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BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

FENESTRATIONS FOR DAYLIGHTING IN THE TROPICS
PART I - THE SKY COMPONENT

General considerations

Fenestrations in walls or roofs allow the entry of light, heat and air inside in direct proportion to their sizes. In India where sun light is available for most part of the year, day-lighting of building interiors should be normally adequate. However, the daily and seasonal variation of daylight makes the problem a little complicated. Environmental climatic variations govern the choice of fenestration dimensions and this digest deals with the design for daylighting.

Definitions

Lux : It is the illumination produced at a distance of one metre by a standard point source of intensity one Candela (Candle).

Lumen/sq. ft: It is the illumination produced by the above source at a distance of one foot.

1 Lm/sq. ft=10.76 Lux.

Luminance : A surface is either self luminous or acquires a luminance by virtue of light incident on it. Brightness is an alternative name for luminance

Sky component : Daylight reaching an indoor point through a fenestration consists of the part coming directly from the sky and that coming in after reflections from exterior or interior objects. A horizontal surface situated outside in the open receives light from the sun and the sky. The former is known as the direct illumination and the latter the diffuse illumination. The ratio of the light reaching an indoor point from the sky through the fenestration to the simultaneous diffuse outdoor illumination is called the sky component. Likewise, the ratio of the light reaching the same point after reflections to the diffuse outdoor illumination is called the reflected component.

Basis for design

Most of the countries of the world have adopted the overcast sky as the basis for design. Since the sky in India is generally clear except during the monsoon season, it is reasonable to base the design on the clear blue sky. Further, the design should be based on the winter conditions when the sunlight availability is a minimum. Further the design should be such as to provide sufficient daylight indoors throughout the normal working hours especially when direct sunlight is not incident on the fenestrations.

The tropical design sky

During the winter months of 1963 and 1964 measurements were carried out on the luminance distribution of the clear blue sky over most of the principal cities of India. Simultaneous observations were also made on the amount of diffuse illumination on a horizontal surface. It was found that for the clear sky the luminance distribution followed a simple pattern especially when the sun was at low altitudes. The equiluminance contours were nearly circles beyond 60° on either side of the sun and a region of minimum luminance occurred on the great circle passing through the sun and zenith about 75° to 90° from the sun. The luminance of the sky from the horizon upto an altitude of 15° was nearly uniform. It was also observed that the minimum sky luminance L_M was related to the diffuse illumination D on the horizontal (direct sunlight being excluded) by the following equation :

$$\frac{L_M}{D} = 0.6 \qquad (1)$$

These considerations led to the formulation of a design sky for use in daylighting design of buildings in the tropics.

Since normal working hours commence between 7 a. m. and 8 a. m., a design based on a solar altitude of 15° in the sky should be adequate.

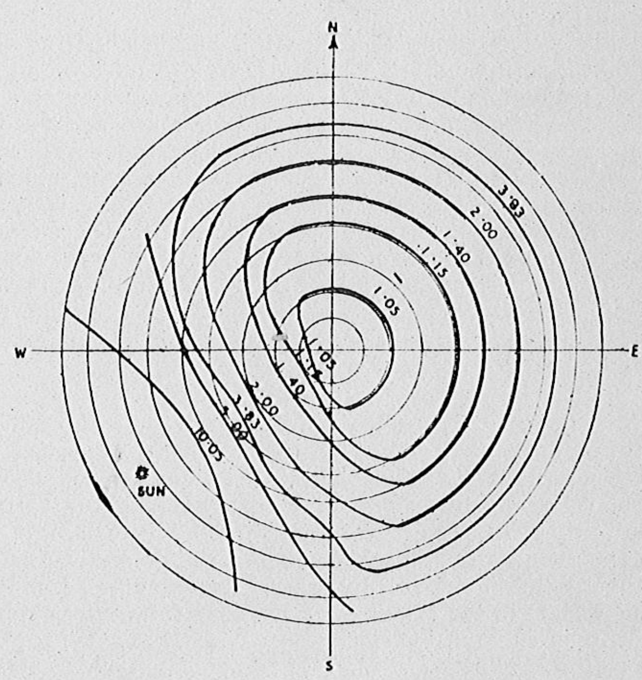


Fig. I

Fig. 1 : A polar diagram of relative equiluminance (L_θ/L_M) contours with sun at 15° altitude

It has been observed that the luminance distribution of the clear sky with the sun at an altitude of 15° and beyond 30° on either side of it can be expressed by a relation of the type :

$$L = \text{constant} \qquad 15° > \theta > 0 \quad \ldots\ldots\ldots \quad (2)$$
$$\text{and } L = L_M \operatorname{cosec} \theta \qquad 90° > \theta > 15° \quad \ldots\ldots\ldots$$
$$\text{and } L_M = 0.6\,D \quad (3)$$

where L_M is the minimum sky luminance and D the diffuse illumination on the horizontal at this time (direct sunlight being excluded). Fig. 1 gives an idea of equiluminance contours for a 15° solar altitude.

Sky component

Based on the above equations 2 and 3 exact mathematical expressions have been derived for the sky component available at any point inside a room through a rectangular window (see fig. 2) ABCD is the rectangular

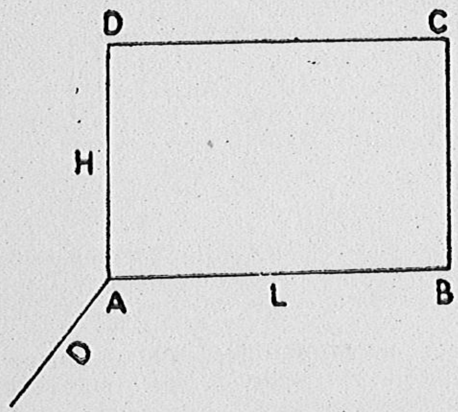


Fig. 2

unobstructed window of length L and height H and the point P is situated at a distance D from A on a normal to the plane ABCD. Three possible orientations of the illuminated plane, viz. horizontal, parallel to the window and perpendicular to the window have been considered. The percentage sky components (S.C.) are presented in tables I to III, which are equally valid for measurements of L, H and D in British or metric units. The methods by which one can estimate the S.C. are listed in the appendix. For design purposes the exterior diffuse illumination from the unobstructed sky may be taken as 8.0 Kilo Lux and interior illumination levels from sky components expressed as a fraction of this value.

Fenestrations for daylight are designed to provide sufficient amount of natural light when the sun does not shine on them directly. Also, the designed fenestration should be capable of providing enough daylight for atleast 90 per cent of the working hours. The values of sky components will hold good between 8 a. m. and 4 p. m. in the extreme north of India and between 7-30 a. m. and 4-30 p. m. in the extreme south during the winter months. An hour's extension on either side during the summer months is allowable.

Table IV gives the various types of visual tasks requiring a certain minimum illumination. These are based on the current accepted practices in U. K. and U. S. A. and the value of the percentage sky component (based on an outside diffuse illumination of 8.0 Kilo Lux) that can provide this illumination are also listed in the same table.

The values of sky components are for unglazed openings. The presence of window bars, glazing and dust settlement on the glass panes result in a proportional reduction in the sky component. Glazing and dust together may reduce the sky component by 20 per cent while the exact reduction due to window bars depend on the proportion of these in the actual window.

It is also to be noted that the illumination inside a room computed from the data presented in this digest presume an unobstructed view of the sky through the window. The presence of external obstructions modify these values. The location of the same-sized windows at different places in the walls will produce variations in the sky component distribution on the working plane. Also interreflections between the various interior surfaces and the decorative finishes on these surfaces result in enhancement of interior illumination.

These factors will form the subject matter of a subsequent digest.

Appendix A

The methods of evaluating the sky component at a given point on the horizontal working plane are given here. Similar methods can be adopted for the estimation of the S. C. on vertical planes like walls or chalk boards on walls. The working plane is an imaginary horizontal plane at a height 2″—9″ (85 cm) from the floor level.

The window, in all the figs. A_1 to A_{9b} is ABCD. AB is the length (L), BC is the height (H). The point P is on the working plane at a distance D from the windows plane. The foot of the perpendicular from P to ABCD is designated as N. All quantities are measured in the same units English or metric.

Ex. I : P is 8 ft. from the window. N coincides with A.

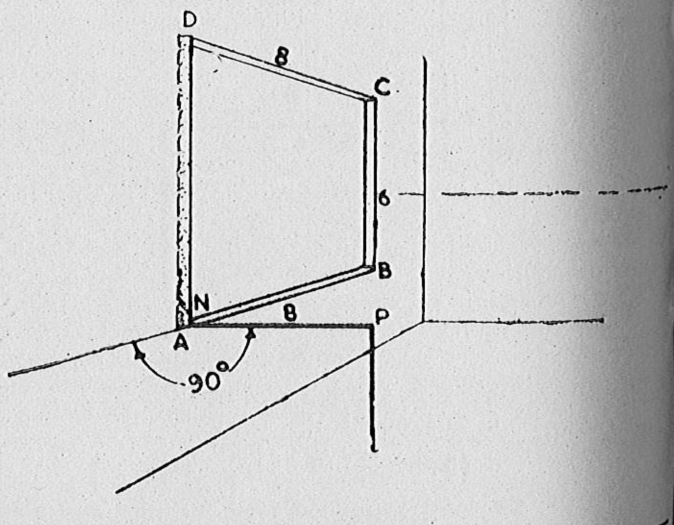


Fig. A I

$L = 8, H = 6$

$\frac{L}{D} = \frac{8}{8} = 1, \frac{H}{D} = \frac{6}{8} = .75$

S. C. from Table I = 6. 43%

Ex. 2 : P. is 10 ft, from the same window (Fig. A 2)
N is 2 ft, from A so that
NA = 2 ft, and NB = 6 ft.
S. C. at P due to Y = 1. 44%

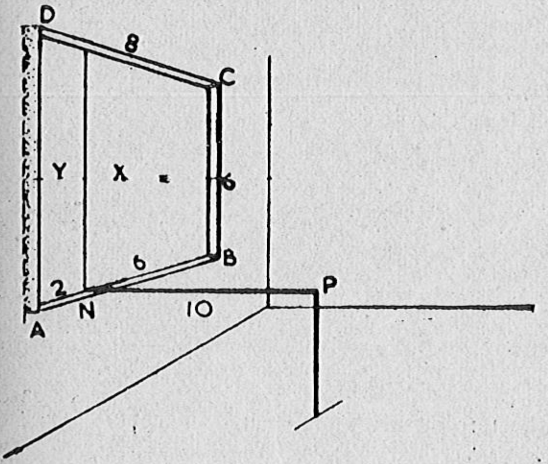


Fig. A2

Since $\left(\frac{L}{D} : .2 \ \frac{H}{D} = .6 \right)$

S. C. at P due to X=3. 78%

Since $\left(\frac{L}{D} = 0.6 \ \frac{H}{D} = 0.6 \right)$

∴ Total S. C. = 5. 22%

Ex. 3 : P is 10 ft, from the same window, but N is 1 ft. from AB and 2 ft. from AD, so that the position of window below N does not illuminate the point P. :— actual window size is 8×5 (Fig. A3)

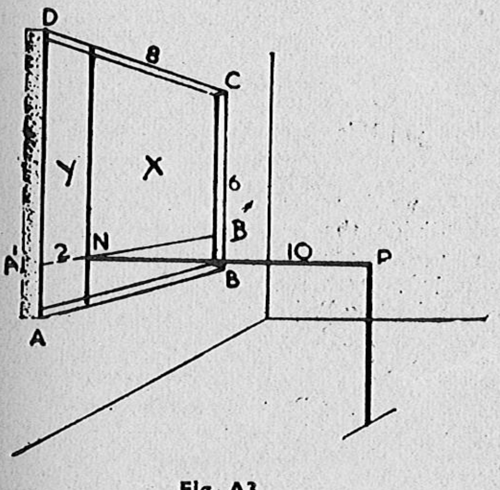


Fig. A3

FA= 2 ft. and NB = 6 ft.

S.C. at P due to Y= 1.189%

$\left(\text{Since } \frac{L}{D} = 0.2 \ \frac{H}{D} = 0.5\right)$

S.C. at P due to X=3.099%

$\left(\text{Since } \frac{L}{D} = .6, \ \frac{H}{D} = .5\right)$

∴ Total S.C. = 4.288%

Ex. 4 : Window size 12 ft.×8 ft.
Point P 10 ft. from window plane (Fig. A4).
Point N 2 ft. below AB on the perpendicu
bisector of AB.

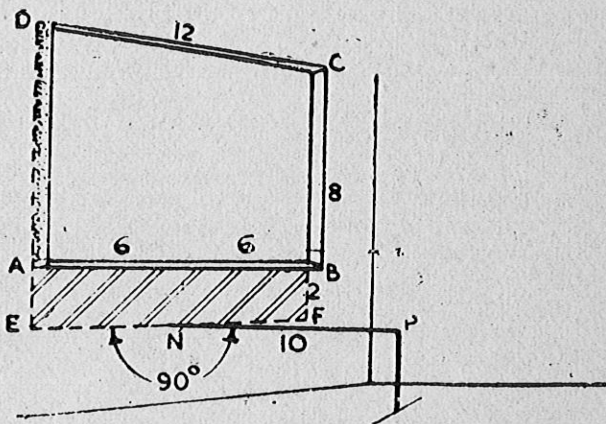


Fig. A4

The window ABCD is now extended below A by 2 ft. The illumination at P is the difference illumination produced at P by the extendi window EFCD minus the illumination at P du to EFBA. Since PN is symmetrically locat with respect to the window, illumination at due to window portions DN and NC are equa So are those due to AN and NB. Illum. due EFCD= 2 illum. due to DN (2×5.78)=11.56 Illum, due to EFBA = 2 × illum. due to AN = 2 (0.70)=1.40%

∴ S. C. at P due to ABCD = 10.16 %

Ex. 5 : Window size 8 ft. × 6 ft. Point N at a distanc 2 ft below AB and 2 ft. to the Rt. of AD. P a 10 ft. from the window plane (Fig. A5).

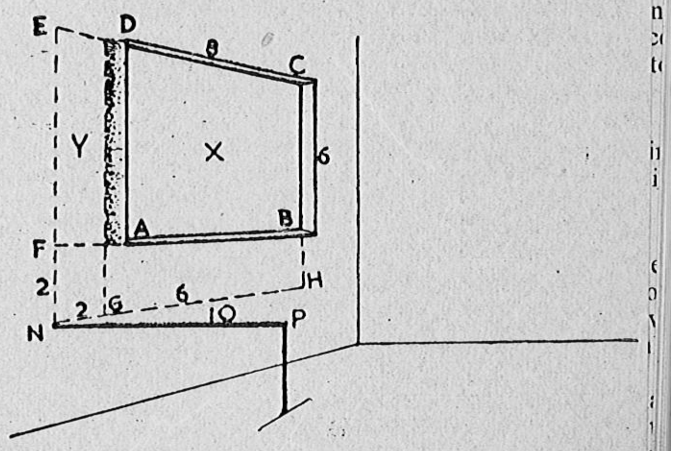


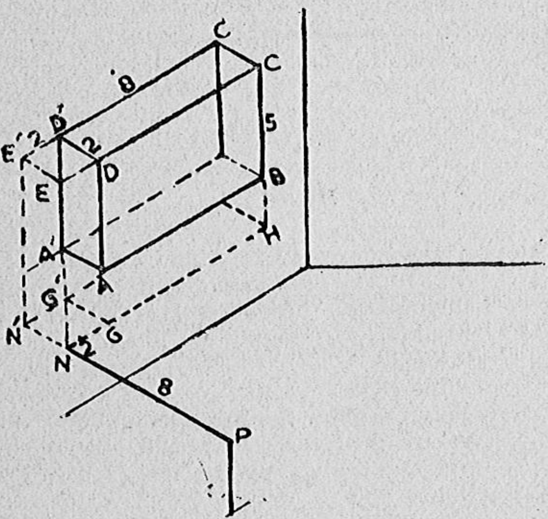
Fig. A5

The S.C. at P due to ABCD } = S.C. at P due to ENHC – S.C. at P due to ENGD – S.C. at P due to FNHB + S.C. as P due to FNGA

S.C. due to ENHC = 6.798
.. ENGD = 1.858
.. ENHB = 0 918
.. FNGA = 0.277

∴ Resultant S.C. at P = 6.798 – 1 858 – 0 918 + 0.277 = 4 299 %

Ex. 6 : ABCD is the window 8 ft. long and 5 ft. high, Thickness of wall = 2 ft. The point N is 2 ft. below sill and 2 ft. to the left of DA (Fig. A6). Proceed as in example 5. The window now is A′B′C′D′ Distance of P from the outer edge of window = 10 ft. The S.C. at P is due to those due to N′C′ – N′D′ – N′B′+N′A′



Fig, A6

For N′C′ $\left(\frac{L}{D} = 1.0, \frac{H}{D} = .7\right)$ the S.C. = 6.034

For N′D′ $\left(\frac{L}{D} = .2, \frac{H}{D} = .7\right)$ the S.C. = 1.665

For N′B′ $\left(\frac{L}{D} = 1.0, \frac{H}{D} = .2\right)$ the S.C. = 0.918

For N′A′ $\left(\frac{L}{D} = .2, \frac{H}{D} = .2\right)$ the S.C. = 0·277

∴ S.C. at P = 6.034 – 1.665 – 0.918 + 0.277 = 3.728 %

Ex. 7 : ABCD is the window of size 8 ft. × 5 ft. There is an obstruction in front of it. The point P is such that N coincides with A. The obstruction as seen from AP is 3 ft. long and 4 ft. high. PN = 10 ft.. (Fig **A** .7)

The S.C. at P is that due to ABCD less that due to AEFG. For ABCD (L/D = .8, H/D = .5) S.C. = 3.740 at P.

For AEFG (L/D = .3, H/D = .4) S.C. = 1.322
∴ Resultant S.C. at P = 2.418%

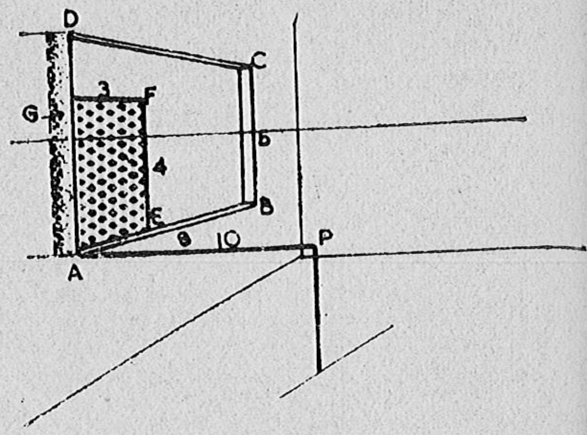


Fig. A7

Ex. 8 : A black board of size 8 ft. long and 4 ft. high is mounted on a well perpendicular to a window of size 6 ft. × 4 ft The lower edge of board is 3 ft. from the floor and that of the window 4 ft. The vertical sides of the window and board are 2 ft. away from the wall corner. Find the S.C. at the centre of the board. (Fig . A8)

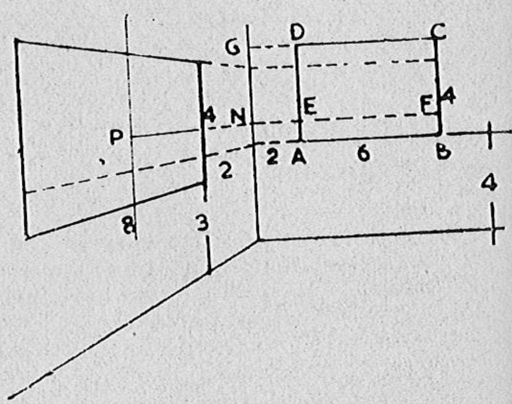


Fig.A8

Point P is situated at 6 ft. from wall corner and 5 ft. above the floor.

If we draw a horizontal plane through P it will divide the window into two parts. The upper portion will be 6 ft. × 3 ft. and the lower 6 ft. × 1 ft. Only the upper portion is effective in illuminating P. The sky component is determined from fig. 3 which gives the s c. on a vertical plane perpendicular to a vertical window.

The S.C. at P is the difference of these between the extended window GF less that due to G.E. PN = 6 ft. Use table II

For GF $\left(\frac{L}{D} = 1.25, \frac{H}{D} = 0.5\right)$, S.C. = 9.555%

For GE $\left(\frac{L}{D} = 0.33, \frac{H}{D} = 0.5\right)$, S.C. = 1.436%

∴ The effective S.C. = 8.119%

Ex. 9 : A black board 10 ft. long and 4 ft. high is located symmetrically parallel to a window 8 ft. × 5 ft. at a distance 20 ft. from it. The lower edge of the board is 3 ft. from floor level and that of the window is 4 ft. Find the S.C. at the centre, the top and lower corners of the board Figs. A9a, A9b

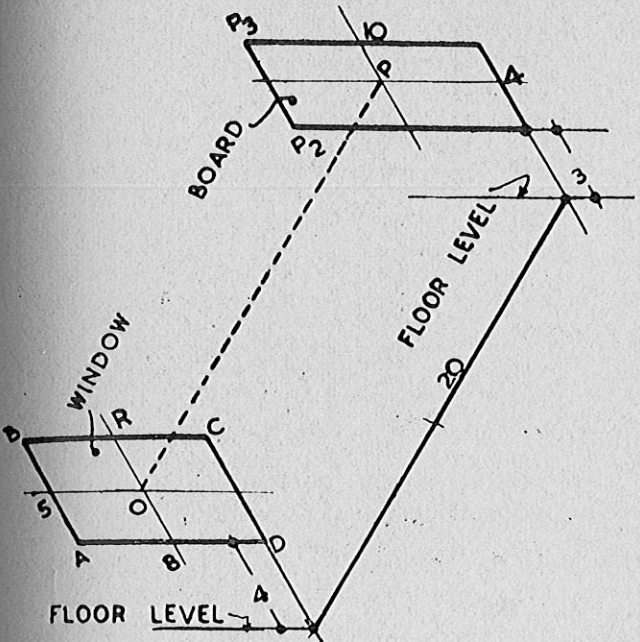


Fig. A 9a

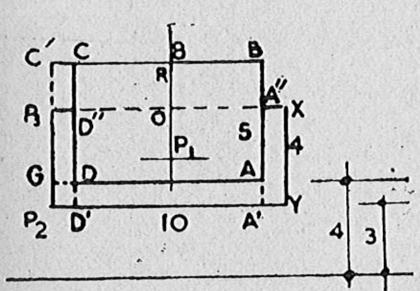


Fig. A 9b

Here we use Table III viz. the S.C. on the vertical plane parallel to a vertical window.

The points at which the S.C. are required are P_1, P_2 and P_3. Centre of the black board is 5 ft. above floor.

At P_1 : The illumination is due to 8 ft. × 4 ft. window i. e.

2 (S.C. due to portion ORCD").
= 2 (2. 803) = 5.606 %

For S.C. at P_2 :—

P_2 P_3 XY is the board on which the window ABCD is projected. Since P_2 does not coincide with D; AD, CD, BC and BA are produced to G. D', C', A' respectively.
The S.C. due to ABCD at P_2 is

= S.C. ($C'BA'P_2$) — SC ($C'CD'P_2$) — SC ($GAA'P_2$) + SC ($GDD'P_2$)

= 8.310 — 1.034 — 1.457 + 0.182

= 6.001 = 6.0 approx. %

At P_3 the illumination is due to C' BA" P_3 less that due to C'CD" P_3

∴ SC at P_3 = SC ($C'BA''P_3$) — S.C. ($C'CD''P_3$)
= 1.457 — 0.182
= 1.275 %

Here the portion of window below P_3 X does not contribute to the S.C. at P_3.

Appendix — B

When the problem is the determination of the sizes of windows that can provide the required sky component at a given distance from the window along a central line normal to the window plane, the answer can be had from figs. B-1 to B-12. In these figures the curves are constant sky component lines with window lengths on the X-axis and window height on the Y-axis. The appropriate distance and the height of window sill above the working plane are given in each figure.

Example :

Given that the sill height is 60 cm, (2 ft.) above the working plane and a 2% S.C. is required at a distance of 300 cm (10 ft.) from the window plane along the central line.

Referring to fig. B-8 and proceeding along the 2 % line we find that a 120 cm long and 100 cm high or a window 180 cm long and 65 cm high will provide the requisite S. C.

These curves should help in the design of fenestrations to fit a given architectural requirement.

Window bars and sashes reduce the effective openings by sizeable amounts. Likewise there is some reductio of light when it passes through the glass panes. The dir settling on glass still further reduces the light going in As a first approximation the latter two causes may reduc lighting going in by about 20%. The reduction due t bars and sashes may sometimes amount to even 45%.

Hence it is a wise practice to allow for these i design and choose a design sky component which i enhanced by these proportions.

For example, if the proposed window bars and sash amount to 30 % of the gross opening and 20 % reductio is due to glass panes and dirt on them, the effecti amount of light that goes through the fenestrations is on 56 %. Hence the design value must be increased by factor 100/56 = 1.8 to compensate for this loss. Th means, to obtain an effecitve sky component of 2 % wi all these reductions one should plan for a sky compone value of 3.6 %.

TABLE I

Percentage Sky Components on the Horizontal plane due to a vertical window for the tropical design sky.

H/D \ L/D	·30	·60	·90	1·20	1·50	1·80	2·0	4·0	10·0	INF
.30	.9	1.5	1.9	2.1	2.2	2 3	2.3	2.4	2.4	2.4
.60	2.1	3.8	4.9	5.6	6.0	6.3	6.4	6 7	6.8	6.8
.90	3.0	5.4	7.1	8.1	8.8	9.3	9.5	0.2	10.3	10.4
1.20	3.5	6.4	8 5	9.9	10.8	11.4	11.7	12 8	13.0	13.0
1·50	3.9	7.1	9.5	11.1	12 2	12 9	13.3	14.7	15 0	15.0
1.80	4.1	7.6	10.1	11.9	13.1	14.0	14.4	86.1	16.5	16.6
2.0	4.2	7.8	10.4	12 3	13.6	14.5	15 0	16.8	17.3	17.4
4.0	4.7	8.6	11.7	13.9	15.5	16.7	17.3	20.1	21.3	21.5
10.0	4.8	8.9	12.1	14.5	16.2	17.5	18.2	21.7	23.7	24.2
INF	4.8	9.0	12.2	14.6	16.3	17.7	18.4	22.1	24.5	26.1

TABLE II

Percentage Sky Components on the vertical plane perpendicular to a vertical window for the tropical design sky

H/D \ L/D	·30	·60	·90	1.20	1.50	1 80	2.0	4·0	10.0	INF
.30	.9	2.8	4.7	6.3	7.4	8.2	8.6	10.1	10.7	10.8
.60	1.3	4.3	7.5	10.2	12.2	13.7	14.4	17·5	18.6	18.8
.90	1.5	4 9	8.7	11.9	14.5	16.4	17.4	21.7	23.3	23.6
1.20	1.6	5.2	9.3	12.8	15 6	17.8	19 0	24.2	26 3	26.7
1.50	1.6	5.4	9.6	3.3	16.3	18.6	19.9	25.8	28.3	28.9
1.80	1.6	5.4	9.7	13.6	16.7	19.1	20.4	26.8	29.8	30.4
2.0	1.6	5.5	9.8	13.7	16.8	19.3	20.7	27.3	30 5	31.2
4.0	1.7	5.6	10.0	14.0	17.3	20.0	21.5	29.1	33.7	35.1
10.0	1.7	5.6	10.1	14.1	17.4	20.1	21 6	29.6	35.1	37.5
INF	1.7	5.6	10.1	14.1	17.4	20.2	21.7	29.7	35.3	39.2

TABLE III

Percentage sky Components on the vertical plane parallel to a vertical window for the the tropical design sky.

H/D \ L/D	.30	.60	.90	1.20	1.50	1.80	2.0	4 0	10.0	INF
·30	5.9	10.3	12.9	14.4	15.2	15.7	15.9	16.5	16.6	16.6
·60	8.9	15.7	20.0	22 6	24.1	25.0	25.4	26.6	26.8	26.8
·90	10.0	17.8	23.0	26.1	28.0	29.1	29.7	31.3	31.6	31.6
1.20	10.6	18.9	24.4	27.8	29.9	31.2	31.8	33.8	34.2	34.2
1.50	10.9	19.4	25.1	28.7	30.9	32.3	33.0	35.2	35.7	35.7
1.80	11.0	19.7	25.5	29 2	31.5	33.0	33.7	36.1	36.6	36.6
2.0	11.1	19.8	25.6	29.4	31.7	33.3	34.0	36 4	37.0	37.1
4.0	11.2	20.1	26.1	30.0	32.5	34.1	34.9	37.7	38.5	38.6
10.0	11.3	20.2	26.2	30.1	32.6	34.2	35 0	38.0	38.9	39.1
INF	11.3	20.2	26.2	30.1	32.6	34.2	35,0	38.0	39.0	39.2

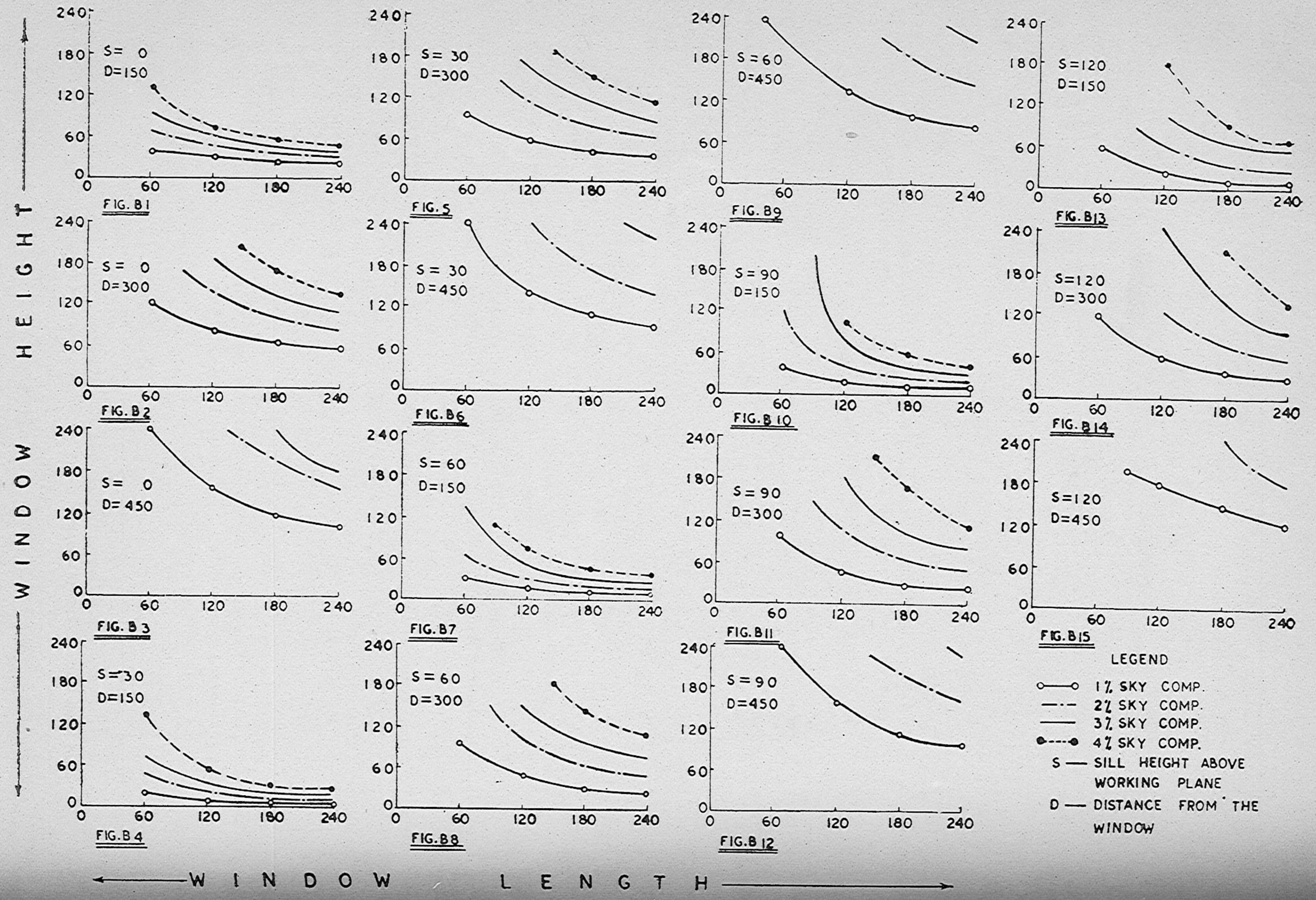

WINDOW HEIGHT
WINDOW LENGTH
S= 0 D=150
FIG. B1
S= 0 D=300
FIG. B2
S= 0 D= 450
FIG. B3
S=30 D=150
FIG. B4
S= 30 D=300
FIG. 5
S= 30 D=450
FIG. B6
S= 60 D=150
FIG. B7
S= 60 D=300
FIG. B8
S= 60 D=450
FIG. B9
S= 90 D=150
FIG. B10
S= 90 D=300
FIG. B11
S= 90 D=450
FIG. B12
S=120 D=150
FIG. B13
S=120 D=300
FIG. B14
S=120 D=450
FIG. B15
LEGEND
1% SKY COMP.
2% SKY COMP.
3% SKY COMP.
4% SKY COMP.
S — SILL HEIGHT ABOVE WORKING PLANE
D — DISTANCE FROM THE WINDOW

TABLE IV

Task Illumination

(Based on British and U. S. Standards)

Task	Min. F.C. requirement	Appropriate Percentage S.C. on task
Homes		
Kitchen	20	2.5
Bathroom	10	1.25
Stairs	10	1.25
Garage	7	1.00
Sewing and darning	70	9.0
Reading casual	15	2.0
Sustained reading	30	4.0
Shops		
General areas	15—30	2.0—4.0
Stock rooms	20	2.5
Hotels		
Entrance Hall	15	2.0
Reception	30	4.0
Dining table	10	1.25
Lounges	15	2.0
Bed rooms	10	1.25

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