BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

NORTHLIGHT SAWTOOTH ROOFS IN THE TROPICS

Introduction

Utilisation of daylight for performing any visual task is healthy and economical. The amount of light required for satisfactory and strainfree performance of the task depends on the nature of task itself and on other factors like contrast detail, fineness of work and acuteness of vision. Small variations of illumination are taken care of by the adjustment of the pupil of the eye but large variations result in undesirable eye strain. These considerations apart, changes in daylight intensity from sunrise to sunset provide a harmoneous variation of the visual environment inside or outside a building normally welcomed in the performance of visual task.

In India, except during the monsoon season, the sky is clear and the sunlight plentiful. The proper utilisation of daylight to get the appropriate illumination levels on the working planes of factories will result not only in considerable economy of electric power but also add to the wellbeing of workers inside the factory.

This digest deals primarily with daylighting inside factories in the tropics and explains the various factors that contribute to the illumination on the working plane and methods of working out the optimum roof slope and bay width.

The Northlight sawtooth roof

There is still a controversy regarding utility of the northlight openings for daylighting the working plane of factory buildings. It is held that northlights could provide only a unidirectional illumination, which casts shadows of the machinery on the floor, thus resulting in poor daylighting conditions inside. Calculations and model measurements at the Central Buildings Research Institute have conclusively proved that in Latitudes north of the Tropic of cancer (23 deg. N) these can provide adequate shadowfree illumination on the working plane in large factories. The duration of sunshine on vertical northlight openings for several latitudes north of the Tropic of Cancer is given in Table I. However these values will change if the northlight are inclined.

Table I

SUNSHINE HOURS ON NORTHFACING WALL

(Solar time)

Location	Sept. 23 to March 21	April 16 to Aug. 27	May 16 to July 28	June 21
23°N	Nil	Upto 7.30 a.m. After 4.30 p.m.	Upto 9.30 a.m. After 2.30 p.m.	Throughout the day
25°N	Nil	Upto 7.20 a.m. After 4.30 p.m.	Upto 9.00 a.m. After 2.50 p.m.	Upto 10.30 a.m. After 1.30 p.m.
27°N	Nil	Upto 7.15 a.m. After 4.40 p.m.	Upto 8.40 a.m. After 3.10 p.m.	Upto 10.C0 a.m. After 2.00 p.m.
29°N	Nil	Upto 7.10 a.m. After 4.50 p.m.	Upto 8.30 a.m. After 3.30 p.m.	Upto 9.20 a.m. After 2.30 p.m.
31°N	Nil	Upto 7.5 a.m. After 4.55 p.m.	Upto 8.20 a.m. After 3.40 p.m.	Upto 9.00 a.m. After 3.00 p m.
33°N	Nil	Upto 7.00 a.m. After 5.00 p.m.	Upto 8.00 a.m. After 4.00 p.m.	Upto 8.50 a.m. After 3.10 p.m.
35°N	Nil	Upto 6.50 a.m. After 5.10 p.m.	Upto 8.00 a.m. After 4.00 p.m.	Upto 8.40 a.m. After 3.30 p.m.

The penetration of direct sunlight through the northlight openings is either during the early morning hours or the late evening hours of the day ; hence for most part of the year this will not cause any serious inconvenience. It is to be borne in mind, however, that incidence of direct sunlight on machinery or moving parts in a factory is to be avoided.

The sky and reflected components of light inside

The daylight reaching the working plane inside a factory through the sawtooth openings consists of two parts viz. that from the sky patch visible from the point of observation and that part of the daylight reaching the same point after reflection from the roof and ceiling surfaces. The former is called the sky component (S.C.) and the latter the reflected component (R.C.).

In Fig. 1 a vertical section of a factory is shown. Successive bays are designated as 1, 2, 3, etc. The daylight that reaches the centre of bay No. 1 is partly from the sky, partly from light reflected from the external surfaces and the 1st ceiling and partly from light reflected by ceilings 2, 3, 4 etc. It has been found both from theory and model measurements that :

(i) only three ceilings on either side of the point contribute significantly to the reflected part of light reaching that point ;

(ii) only three northlights openings north of a point contribute to the sky component at that point ; and

(iii) the level of the daylight becomes quite steady after the third bay and beyond starting from the north.

For most purposes a working plane at a height of 3 ft. from the ground is taken as a reference plane in design work. In this digest, however, the working plane is related to its distance below the lower edge of the northlight opening so as to provide for the variations in the height of working planes from the floor for simplicity of calculations.

Reflection factors of building surfaces

The amount of reflected light reaching a point on the working plane is a function of the incident solar illumination on the roof and the reflection coefficients of the roof and ceiling surfaces. For simplification of design procedure reflections from the end and side walls may he neglected, as the inter-reflections from these surfaces in a large factory may amount to only a negligible part of the total illumination.

Typical diffuse reflectance (values which is the ratio of the diffusely reflected light to the incident light) of some building materials are shown in Table II. These values are likely to decrease in course of time due to the effects of exposure and weathering of the material.

TABLE II

Reflectance values of some building materials

Material	Diffuse reflectance percent
White plaster	90
White paint (matt)	75-90
Cement	27
Concrete	55
AC sheet	50-70
Bitumenfelt	15-20
G. I. Sheet	20-30

Factors affecting the design for daylighting

The daylight level on the working plane varies with the external sky conditions and the incident solar illumination on the roof which penetrates inside after reflections. Fortunately, however, the clear North sky does not vary much in its brightness between 9 AM and 4 PM. For most design work, therefore, the brightness may be taken as 1000 ft. lamberts. (This will provide a 1000 lm/sq. ft. illumination on an unobstructed horizontal surface in the open). The incident solar illumination on the roof varies considerably during the year, the maximum occuring in summer and the minimum in winter. On an average, 4000 lumens per sq. ft. may be taken as a reasonable average incident total solar illumination on a sloping roof. A typical set of observations taken at Roorkee on the availability of solar illumination on variously inclined surfaces facing south, between 9 AM and 3 PM in November is reproduced in Table III.

TABLE III

Solar illumination on sloping roofs facing south (Roorkee November)*

Angle of inclination to horizontal (Degree)	Total solar illumination lm/sq. ft.			
	9 AM	11 AM	1 PM	3 PM
5	1800	3800	3660	2080
15	2860	4680	4810	2860
25	3380	5200	5260	3250
35	3900	5730	5720	3840
Average value : 3930 lm/sq. ft.				

*Note : These values get reduced before penetrating inside because of roof reflectance depending upon the material and colour of the surface.

Studies on northlight in this Institute have proved that maximum uniformity of daylighting on the working plane is related to the width of the fenestration (distance between bottom and top edge of the North light opening) and the width of the bay distance

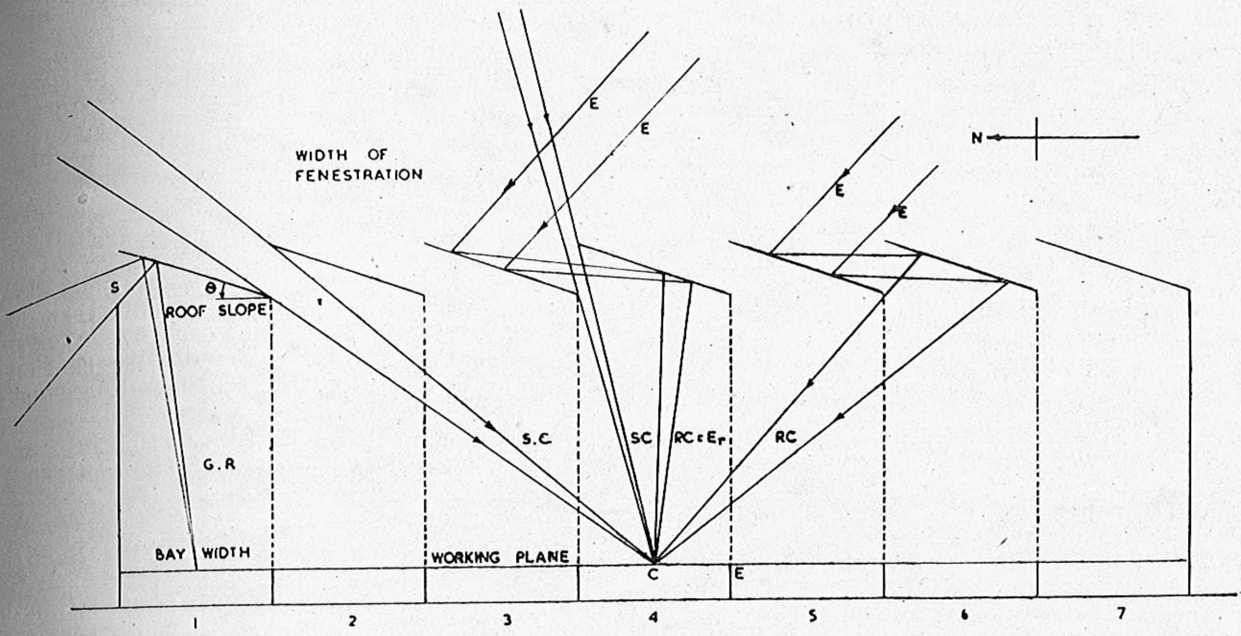

FIG. 1. ELEVATION OF A FACTORY WITH SAWTOOTH NORTHLIGHT OPENINGS

(S.C.=sky component, R C.=Reflected component, C=Centre of bay, G.R.=Ground reflected light in bay 1, e=edge of a bay, S=sill. E=Incident total solar illumination roof)

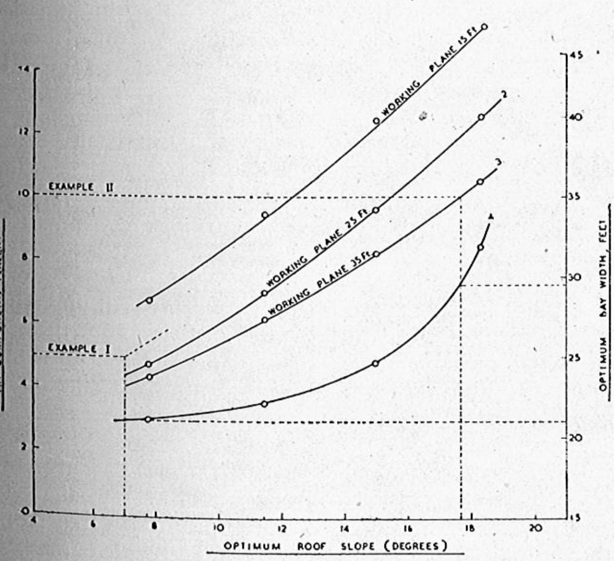

FIG 2. OPTIMUM DESIGN CHART

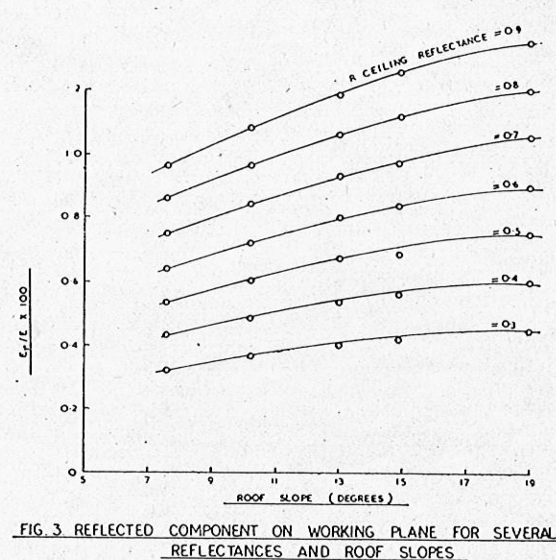

FIG. 3 REFLECTED COMPONENT ON WORKING PLANE FOR SEVERAL CEILING REFLECTANCES AND ROOF SLOPES

(E is incident total solar illumination on roof. Roof reflectance assumed constant as 0.2) between successive Northlight openings. In other words, there is a critical bay width for a given roof slope that results in a most uniform daylighting of the working plane.

The design of the sawtooth roof

Depending on the task to be performed inside the factory a level of illumination is chosen from Table IV.

TABLE IV

Recommended Lighting Levels for Factory Interiors*

(After the I.E.S. code 1961, I.E.S., London)

Type of work	Recommended illumination lm/sq. ft.
Assembly shops:	
Rough work, frame assembly, assembly of heavy machinery	15
Medium work, machine parts, engine assembly	30
Fine work, Radio and telephone equpt., typewriter assembly	70
Very fine work—Instruments	150
Bookbinding:	
Folding, pasting, stitching	30
Boot and shoe factory	70—100
Carpet factory	20— 45
Chemical works	20— 30
Clothing factory	30—100
Electricity generating stations	10 -- 30
Forges	15
Foundries	15— 30
Iron and steel works	2— 30
Machine and fitting shops	15— 70
Paint works	20
—do— colour matching	70
Paper works	20— 30
Printing works	20— 70
Soap factory	15— 30
Textiles	15— 70
Warehouses and storing	10— 15

*Note: Illumination level varies according to task where design levels in Lumens per sq. ft. are given for some typical workshop jobs. Two thirds of the desired level of illumination is obtained from the sky component and remaining one-third from the reflected component.

The size of the machinery employed decides the height at which the northlight openings are to be located. Once the illumination level and the height of the sill above the working plane has been decided upon, further steps in the design will be as under :—

1. Express the sky component (now in lm/sq. ft.) as a percentage fraction of 1000 lm/sq. ft. This is the expectable illumination on an outside horizontal surface from an unobstructed sky of uniform luminance 1000 of ft-lamberts.

2. There is a reduction of lighting levels due to (a) glass transmission, (b) maintenance factor of glass, (c) reduction in glass area due to obstructing window sashes and (d) reduction due to structural members, each approximately reducing the light by 80 per cent, thereby leaving only 40 per cent, of the light on an average, to reach the working plane. Hence the sky component as well as the reflected component in (1) above should be multiplied by 2.5 (this is to restore the levels to the original design requirement) and the value used for design.

3. In the optimum Design Chart, Fig. 2, the three upper curves are for working planes 15,25, and 35 ft. below the sill of the northlight and intermediate values can be had by intrapolation. The sky component got from (2) above is located on the left hand (sky component) ordinate and a horizontal drawn to meet the desired working plane curve. From the point of intersection a vertical line is drawn to meet the horizontal axis as well as curve No. IV. The point of intersection on the horizontal axis gives the optimum roof slope. A horizontal drawn from the point of intersection of the vertical line and curve IV to meet the right hand ordinate yields the optimum bay width which when used in conjunction with the optimum roof slope, results in the most unifo-m daylighting of the working plane.

4. An estimate of the reflected component reaching the working plane, once the roof slope is decided in (3) above is then made with reference to Fig. 3, where the expectable reflected component E_r at any point on the working plane is plotted against the optimum roof slopes for several values of ceiling reflectances. E is the total incident solar illumination on the roof which for most design work (at places on the northern side of the Tropic of Cancer) may be taken as 4000 Lm/sq. ft., between 9 A.M. and 4 P.M. The reflectance of the roof is taken to be constant at 0.2 and such low values are possible with most weathered roof surfaces. From Fig. 3 the ceiling reflectance that would provide the required reflected component of daylight on the working plane may be estimated.

Slight differences are likely between the illumination at the centre of a bay and the edge of it. In the case of the working plane at 15 ft. from the sill it may amount to about 20% and for all other working planes as less than 1%.

It is to be remembered that all the aforesaid procedures are based on the assumption that the factory length is infinity. In any case, a length corresponding to four times the bay width may be treated as approaching the infinite length with negligible deviations from the computed values.

The design based only on illumination requirements, may not always tally with the constructional, structural and architectural requirements and fall in line with general practices. However, instead of starting the design from daylighting considerations, one may start from architectural and structural considerations and choose a suitable baywidth and the corresponding roof slope from fig. 2 curve IV. The resulting illumination will be uniform but may be far in excess of task requirements. The problem then will be one of reducing this illumination by using window glasses of low transmission factors.

EXAMPLES

Two illustrative examples of design are given below to make the suggested procedures clear

Example 1 : Design a factory for woodworking processes requiring an illumination level of 30 lm/sq.ft. on the work plane 20 ft. below the sill.

Step I Split 30 lm/sq. ft. in the ratio 2 : 1 Sky comp. is 20 lm/sq.ft. and reflected component 10 lm.sq.ft.

Step II Increase each by a factor of 2.5 S.C. is 50 lm/sq.ft. R.C. is 25 lm/sq.ft.

Step III Expressing 50 lm/sq.ft. as a percentage of 1000, the design value of sky luminance, we get 5%.

Step IV Locate 5% on the left hand ordinate of fig. 2 Proceed horizontally. Intrapolating for 20 ft. (i.e. between 15 and 25 ft.) work planes one gets the roof slope as 7° and optimum bay width as 21 ft.

Step V Now $E_r/E \times 100 = 0.625$ to get 0.625 from ceiling reflections is 0.6, i.e. the ceiling should be fiinshed with a matt white paint of reflectance 0.6.

Hence, the projected factory will have a width per bay of 21 ft. roof slope of 7 degrees and a ceiling reflectance of 60%.

Example 2 : Design a factory for precision instruments where the illumination level should be 60 lm/sq.ft. and sill 35 ft. above the work plane.

Step I Dividing 60 lm/sq. ft. in the ratio of 2:1 we get 40 and 20 lm/sq. ft.

Step II Increase them by a factor of 2.5 and get S.C. 100 add R.C. 50 lm/sq. ft.

Step III Expressing the S.C. as a percentage fraction of 1000 we get 10%.

Step IV In fig. 2 locating 10% on the left ordinate and moving horizontally meet the 35 ft. work plane. Moving vertically down and get 17.5 deg. as the optimum slope. From curve IV the optimum bay width is 30 ft.

Step V $Er/E \times 100 = \frac{50 \times 100}{4000} = 1.25$, which can be had for this roof slope by having a ceiling reflectance of 0.85.

Hence we find that the factory will have 60 lm/sq.ft. on the work plane when the roof slope is 17.5 degrees, bay width 30 ft. and the ceiling reflectance 0.85.

There is a demand for short notes summarising available information on selected building topics for the use of Engineers and Architects in India. To meet the need this Institute is bringing out a series of Building Digests from time to time and the present one is the twenty third in the series.

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