discrete values, ^/v intervals.



<u>Fig. 2</u> Daily variation of the ratio of diffuse to global radiation impact on straight circular cylinders of different shape under summer and winter conditions. Valid for latitude 47° N and 0 m altitude.

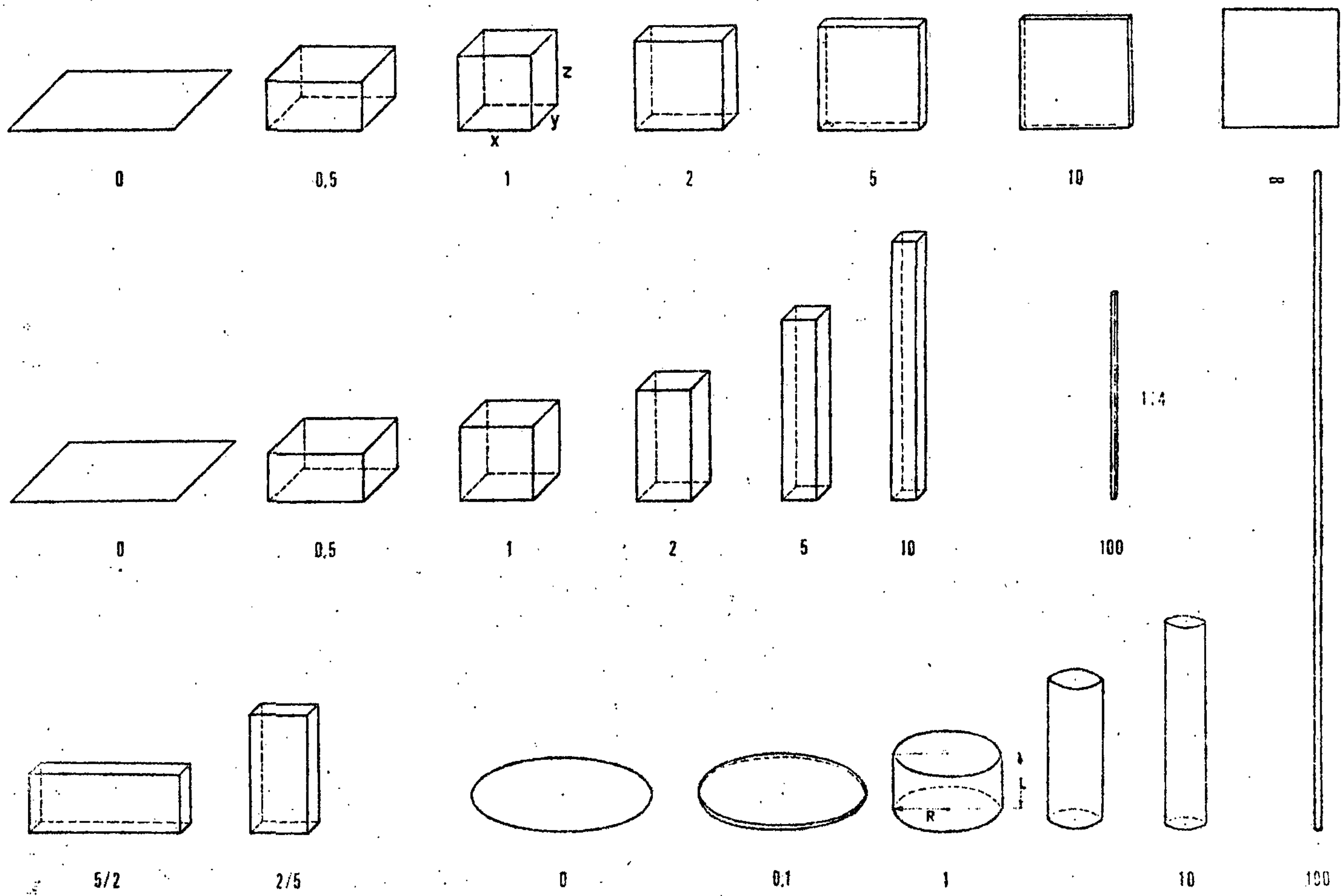


Fig. 3 Rectangular blocks and straight circular cylinders of different shape but unit total exposed surface, chosen as example for radiation load computations.

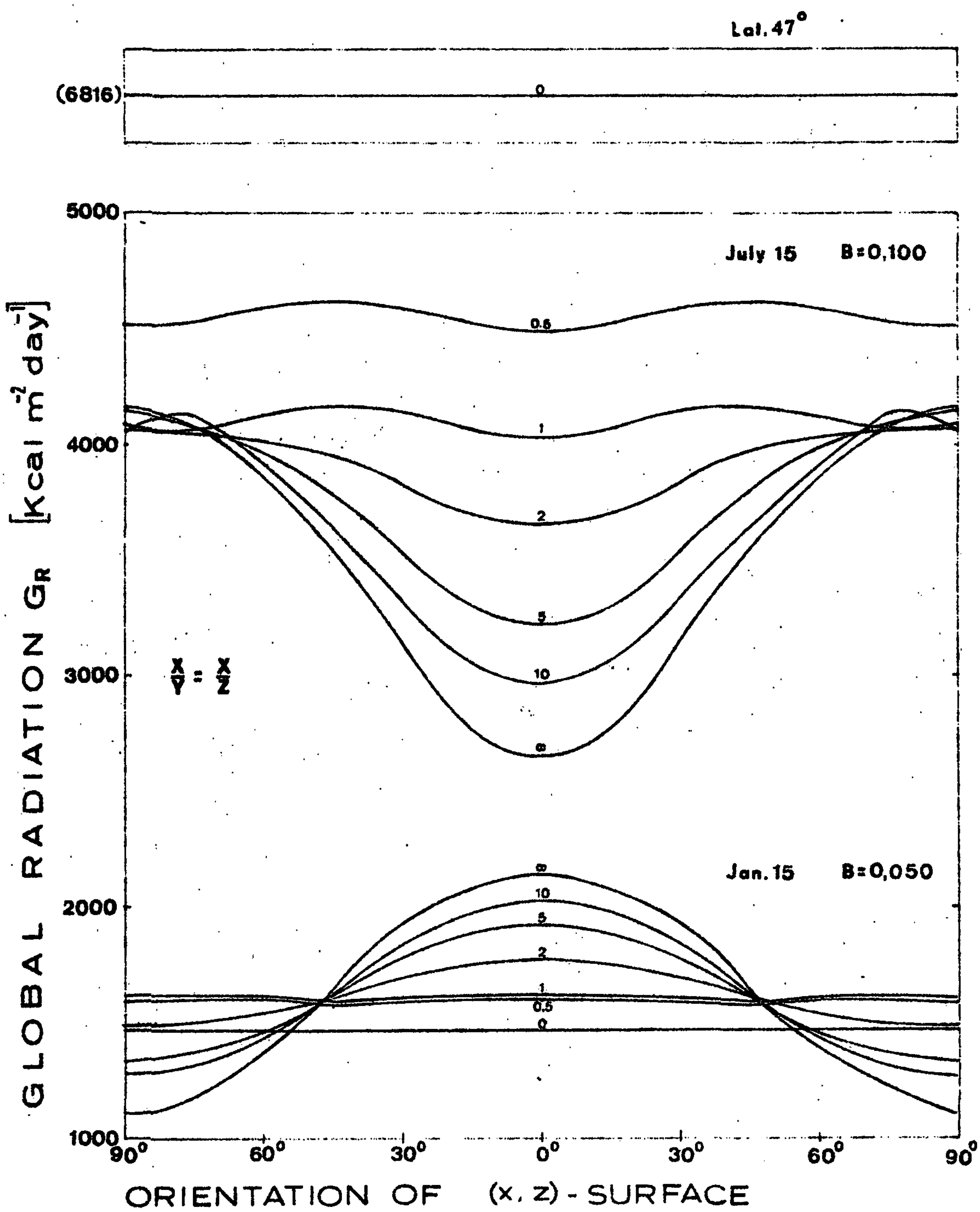


Fig.4 Global radiation load on the x/y = z/y blocks (first row in Fig.3) depending on orientation, under summer and winter conditions.