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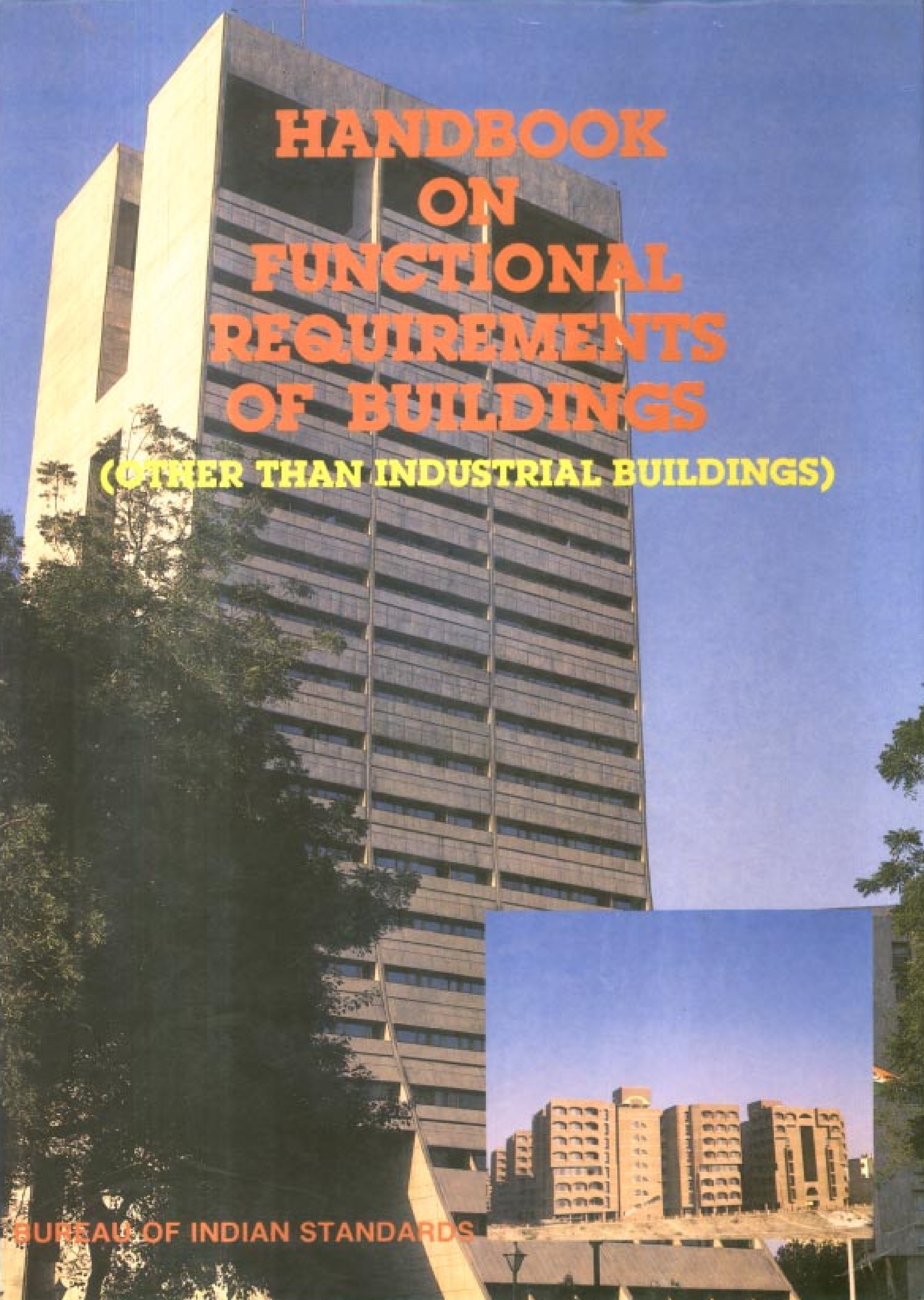
HANDBOOK ON FUNCTIONAL REQUIREMENTS OF BUILDINGS

(OTHER THAN INDUSTRIAL BUILDINGS)



BUREAU OF INDIAN STANDARDS

HANDBOOK ON FUNCTIONAL REQUIREMENTS OF BUILDINGS (OTHER THAN INDUSTRIAL BUILDINGS)

(PARTS 1-4)

BUREAU OF INDIAN STANDARDS
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FOREWORD

Users of various civil engineering codes have been feeling the need for explanatory handbooks and other compilations based on Indian Standards. The need has been further emphasized in view of the publication of the National Building Code of India in 1970 and its implementation. The Expert Group set up in 1972 by the Department of Science and Technology, Government of India carried out in-depth studies in various areas of civil engineering and construction practices. During the preparation of the Fifth Five-Year Plan in 1975, the Group was assigned the task of producing a Science and Technology Plan for research, development and extension work in the sector of housing and construction technology. One of the items of this plan was the production of design handbooks, explanatory handbooks and design aids based on the National Building Code and various Indian Standards, and other activities in the promotion of the National Building Code. The Expert Group gave high priority to this item and on the recommendation of the Department of Science and Technology, the Planning Commission approved the following two projects which were assigned to the Bureau of Indian Standards:

a) Development programme on code implementation for building and civil engineering construction, and

b) Typification for industrial buildings.

A Special Committee for Implementation of Science and Technology Projects (SCIP) consisting of experts connected with different aspects was set up in 1974 to advise the BIS Directorate General in identifying the handbooks and for guiding the development of the work. Under the first project, the Committee has so far identified subjects for several explanatory handbooks/compilations covering appropriate Indian Standards/Codes/Specifications which include the following:

Design Aids for Reinforced Concrete to IS : 456-1978 (SP : 16-1980)
Explanatory Handbook on Masonry Code (SP : 20-1981)
Explanatory Handbook on Codes of Earthquake Engineering (IS : 1893-1975 and IS : 4326-1976) (SP : 22-1982)
Handbook on Concrete Mixes (SP : 23-1982)
Explanatory Handbook on Indian Standard Code of Practice for Plain and Reinforced Concrete (IS : 456-1978) (SP : 24-1983)
Handbook on Causes and Prevention of Cracks in Buildings (SP : 25-1984)
Summaries of Indian Standards for Building Materials (SP : 21-1983)
Handbook on Concrete Reinforcement and Detailing (SP : 34-1987)
Handbook on Water Supply and Drainage with Special Emphasis on Plumbing (SP : 35-1987)
Functional Requirements of Industrial Buildings
Handbook on Timber Engineering (SP : 33-1986)
Foundation of Buildings
Steel Code (IS : 800-1984)
Building Construction Practices
Bulk Storage Structures in Steel
Formwork
Fire Safety
Construction Safety Practices
Tall Buildings
Loading Code
Prefabrication

One of the handbooks identified is on Functional Requirements of Buildings (other than Industrial Buildings). This handbook provides detailed information on climatology, heat insulation, ventilation and lighting in non-industiral buildings which would be helpful in the planning and functional design of buildings as applicable to Indian conditions based on Indian Standards and other relevant literature on the subject. These aspects have been dealt in separate parts as indicated below:

i) Part 1 deals with basic climatic elements, namely, air temperature, solar radiation, humidity, rainfall and wind. The zoning of several regions of the country from climatic considerations is brought out.

ii) Part 2 deals with heat insulation of buildings, such as dwelling, hospitals, schools and office buildings both for non-air-conditioned and air-conditioned buildings.

iii) Part 3 gives detailed information on the requirements of ventilation and design guidelines for achieving desired ventilation rates in buildings. The basic principle of ventilation which act as useful tool for the designer to evolve ventilation design for numerous typical cases is also covered. In addition, design factors governing pattern and air flow in-doors are also covered.

iv) Part 4 deals with design methods for provisions of daylighting, artificial lighting and supplementary artificial lighting which would depend upon the type of buildings and the visual task being performed by the occupants. Design curves provided enable to determine the area of window opening required for a given daylight factor. To simplify the design calculations, the sky component protractors based on the tables of sky components and nomograms for internal reflected components have been provided. Use of these design aids is illustrated with worked examples. Artificial lighting design has been covered through lumen method and point-by-point method.

Energy conservation aspects have also been covered.

This Handbook, it is hoped, would provide useful guidance to architects, engineers and other agencies dealing with lighting, ventilation, air-conditioning and illuminating engineering aspects of non-industrial buildings.

This Handbook is based on the draft prepared by the Central Building Research Institute (CBRI), Roorkee. The draft handbook was circulated for review to Shri B. J. Ramrakhiani, New Delhi; Peico Electronics & Electricals Ltd, Bombay; General Electric Company of India Ltd, Calcutta; Central Public Works Department, New Delhi; Bharat Electrical Industries Ltd, Calcutta; Crompton Greaves Ltd, Bombay; Housing & Urban Development Corporation Ltd, New Delhi; Dr. V. Narasimhan, Madras; Headquarters Chief Engineer, Rajasthan and Gujarat Zone, Jaipur; National Physical Laboratory, New Delhi; Central Mechanical Engineering Research Institute, Durgapur; Directorate General of Meteorological Department, New Delhi; Danfoss (India)Ltd, New Delhi; Headquarters, Southern Command, Engineers Branch, Pune and S.F. India Ltd, Bombay; and the views received were taken into consideration while finalizing the Handbook.

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CONTENTS

PART 1 CLIMATOLOGY

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PART 1 CLIMATOLOGY

1. CLIMATE

1.1 Introduction — Climate plays a major role in the day-to-day and overall life of human beings. Their life patterns, activities and behaviour are greatly influenced by the elements of climate. The basic elements, namely, air temperature, solar radiation, humidity, rainfall and wind form the general climate of a place. Variations in the levels of these elements occur throughout the country.

The classification of climate for types of building is an aid to the functional design of dwellings. It implies the zoning of the country into several regions such that the differences of climate from region to region are capable of being reflected in building design, warranting some special provision for each region. The constituents of climate which promote a particular mode of heat dissipation from the human body and thus require certain specific features in building design are grouped together to form a climatic zone.

1.2 Terminology

1.2.1 *Design Temperature* — It is the representative temperature of the outdoor air which is taken for calculating heating/cooling loads for buildings.

1.2.2 *Dry Bulb Temperature (DBT)* — The temperature of the air, read on a thermometer, taken in such a way as to avoid errors due to radiation.

1.2.3 *Effective Temperature (ET)* — An arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body and its numerical value is that of the temperature of still saturated air which would induce an identical sensation.

1.2.4 *Globe Temperature (GT)* — It is the temperature measured by a thermometer whose bulb is enclosed in a matt black painted thin copper globe of 150 mm diameter. It combines the influence of air temperature and thermal radiation received or emitted by the bounding surfaces.

1.2.5 *Psychrometric Chart* — It is a graphic representation of the relationship between dry bulb temperature, wet bulb temperature, absolute and relative humidity, and vapour pressure.

1.2.6 *Relative Humidity (RH)* — The ratio (expressed as percentage) of the actual to the partial pressure of the water vapour at the same temperature.

1.2.7 *Wet Bulb Temperature (WBT)* — The steady temperature finally given by a thermometer having its bulb covered with gauze or muslin moistened with distilled water and placed in an air stream of not less than 4.5 m/s.

1.3 Classification of Climatic Zones — Basically, there are four types of climate relevant to building design, namely, hot and arid, hot and humid, warm and humid, and cold. In India, many regions alternately experience two or even three types of climate during the course of a year with varying degrees of intensity and duration. Such regions are said to have a composite climate. For instance, the plains of Northern India experience hot dry conditions during April to June; warm humid conditions during July to September; and cold to very cold conditions during December, January and February. For a functional design of buildings in such climates, the designer ought to incorporate the salient design requirements in respect of all the prevailing types depending upon their duration and severity, and to make compromise decisions regarding the conflicting features accordingly.

As a guidance, the country may be divided into following climatic zones as described in IS : 3792-1978 'Guide for heat insulation of non-industrial buildings (*first revision*)'.

1.3.1 *Hot and Arid Zone* — Regions, where mean daily maximum dry bulb temperature is 38°C or higher and relative humidity of 40 percent or less prevail during the hottest month of the year, and where the altitude is not more than 500 m above mean sea level, may be classified as hot and arid zones. Some representative towns falling under this zone are given in Appendix A.

1.3.2 *Hot and Humid Zone* — Regions, where mean daily maximum dry bulb temperature is above 32°C and relative humidity above 40 percent prevail during the hottest month of the year and where the altitude is not more than 500 m above mean sea level, may be classified as hot and humid zones. Some representative towns falling under this zone are given in Appendix A.

1.3.3 *Warm and Humid Zone* — Regions, where mean daily maximum dry bulb temperature is 26 to 32°C and relative humidity of 70 percent or above prevail during the hottest month of the year and where the altitude is not more than 100 m above mean sea level, may be classified as warm and humid zones. Some representative towns falling under this zone are given in Appendix A.

1.3.4 *Cold Zone* — Regions, where mean daily minimum dry bulb temperature is 6°C or less prevail during the coldest month of the year and where the altitude is more than 1 200 m above mean sea level, may be classified as cold zones. Some representative towns under this zone are given in Appendix A.

1.4 Climatic Data for Buildings

1.4.1 Basically, India is a warm country, though extremes of climate do occur in many regions. As such, buildings in most parts of the country are designed to keep the heat out for a greater part of the year, except of course in the high altitude cold regions.

The computation of the quantity of heat entering an indoor space requires a knowledge of the hour-wise values of air temperature, solar radiation, humidity, together with the thermophysical properties of building components. As such, the outdoor climatic data needed for the purpose should comprise:

a) hourwise dry bulb temperatures for summer months,

b) hourwise wet bulb temperatures for summer months, and

c) hourwise solar radiation incident on the horizontal and the differently oriented vertical surfaces during the representative hot/cold month.

1.5 Design Dry Bulb and Wet Bulb Temperatures

1.5.1 In order to make the climatic data representative of the severity of hot climate at any station, ten-year hourly dry bulb and wet bulb temperatures were obtained from the Indian Meteorological Department for some representative stations in the country. From these data, hourly design temperatures were obtained by carrying out hour-wise frequency analysis of dry bulb and wet bulb temperatures, and determining the temperatures equalled or exceeded for 5 percent hours of the total duration. It was found from working experience that the maximum value of 5 percent exceeded or equalled 24-hour design temperature cycle was very close to the single value of 1 percent exceeded or equalled design temperature for all the 24 h. Hence a 5 percent hour-wise design temperature cycle was considered sufficiently representative of the near worst summer conditions for various stations.

1.5.2 The summer design dry bulb (DB) and wet bulb (WB) temperatures, as determined for towns representing various hot/warm climates, are reproduced in Table 1.

TABLE 1 HOUR-WISE DESIGN DRY BULB AND WET BULB TEMPERATURES

(*Clause* 1.5.2)

Hours	Jodhpur		Bombay		New Delhi		Hyderabad	
	DB °C	WB °C	DB °C	WB °C	DB °C	WB °C	DB °C	WB °C
01	35.4	26.0	30.0	27.3	36.1	26.8	32.1	23.5
02	34.5	25.8	30.0	27.1	35.6	26.7	31.5	23.5
03	33.5	25.7	30.0	26.9	35.0	26.7	31.0	23.0
04	33.1	25.5	29.5	26.8	34.6	26.6	30.3	23.3
05	32.5	25.4	29.5	26.8	34.2	26.5	29.7	23.3
06	31.9	25.3	29.0	26.9	33.7	26.5	29.4	23.2
07	31.5	25.4	30.0	27.1	34.2	26.5	29.8	23.3
08	32.5	25.5	31.0	27.2	35.4	26.5	31.4	23.4
09	34.7	25.7	32.0	27.5	37.5	26.7	33.5	23.4
10	37.1	25.9	32.5	27.8	38.9	26.8	35.4	23.6
11	39.6	26.2	33.0	28.1	40.4	26.9	36.9	23.9
12	41.5	26.5	33.5	28.3	41.4	26.9	38.0	24.2
13	42.2	26.8	34.0	28.3	42.2	27.1	38.8	24.5
14	43.2	27.0	34.5	28.3	42.7	27.1	37.3	24.8
15	43.5	27.1	34.7	28.2	43.0	27.1	39.6	24.9
16	43.5	27.2	34.5	27.9	43.2	27.1	39.7	24.9
17	43.1	27.1	34.0	27.7	43.1	27.1	39.4	24.7
18	42.5	26.9	33.5	27.5	42.7	27.1	38.7	24.3
19	41.5	26.7	33.0	27.4	41.5	27.0	37.9	24.2
20	40.3	26.6	32.5	25.4	40.1	27.0	36.0	24.0
21	39.1	26.5	30.0	27.3	39.1	26.9	35.1	23.9
22	38.0	26.3	31.0	27.3	38.1	26.9	34.3	23.8
23	37.4	26.1	30.0	27.3	37.3	26.9	33.6	23.8
24	36.4	26.0	30.0	27.3	36.6	26.8	32.8	23.6

1.6 Solar Radiation

1.6.1 Solar radiation incident on a horizontal surface comprises direct and diffuse components but that on a vertical surface includes, in addition, the component reflected from the ground (GRC).

The quantity of solar radiation reaching the earth's surface depends on the clearness of the atmosphere. If I_N represents the quantity of solar radiation at normal incidence reaching the earth's surface and β the solar altitude, then the direct component I_{dH} on a horizontal surface is given by:

$$I_{dH} = I_N \sin \beta \qquad .. (1)$$

Similarly, if I_{dH} represents the diffused sky radiation on a horizontal surface for a solar altitude of β, then the total radiation I_{TH} on a horizontal surface is given by:

$$I_{TH} = I_N \sin \beta + I_{dH} \qquad .. (2)$$

Similarly, if α represents the wall solar azimuth angle, that is, the angle between the directions of sun and the wall in plan, the total radiation on a vertical surface I_{TV} is given by:

$$I_{TV} = I_N \cos \beta \cos \alpha + I_{dV} + \text{GRC} .. (3)$$

where $I_{dV} = \frac{1}{2} I_{dH}$ for a uniformly radiating atmosphere and GRC is taken as 20 percent of the total solar rediation incident on the horizontal surface.

1.6.2 The computations of hour-wise total solar radiation on the horizontal and eight vertical surfaces (cardinal and semicardinal directions) are presented for the four representative towns in Tables 2 to 5.

2. THERMAL COMFORT

2.1 Introduction — The primary purpose of building design and choice of materials is the creation of an indoor thermal environment which is conducive to the well being of the occupants. The most important physiological requirement of human health and general well-being is the ability of the human body to maintain a constant internal temperature. The necessary condition for it is that the rate of heat production within the body should balance the rate of heat loss from it, regardless of the wide variations in the external environment. The body constantly generates heat, uses a minor fraction of it as work and exchanges the rest with the surroundings through the usual processes of heat transfer, namely, convection, radiation and evaporation. The conditions under which thermal balance is achieved and the state of the body when it is in thermal equilibrium with the surroundings depend on many factors, significant ones being the environmental factors. The heat exchange of the body can be considerably modified by these factors.

2.2 Heat Exchange of the Body

2.2.1 The heat balance of the body with the surroundings is governed by the equation:

$$M - W = \pm R \pm C + E \pm S$$

where

M = metabolic heat generation rate,
W = work rate of mechanical energy leaving the body;
R = rate of heat loss or gain by radiation;
C = rate of heat loss or gain by convection;
E = rate of evaporative heat loss; and
S = rate at which heat is being stored within the body, + ve sign denoting chilling of the body.

R, C and E are functions of the external environment, skin temperature and vapour pressure. The apportionment of the total heat loss

TABLE 2 HOUR-WISE TOTAL SOLAR RADIATION FOR JODHPUR (IN W/m²)

(*Clause* 1.6.2)

Hour	Vertical Surfaces								Horizontal Surfaces
	N	NE	E	SE	S	SW	W	NW	
6	210	435	442	229	65	65	65	65	203
7	237	604	661	375	75	75	75	75	415
8	192	584	682	427	81	81	81	81	606
9	136	370	630	391	84	84	84	84	719
10	98	349	463	357	105	88	88	88	915
11	89	205	294	262	131	89	89	89	997
12	90	90	90	132	148	132	90	90	1 022
13	89	89	89	89	131	262	294	205	997
14	98	88	88	88	105	357	463	349	915
15	136	84	84	84	84	391	630	370	719
16	192	81	81	81	81	427	682	584	606
17	237	75	75	75	75	375	661	604	415
18	210	65	65	65	65	229	442	433	203

TABLE 3 HOUR-WISE TOTAL SOLAR RADIATION FOR NEW DELHI (IN W/m²)

(*Clause* 1.6.2)

Hour	Vertical Surfaces								Horizontal Surfaces
	N	NE	E	SE	S	SW	W	NW	
6	216	448	458	236	65	65	65	65	211
7	233	604	665	381	75	75	75	75	423
8	176	374	684	440	81	81	81	81	605
9	112	236	653	379	82	82	82	82	662
10	88	330	462	375	121	88	88	88	914
11	89	184	295	284	160	89	89	89	999
12	90	90	90	153	177	153	90	90	1 020
13	89	89	89	89	160	284	295	184	999
14	88	88	88	88	121	375	462	330	914
15	112	82	82	82	82	379	653	236	662
16	176	81	81	81	81	440	684	374	605
17	233	75	75	75	75	381	665	604	423
18	216	65	65	65	65	236	458	448	211

TABLE 4 HOUR-WISE TOTAL SOLAR RADIATION FOR BOMBAY (IN W/m²)

(*Clause* 1.6.2)

Hour	Vertical Surfaces								Horizontal Surfaces
	N	NE	E	SE	S	SW	W	NW	
6	122	245	258	153	57	57	57	57	138
7	213	568	632	370	73	73	73	73	350
8	193	590	688	430	80	80	80	80	570
9	156	511	618	413	88	85	85	86	758
10	123	399	480	341	88	88	88	88	902
11	108	273	291	227	101	90	90	90	995
12	105	101	90	101	105	101	90	90	1 024
13	108	390	90	90	101	227	291	237	995
14	123	89	88	88	88	341	480	389	902
15	156	85	85	85	88	413	619	511	758
16	193	80	80	80	80	430	688	590	570
17	213	73	73	73	73	370	632	568	350
18	122	57	57	57	57	153	258	245	138

TABLE 5 HOUR-WISE TOTAL SOLAR RADIATION FOR HYDERABAD (IN W/m²)

(*Clause* 1.6.2)

Hour	Vertical Surfaces								Horizontal Surfaces
	N	NE	E	SE	S	SW	W	NW	
6	104	195	204	126	55	55	55	55	125
7	221	568	625	358	72	72	72	72	341
8	209	600	686	417	80	80	80	80	562
9	179	528	619	396	90	84	84	84	752
10	151	411	483	323	88	88	88	88	897
11	125	255	290	207	90	90	90	90	995
12	119	111	90	90	90	90	90	111	1 024
13	125	90	90	90	90	207	290	255	995
14	151	90	88	88	88	323	483	411	897
15	179	84	84	84	90	396	619	528	752
16	209	80	80	80	80	417	686	600	562
17	221	72	72	72	72	358	625	568	341
18	104	55	55	55	55	126	204	195	125

into the radiative, evaporative and convective components depends upon the level of environmental factors like air temperature, vapour pressure, radiation and air movement. For instance, the evaporative loss of a clothed person at 20°C air temperature may be only 20 percent of the total heat loss from the body whereas at 40°C it may rise to as high as 50 percent for low relative humidity conditions. The radiative loss is high at low ambient temperature but decreases as the temperature of the bounding surfaces approaches the skin temperature. At temperatures of the surrounding surfaces higher than the skin temperature, the radiative heat loss turns into radiative heat gain. Similarly the convective heat loss is high at low air temperatures and decreases with increasing air temperatures, turning into gain when air temperture rises above skin temperature.

2.2.2 There are four environmental factors which essentially determine the heat exchange ol the human body. These are air temperature, mean radiant temperature, relative humidity or water vapour pressure of air and air movement. These can vary independently of each other and can influence one or more modes of heat transfer at a time.

2.3 Indices of Thermal Comfort

2.3.1 The environmental factors vary independently of each other but act simultaneously on the human body. It is not possible to express the thermal response of the human body in terms of any single factor as the influence of any one depends upon the level of others. Many attempts have been made to integrate the effect of two or more environmental factors and to express the thermal response in terms of the integrated parameter. These attempts have resulted in formulae or nomograms on theoretical or experimental grounds which can estimate the thermal stress due to a wide range of climatic conditions. Such a combination of influencing environmental factors into a single parameter is called 'Index of Thermal Comfort' or simply comfort.

2.3.2 Large number of thermal indices have been developed in various countries throughout the world, but none of them appears to be universally satisfactory over the entire range of environmental conditions. For an index to be valid, its functions must correlate well with the thermal sensation of people engaged in their normal life routine. The divergence appears to be mainly on physiological grounds; partly due to the rapid and complex adjustments the body continually makes to counter environmental changes, partly to the fact that thermally equivalent conditions produce different subjective sensations and partly to the individual variations in adaptation to a given environment.

2.3.3 Two of the thermal indices which find applications for hot environments are described as follows. These are:

a) Effective temperature (ET)

b) Tropical summer index (TSI)

2.3.3.1 *Effective temperature*

a) The effective temperature (ET) was first developed by Houghton and Yaglou (1923) by sampling the instantaneous thermal sensations of human subjects moving between rooms maintained at different environmental conditions. Effective temperature is defined as the temperature of still, saturated air which has the same general effect upon comfort as the atmosphere under investigation. Combinations of temperature, humidity and wind velocity producing the same thermal sensation in an individual are taken to have the same effective temperature.

b) Initially two scales were developed, one of which referred to men stripped to the waist, and called the basic scale. The other applies to men fully clad in indoor clothing and called the normal scale of effective temperature. Bedfort (1946) proposed the use of globe temperature reading instead of the air temperature reading to make allowance for the radiant heat. This scale is known as the corrected effective temperature (CET) scale. No allowance, however, was made for the different rates of energy expenditure. The scale was compiled only for men either seated or engaged in light activity.

c) Figure 1 represents the corrected effective temperature nomogram. The CET can be obtained by connecting the appropriate points representing the dry bulb (or globe) and wet bulb temperatures and reading the CET value at the intersection of this line with the relevant air velocity curve from the family of curves for various air velocities running diagonally upwards from left to right.

d) The effective temperature scale may be considered to be reasonably accurate in warm climates where the heat stress is not high but it may be misleading at high levels of heat stress. There appears to be an inherent error in this scale if used as an index of physiological strain, the error increasing with the severity of the environmental conditions. For low and moderate degrees of heat stress, the effective temperature scales appear to assess climatic heat stress with an accuracy which is acceptable for most practical purposes.

2.3.3.2 *Tropical summer index*

a) Tropical summer index (TSI) has been developed at the Central Building Research Institute, Roorkee from the subjective sensations of 24 male observers during the

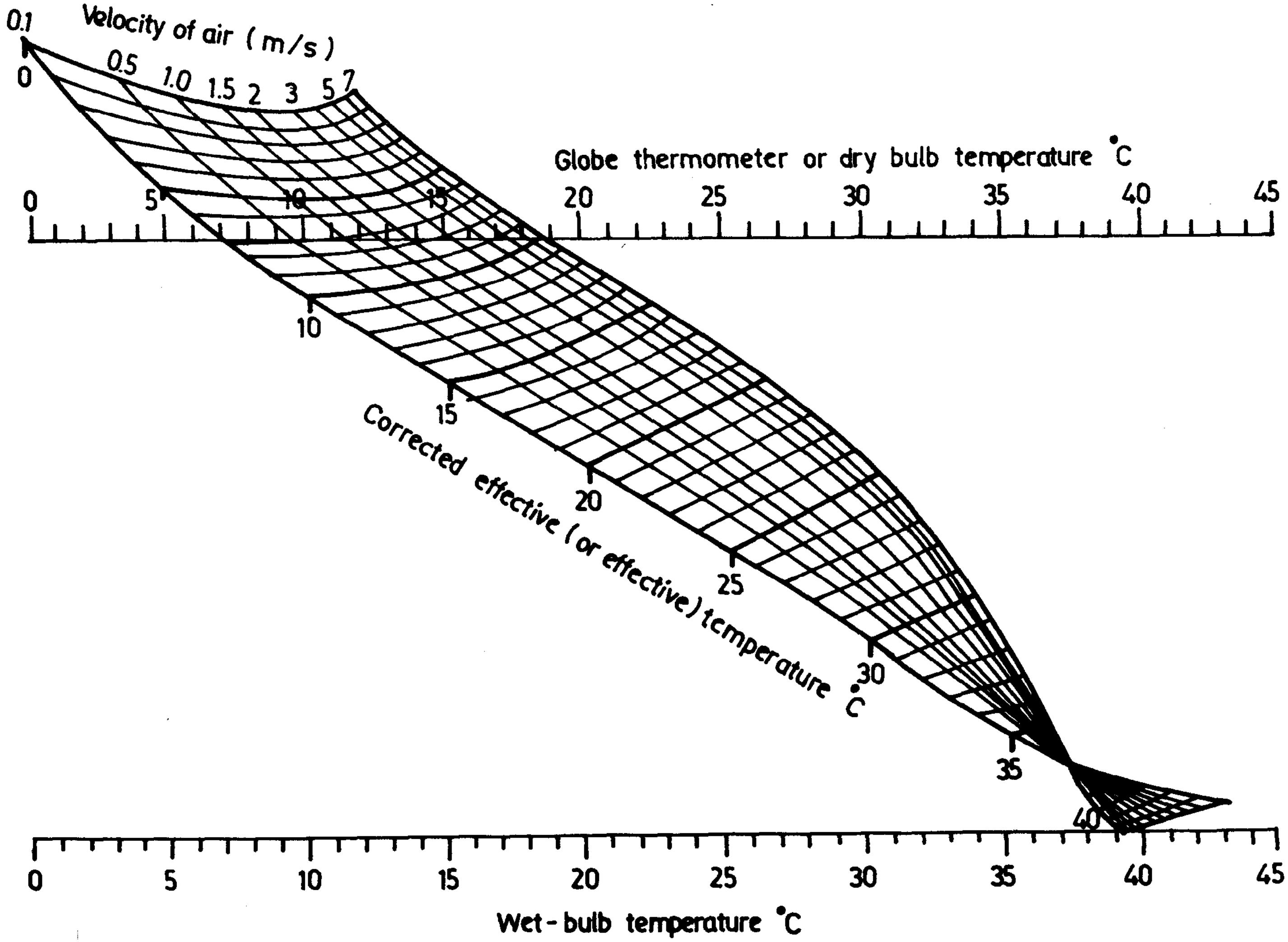


FIG. 1 CORRECTED EFFECTIVE TEMPERATURE NOMOGRAM

hot dry and warm humid indoor conditions obtaining in northern India during summer and monsoon months. Observations numbered around 5 000 and were spread over three consecutive years covering warm humid and hot dry seasons. The subjects were young, healthy adults engaged in light activity or sedentary work. They were clad in the usual light summer dress comprising a half sleeve bushshirt, trousers and under-garments. Observations were carried out around a period of the season when discomfort due to dry heat or humidity was greatest, implying that by this time the subjects were fully acclimatized to the prevailing environmental conditions.

b) The TSI is defined as the temperature of calm air, at 50 percent relative humidity which imparts the same thermal sensation as the given environment. The 50 percent level of relative humidity is chosen for this index as it is a reasonable intermediate value for the prevailing humidity conditions. Mathematically, TSI (°C) is expressed as

$$\text{TSI} = 0.308 t_w + 0.745 t_g - 2.06 \sqrt{V + 0.841} \quad \ldots (4)$$

where

t_w = wet bulb temperature in °C,
t_g = globe temperature in °C, and
V = air speed in m/s.

c) On the assumption that, for indoor conditions, globe temperature is very nearly similar to the dry bulb temperature in conventional buildings, lines of equal TSI are drawn in a psychrometric chart in Fig. 2 for various combinations of dry and wet bulb temperatures at intervals of 5°C. The intermediate values can be easily interpolated. These TSI values (*see* Fig. 2) refer to calm air conditions and the influence of air movement in reducing the TSI values (below those shown in Fig. 2) is given in Table 6. Psychrometric chart is a graphical representation of the thermodynamic properties of moist air. Its distinctive features are of practical values in solving engineering problems. Climatic conditions of any place can also be represented on a psychrometric chart.

d) The ranges of environmental conditions and TSI covered in this study are:

Globe temperture	: 20-42°C
Wet bulb temperature	: 18-30°C
Air speed	: 0-2.5 m/s
TSI	: 15-40°C

The thermal comfort of subjects was found to lie between TSI values of 25 and 30°C with optimum conditions at 27.5°C.

TABLE 6 REDUCTION IN TSI VALUES FOR VARIOUS WIND SPEEDS

[*Clause* 2.3.3.2 *(c)*]

Air Speed m/s	Decrease in TSI °C
0.5	1.4
1.0	2.0
1.5	2.5
2.0	2.8
2.5	3.2

The warmth of the environment was found tolerable between 30 and 34°C (TSI), and too hot above this limit. On the lower side, the coolness of the environment was found tolerable between 19 and 25°C (TSI) and below 19°C (TSI), it was found too cold.

e) The merit of TSI lies in the fact that it is simple to compute and is based on the relevant climatic conditions, living habits and clothing patterns in the country.

For quick assessment of environmental comfort, Equation (4) may be simplified to the approximate form of

$$\text{TSI} = \frac{1}{3} t_w + \frac{3}{4} t_g - 2\sqrt{V} \quad \ldots (5)$$

A comparison of exact and approxiamte TSI values for different combinations of globe and wet bulb temperatures for zero wind velocity conditions is shown in Table 7. It can be seen in Table 7 that, for relative humidity conditions below 50 percent level, TSI values are lower than the globe temperature. Above this level, the TSI values are higher than the air or globe temperature values.

Amongst the environmental factors, globe temperature and air temperature are found to have the highest and next best correlation with thermal sensation. The contribution of globe temperature to thermal sensation is found to be the maximum. For this reason, presumably the coefficient of globe temperature term in the TSI equation is high compared to others.

2.4 Climatic Zones and Thermal Requirements

2.4.1 Although classification of climatic zones according to IS : 3792-1978 has been given in **1.2** but the predominant types of climate occurring in different parts of India are hot dry, warm humid and cold. This is because most of the cities classified under hot and humid zone in IS : 3792-1978 remain warm and humid for most of the time in a year. One or more types occur at some places during a year. The degree of heat or cold

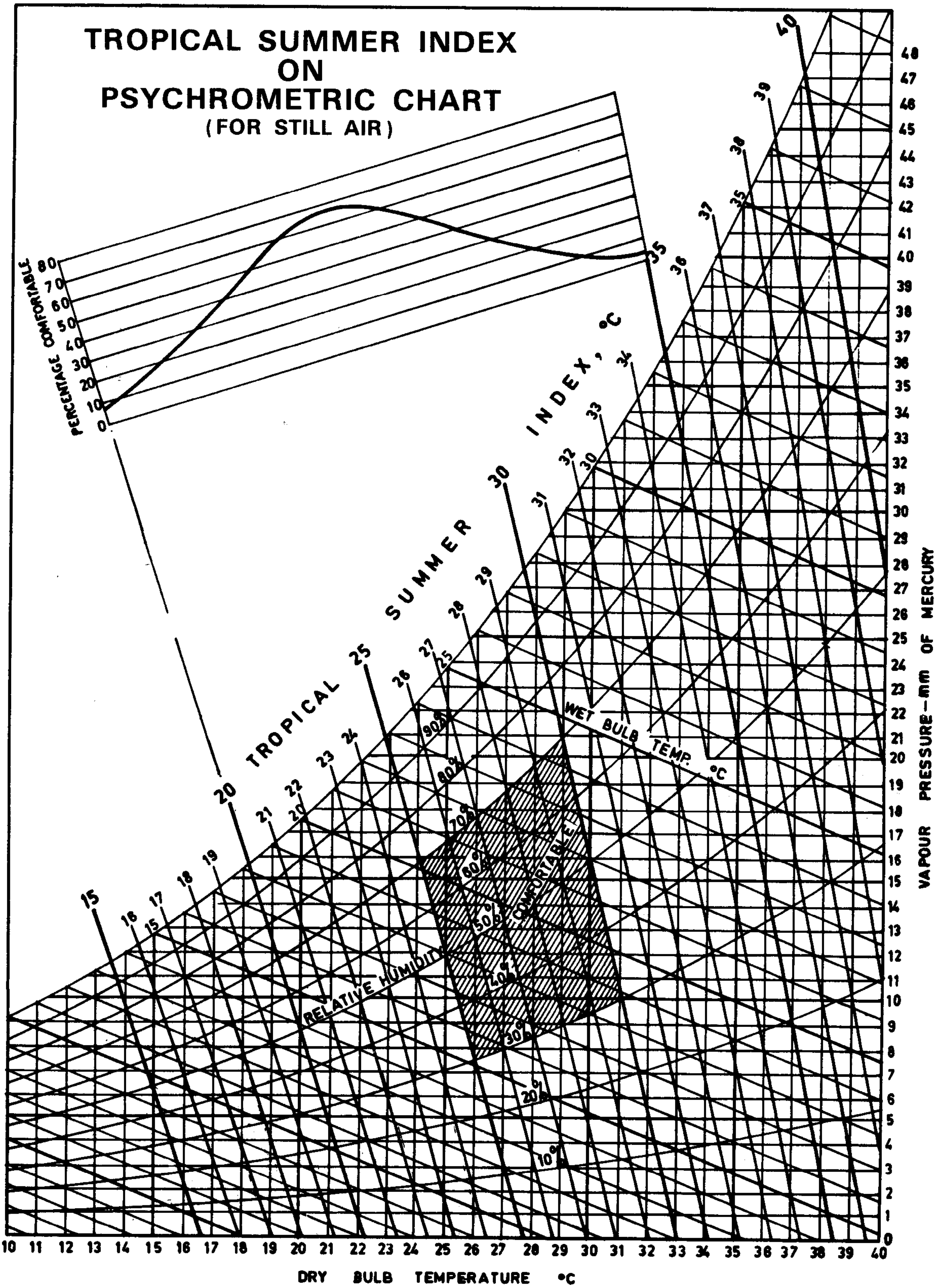


FIG. 2 TROPICAL SUMMER INDEX ON PSYCHROMETRIC CHART

TABLE 7 COMPARISON OF EXACT AND APPROXIMATE TSI VALUES

[*Clause* 2.3.3.2 *(e)*]

SL No.	GLOBE TEMPERATURE °C	WET BULB TEMPERATURE °C	EXACT TSI °C	APPROXIMATE TSI °C
i)	40.0	30.0	39.9	40.0
ii)	36.0	30.0	36.9	37.0
iii)	36.0	24.0	35.05	35.0
iv)	32.0	27.0	33.0	33.0
v)	30.0	27.0	31.5	31.5
vi)	30.0	18.0	28.7	28.5
vii)	26.0	21.0	26.7	26.5
viii)	24.0	21.0	25.2	25.0

and level of moisture content of air also show wide variation from place to place. But the overall ranges of temperatures (dry bulb and wet bulb) and vapour pressure within the country lie within the limits shown in Table 8. Fluctuations on either side of these limits for some regions are not ruled out, but these figures cover the climatic conditions in most regions of the country during a year.

TABLE 8 INCIDENCE OF DRY BULB AND WET BULB TEMPERATURES AND VAPOUR PRESSURE IN INDIA

(*Clause* 2.4.1)

SL No.	ELEMENT	HOT DRY SEASON	WARM HUMID SEASON	COLD SEASON
i)	Dry bulb temperature °C	20-45	25-35	0-25
ii)	Wet-bulb temperature °C	15-25	24-30	10-20
iii)	Vapour pressure	5-20	20-30	5-15

2.4.2 These climatic conditions are shown on psychrometric chart in Fig. 3 for all the three seasons. Also superposed on the same chart are lines of equal TSI for various levels of thermal comfort.

The line *A* (Fig. 3) indicating a TSI value of 27.5°C on the psychrometric chart shows the conditions of optimum comfort. It lies almost centrally over the hot dry region. The lines *B* and *C*, connoting 25 and 30°C (TSI) respectively on both sides of the line *A* indicate the lower and upper limits of thermal comfort. The lines *D* and *E* representing 19 and 34°C (TSI) are the lower and upper limits respectively of easily tolerable cold and warm conditions. Similarly the line *F* represents 34°C (TSI), the upper limit of easily tolerable warmth at a wind velocity of 2.5 m/s, the maximum value usually available under a ceiling fan. In the absence of wind velocity, the line *F* represents 37°C (TSI), a value well within the limits of thermal discomfort due to warmth.

2.4.3 It can be seen from Fig. 3 that, in the cold season, day time temperatures are generally within tolerable thermal comfort conditions at 19°C (TSI) or more but nights are abnormally cold at many places in northern India. During the hot dry season, the ambient conditions lie within the limits of thermal comfort for a sufficient period and can be made so with various levels of air movement up to the line *F*. But still there is some region beyond this line when air movement alone is not enough to bring about thermal comfort. In this region of the hot dry conditions, wet bulb temperatures are not high compared to dry bulb temperatures and evaporative cooling appears to be effective in creating thermally comfortable conditions. Evaporative cooling causes the wet bulb temperature to remain constant. It is seen from the psychrometric chart that even at a high wet bulb temperature of 24°C, the dry bulb temperature falls from 44 to say 29°C by merely increasing the relative humidity from about 18 percent to 67 percent by evaporative cooling. The resulting conditions lie within comfort limits. In the warm humid season, high air movement (2.5 m/s) appears to be adequate (line *F*) to bring about tolerable comfort conditions.

2.4.4 It is, therefore, apparent from Fig. 3 that problems of thermal discomfort, both due to warmth and cold are present in the climatic conditions available in India and mechanical aids are a necessary adjunct. It is possible to minimize the rigours of thermal discomfort by a judicious choice of orientation, layout plan and building materials in the construction of buildings to suit the outdoor climate.

3. SHADING DEVICES

3.1 Solar Chart and Design of Louvers

3.1.1 Solar chart is a graphical representation of the paths of sun in the sky for various days in the year. The hemisphere of the sky is represented by a circular plane diagram, the centre of which represents the zenith and the outer circumference the horizon line. The various angles of compass are shown along the circumference of the chart and the altitude angles are represented by concentric circles, the outermost circumference denoting zero and the centre denoting 90° of altitude. The relative spacings of the concentric circles for various altitude angles depend upon the type of projection employed. In equidistant projection used for solar chart as shown in Fig. 4, the spacing is proportional to the altitude angle. The radius of the outermost circle is divided into nine equal parts and concentric circles passing through each of these divisions, therefore, represent ten-degree steps of altitude. Individual solar charts are prepared for each geographical latitude.

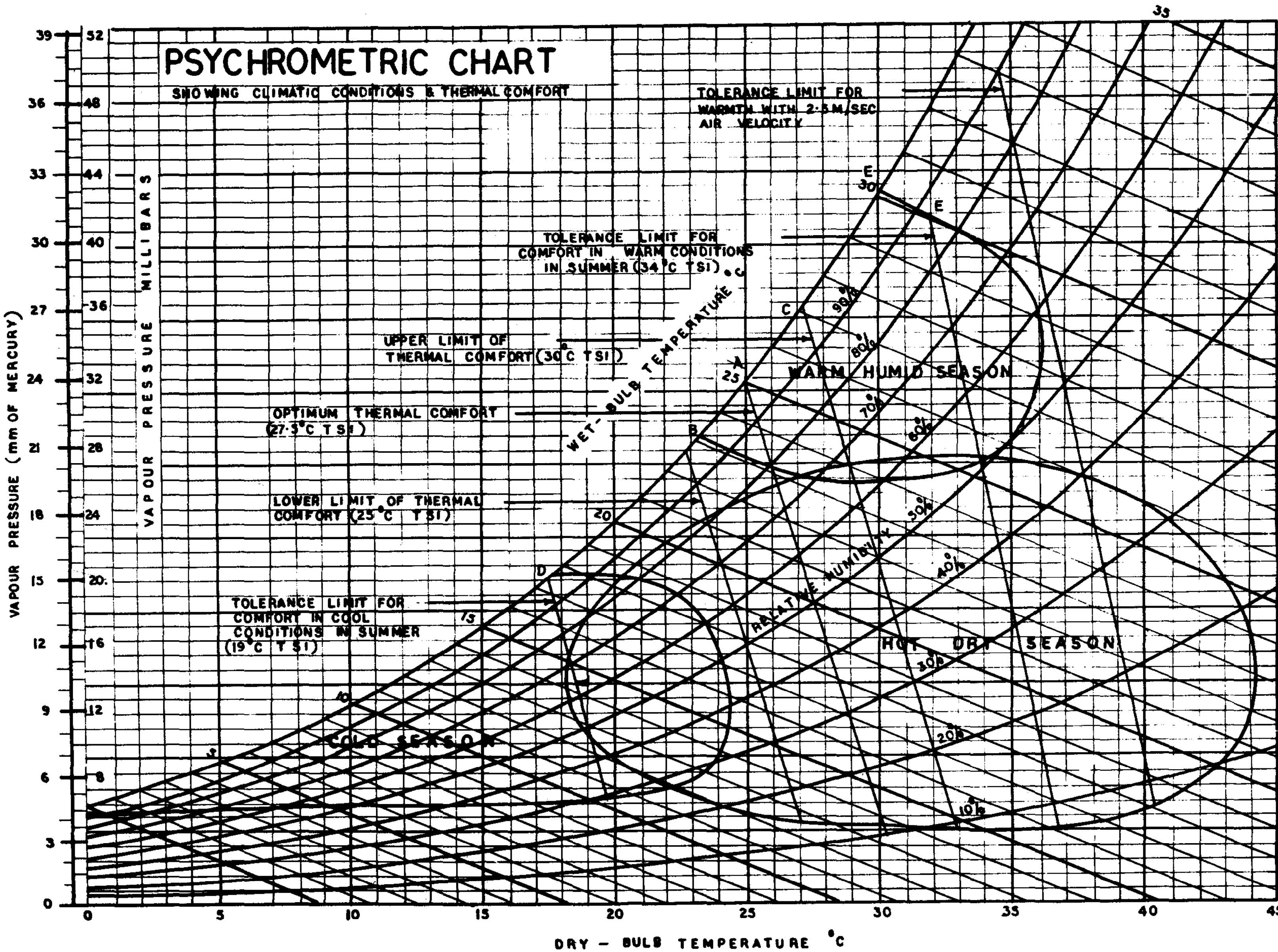


FIG. 3 PSYCHROMETRIC CHART (SHOWING CLIMATIC CONDITIONS AND THERMAL COMFORT)

SOLAR CHART

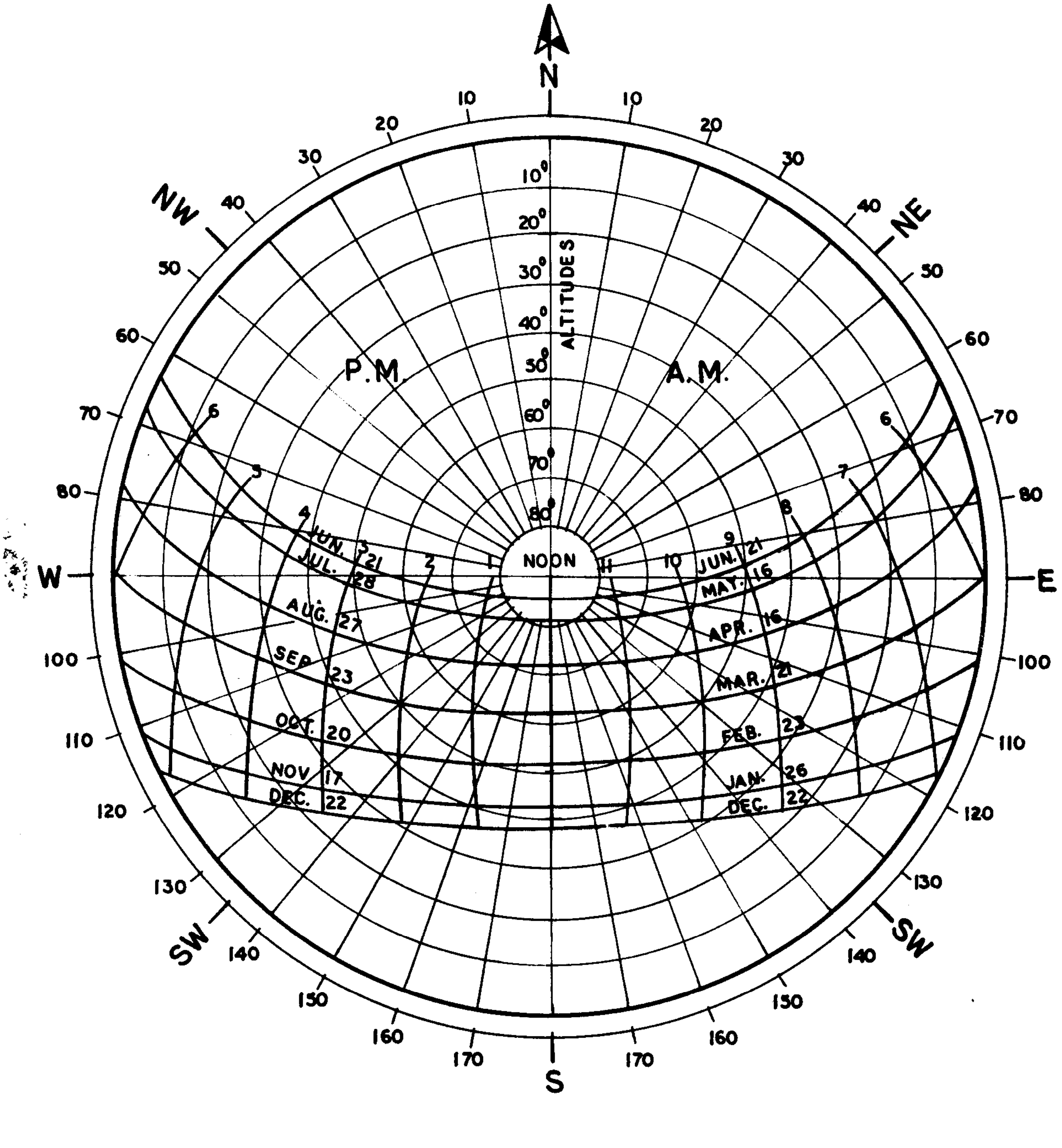


FIG. 4 LATITUDE 29° NORTH

3.1.2 The solar paths are represented by curved lines running from east to west, the upper and lower curves being for summer and winter solstices. The other curves are for two dates having the same declination angle of the sun. These curves are crossed by hour lines, which refer to solar time. A correction for each town is applied to the solar time to convert it into Indian Standard Time. The intersection of the solar path for any date with any hour line represents the altitude and azimuth of the sun on that date and hour. Sunrise and sunset are shown by the intersection of the sun path curve with the outermost circle (horizon). The hours of sunrise and sunset can be determined from the relative positions of the hour lines. It is significant that the sun rises in true east and sets in true west at any geographical latitude only on equinox days (21 March and 23 September).

3.1.3 In order to determine the type and size of shading devices, a shadow angle protractor is used as an overlay in conjunction with the solar chart. The shadow angle protractor is a semi-circular figure as shown in Fig. 5 drawn on a transparent paper or celluloid sheet, the diameter of which is the same as that of the solar chart. The base line of the semi-circle represents a vertical wall. The series of curved lines joining the two extremities of the base line and another of radial lines represent the vertical and horizontal shadow angles respectively. The vertical and horizontal shadow angles are the vertical and horizontal angles between the sun and the normal to the wall surface. Every point within the semi-circle, therefore, refers to some values of vertical and horizontal shadow angles.

3.2 Window Angles

3.2.1 The angle with the horizontal plane subtended by the plane joining the outer edge of a horizontal louver on the top of a window to the lower edge of the window is called the vertical window angle. For a given window height, this angle indicates the size of the horizontal louver on the top of the window as shown in Fig. 6. The sun is masked from entering the window by the horizontal louver for all regions of the sky which have a vertical shadow angle larger than the vertical window angle. On the shadow angle protractor, the masked region of the sky is indicated by the hatched area shown in Fig. 7.

3.2.2 Similarly the angle subtended by the plane joining the outer edge of a vertical louver on one side edge of the window to the other vertical edge of the window, with a vertical plane normal to the window, is called the horizontal window angle as shown in Fig. 8. For a given window width, this angle represents the size of the vertical louver on one side edge of the window. The sun is masked by the vertical louver from entering the window as long as the horizontal shadow angle of the sun's position is greater than the horizontal window angle.

3.2.3 The masked region due to a vertical louver on the shadow angle protractor is shown in Fig. 9. Similarly the masking due to a vertical louver of similar size on the other side of the window is presented by a similarly masked area on the other side as shown in Fig. 10. The total masking due to both vertical louvers is shown in Fig. 11.

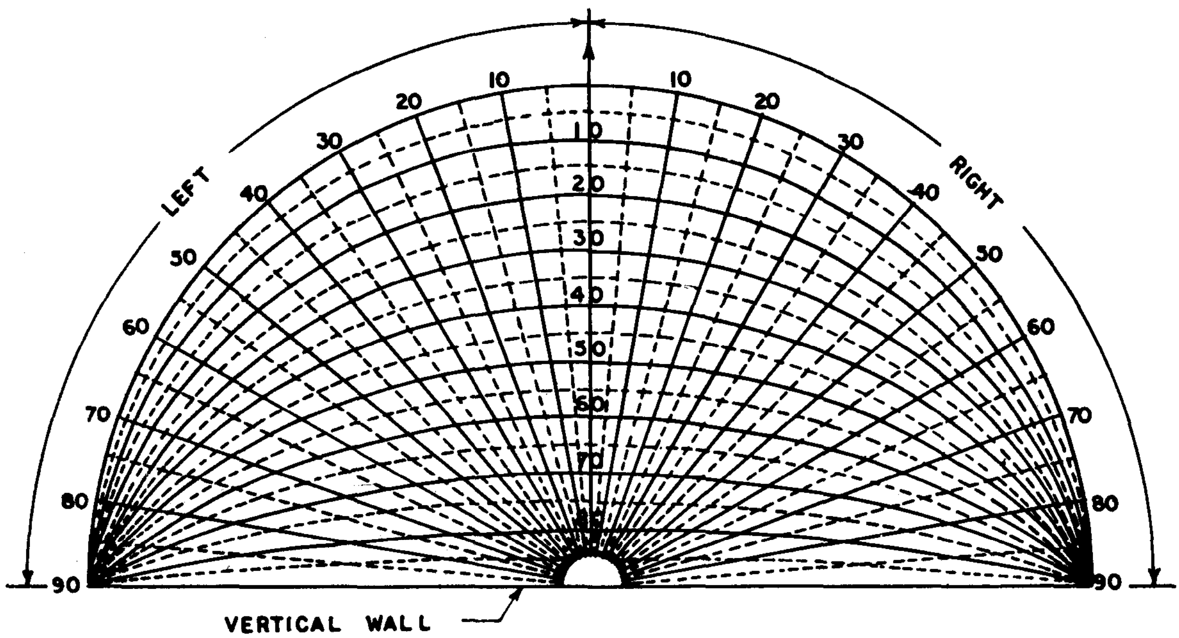


FIG. 5 SHADOW ANGLE PROTRACTOR

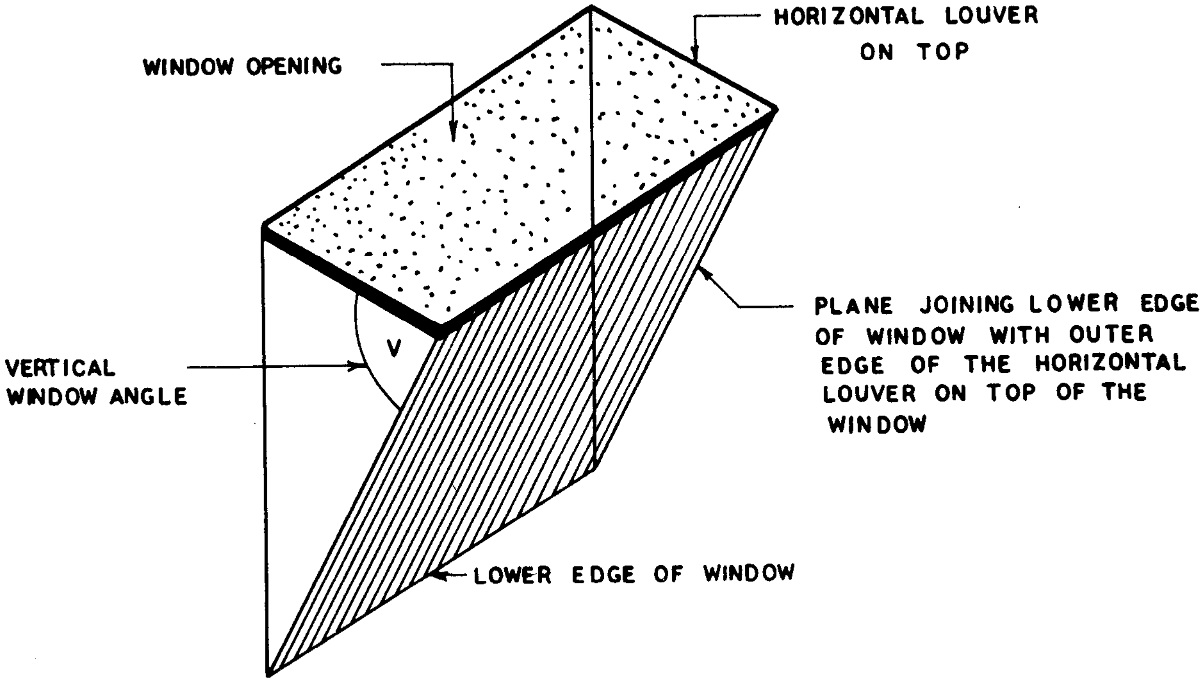


FIG. 6 VERTICAL WINDOW ANGLE

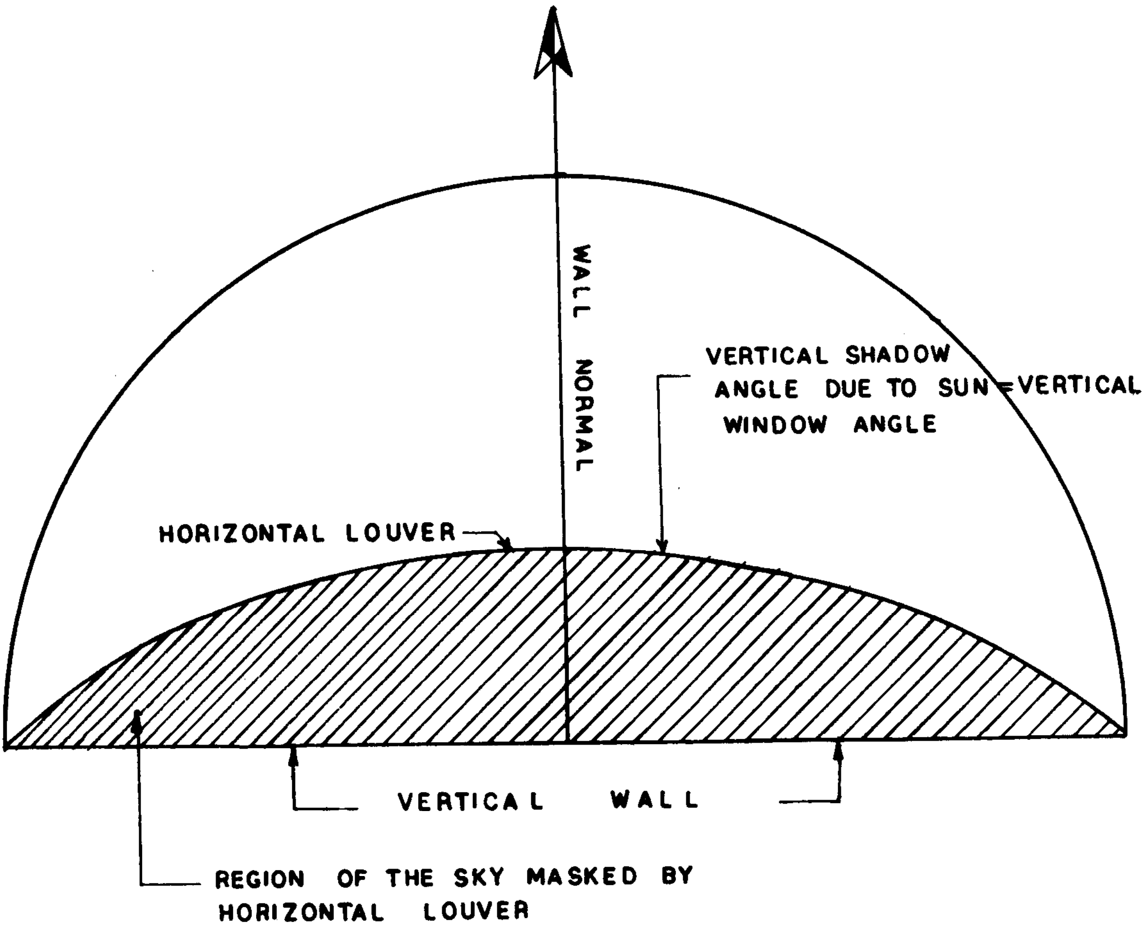


FIG. 7 REGION OF THE SKY MASKED BY HORIZONTAL LOUVER

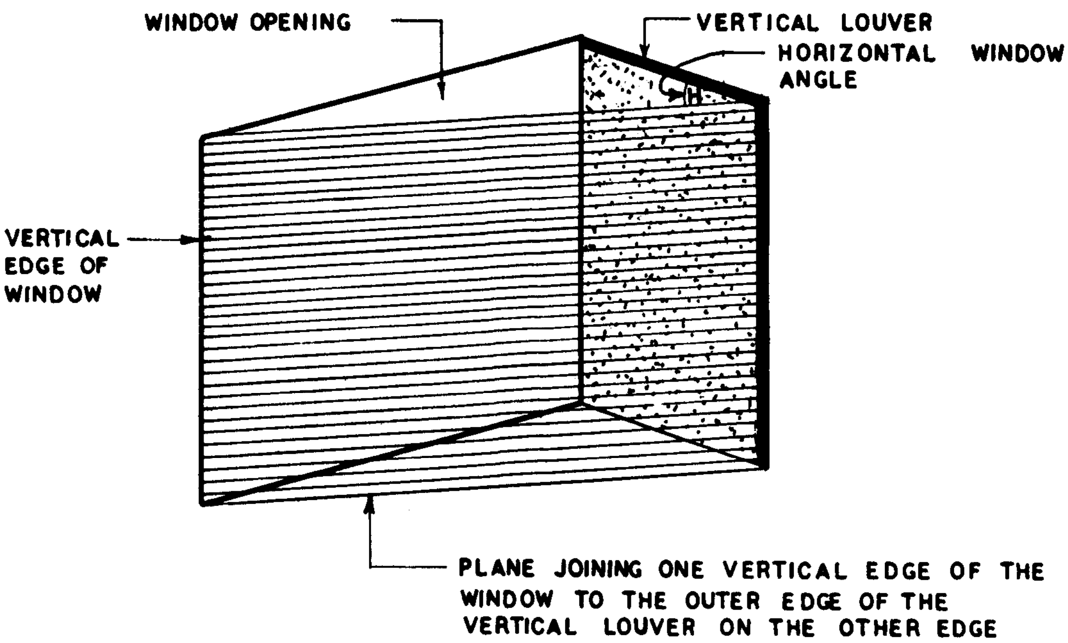


FIG. 8 HORIZONTAL WINDOW ANGLE

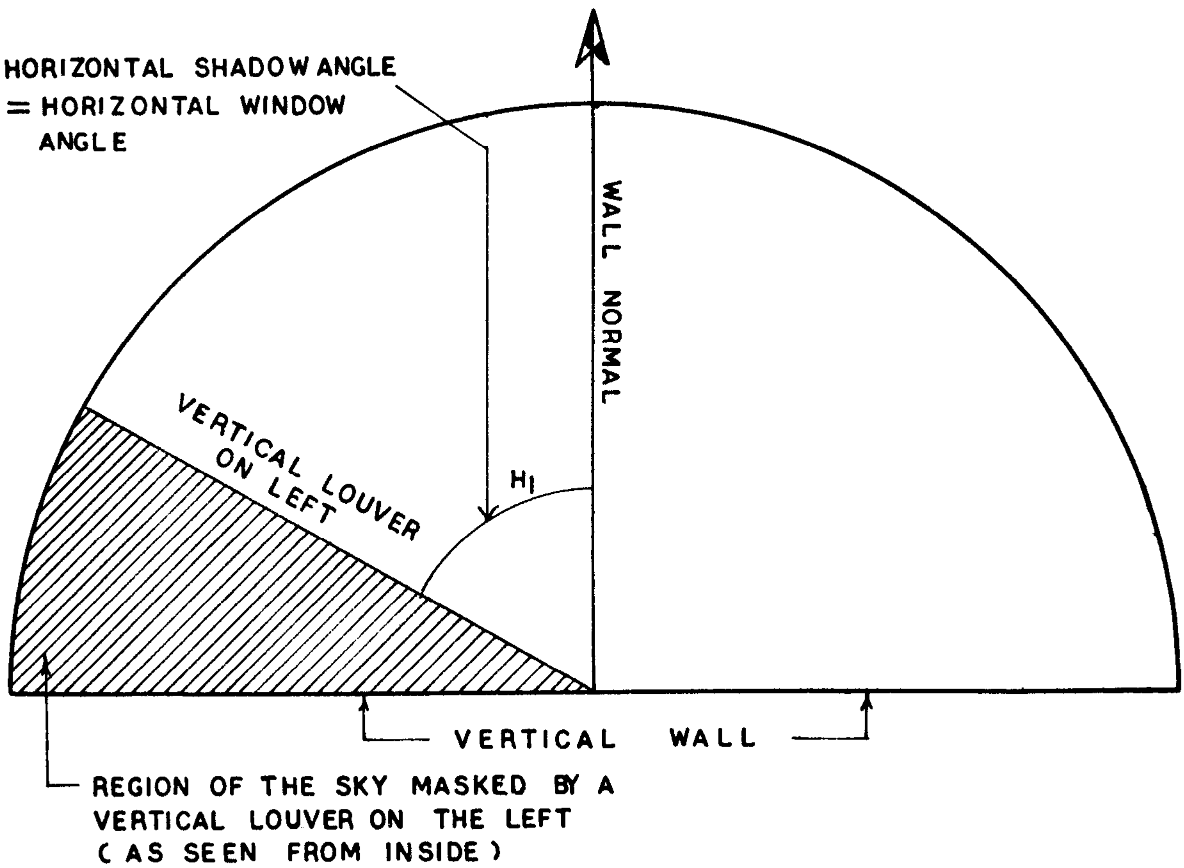


FIG. 9 REGION OF THE SKY MASKED BY A VERTICAL LOUVER ON THE LEFT SIDE

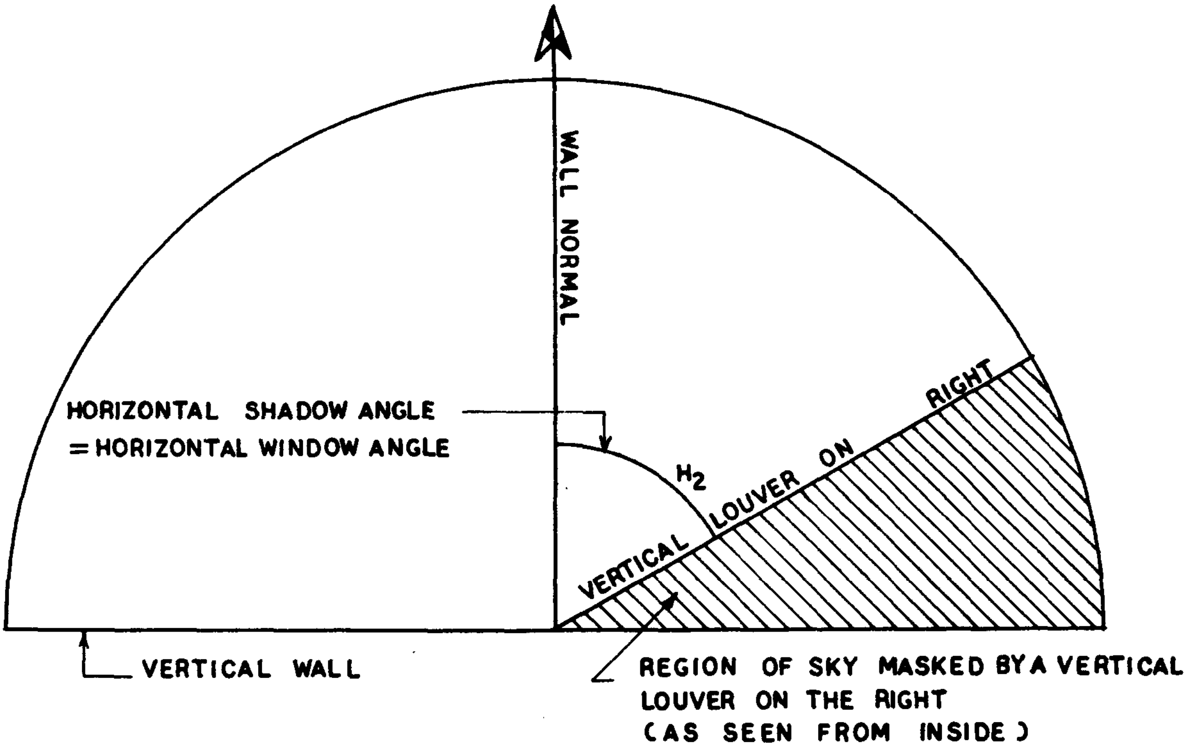


FIG. 10 REGION OF SKY MASKED BY A VERTICAL LOUVER ON THE RIGHT SIDE

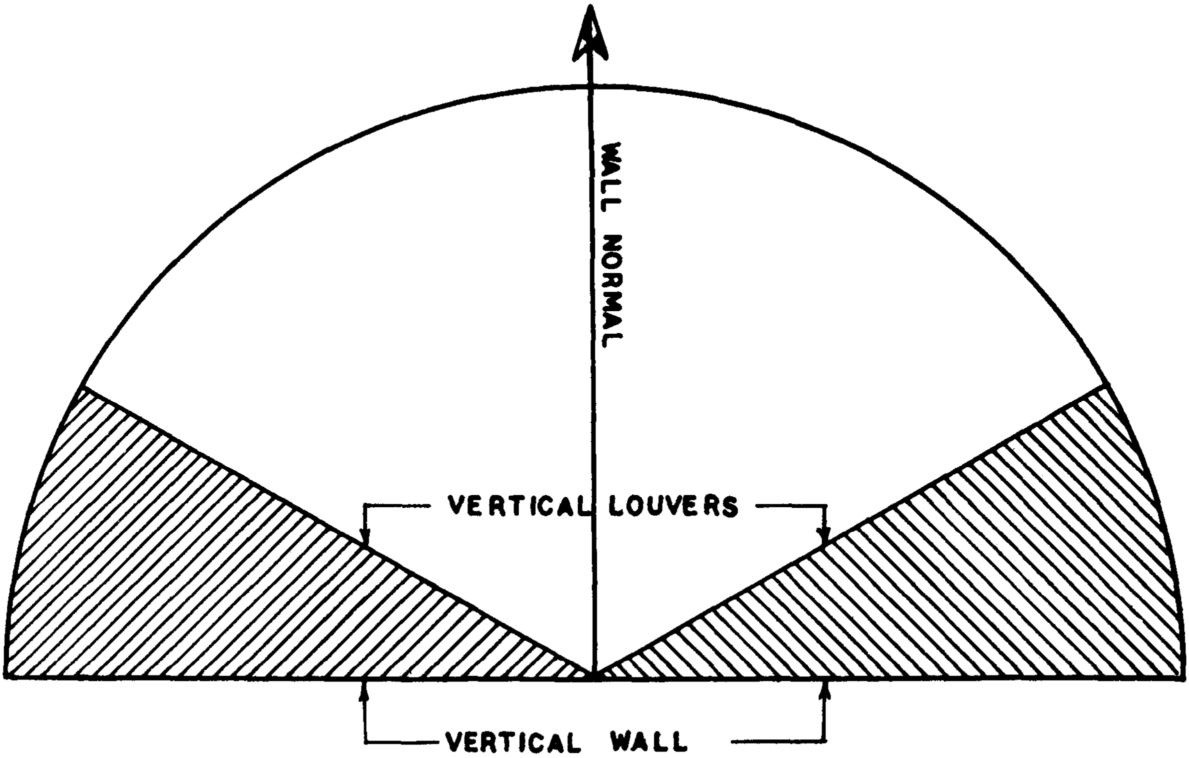


FIG. 11 SHADING MASK DUE TO VERTICAL LOUVERS ON BOTH SIDES

3.2.4 The protractor is placed on the solar chart of the desired latitude, its centre coinciding with that of the solar chart. The base line is oriented in the direction of the wall having the window opening for which the louvers are to be determined. Before this is done, the hot period during the year, when sunlight entry is to be cut-off, should invariably be marked on the solar chart. The endeavour is then to find the vertical or horizontal window angles (or a combination of both) which successfully mask-off the undesirable (hot) region of the solar chart.

3.3 Inclined Louvers — Once the requisite horizontal or vertical window angles are determined, it is simple to determine the size of the louver. The required horizontal window angle *H* is shown in Fig. 12. *AB* is the resulting vertical louver, normal to the wall. *AB* can also be replaced by an inclined louver *AC* without any effect on the masking angle of *AB*. The size of the inclined louver *AC* is less than that of the normal louver *AB*. Inclined louvers are resorted to only for economy of space and material, although they restrict outside view and daylight, and also influence the wind flow pattern indoors. In a situation where the hot period marked on the solar chart happens to be only on one side and can be covered by the mask of a vertical louver as shown in Fig. 10 (the required louver is shown worked out in Fig. 12); there is no need for a vertical louver on the other edge of the window since no undesirable sun is likely to come from the other side. However, if the required shading mask is of the type shown in Fig. 11, vertical louvers will be needed on either side of the window opening. Similarly, with a knowledge of the desired window angle, the size of the horizontal louver on top of the window or an equivalent inclined louver can also be determined.

3.4 Shading Devices—Application

3.4.1 An application of the solar chart and shadow angle protractor has been made in devising shading devices for openings in the eight cardinal and semi-cardinal orientations. The whole country has been divided into two regions, namely, (a) northern, that is, north of latitude 20°N and (b) southern, that is, south of latitutde 20°N. It is found that the same shading device is adequate for a whole region and the difference from one region to the other also is small.

3.4.2 The following three categories of shading devices are generally used in practice:

a) Horizontal type (*H*);

b) Vertical type (*V*); and

c) Egg-crate type (*C*), that is, a combination of types *H* and *V*.

3.4.3 The required dimensions of the desired type for various facades are presented in Tables 9 and 10 for both the regions of the country. Recommendations for the optimum design are also given in the last column of the tables together with their expected performance.

3.4.3.1 *Terms and symbols used in the tables*

a) *P* — It denotes the outward projection of the louver system perpendicular to the wall. All other dimensions are given in terms of *P* only.

b) *B* — It is the angle of inclination of the louver away from the normal to the wall. A value of $B = 0$ signifies a vertical or horizontal louver normal to the wall.

c) *Spacing* — It is the horizontal or vertical distance between the corresponding points of adjacent vertical or horizontal louvers respectively. For the same value of *P*, it always increases with the increase in the angle of inclination of the louver thereby reducing their number.

P, *B* and spacing are shown in Fig. 13.

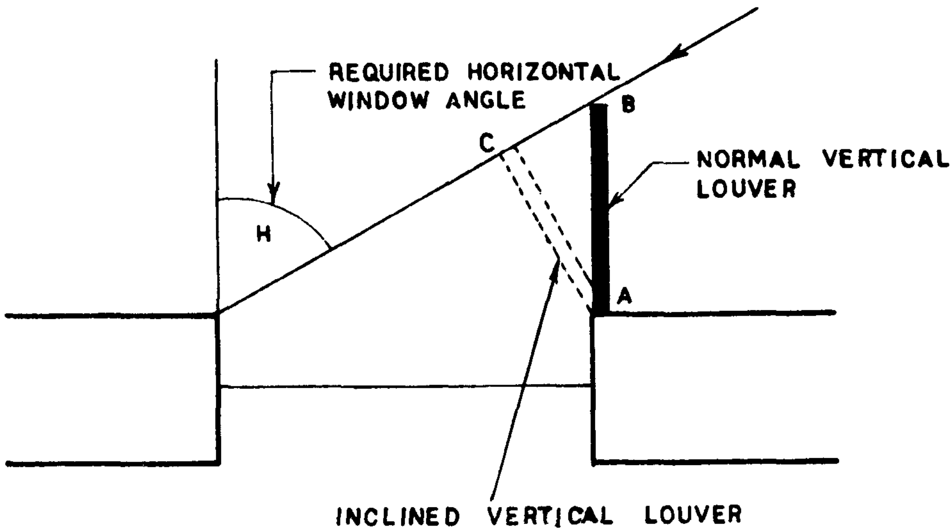
3.4.3.2 *Use of Tables 9 and 10*

a) An external shading device is characterized by (1) outward projection, (2) spacing between individual louvers, and (3) angle of inclination. In Table 9 and 10, the spacings between individual louvers are given in terms of their outward projection for various angles of inclination, the net performance remaining unchanged. Here the designer has to decide the outward projection of the louvers and the other characteristics can then be worked out from the values given in the tables.

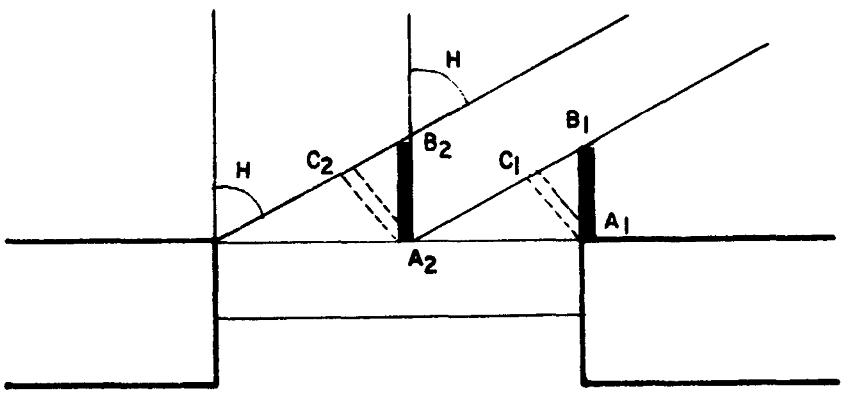
b) The performance of the louvers is such that the summer sun is fully excluded from reaching inside. The winter sun is generally allowed to come in but at times the winter sun is also excluded as a result of some shading devices meant for cutting off summer sun.

3.5 Types of Louvers on Various Facades—Worked-out Examples — Suppose it is desired to shade a window 200 cm wide and 120 cm high in any of the facades on the northern region. Reference to Table 9 should be made and the following procedure adopted to obtain the dimensions of the required shading system.

3.5.1 *North* — Vertical members normal to the wall, capped by a horizontal member of the same width on top are adequate enough. The vertical members can also be extended to similarly placed windows in the upper storeys and capped finally at the top. If it is decided to provide vertical members on either extremity of the window, spacing should be taken equal to the width of the window that is, 200 cm and thus *P* can be worked out.



12A WINDOW PLAN—ONE VERTICAL (NORMAL/INCLINED) LOUVER FOR THE WHOLE WINDOW



12B ALTERNATIVELY, WINDOW SPLIT INTO TWO—LOUVER LENGTHS ALSO GET HALVED—ONE LOUVER FOR EACH HALF

FIG. 12

TABLE 9 SPACING DISTANCES BETWEEN VERTICAL OR HORIZONTAL MEMBERS OF LOUVER SYSTEMS (NORTHERN REGION)

(*Clause* 3.4.3)

Direction	Type of Louver	Spacing Between Vertical or Horizontal Angle of Inclination					Direction of Inclination	Performance	Recommended
		B = 0°	B = 15°	B = 30°	B = 45°	B = 60°			
A North									
Case 1	*V*	3.73 *P*	Inclining	Not desirable			—	Cuts-off after 7 am during June and completely in other months	For air-conditioned buildings.
Case 2	*V*	2.15 *P*	—	do	—		—	Cuts-off completely at all times	do
B South									
Case 1	*H*	1.73 *P*	2 *P*	2.3 *P*	2.73 *P*	2.46 *P*	Downwards	Completely cuts-off summer sun and allows winter sun indoors	Type H (B = 0)
C East/West									
Case 1	*V*	Inclining up to 30°		Not desirable	0.73 *P*	1.46 *P*	Towards north away from normal	Cuts-off both summer and winter sun	
Case 2	*H*	0.27 *P*	0.54 *P*	0.85 *P*	1.27 *P*	2 *P*	Downwards	Cuts-off only after 7 am in summer and winter	Type C
Case 3	*C* Vertical member	Inclining up to 15° not desirable		0.21 *P*	0.64 *P*	1.37 *P*	Away from normal towards south	Completely cuts-off only summer sun but allows winter sun to come partially	Combination of types V(B = 30°) and H(B = 0°)
	Horizontal member	0.84 *P*	1.11 *P*	1.42 *P*	1.84 *P*	2.57 *P*	Downwards	—	—

(*Continued*)

TABLE 9 SPACING DISTANCES BETWEEN VERTICAL OR HORIZONTAL MEMBERS OF LOUVER SYSTEMS (NORTHERN REGION) — *Contd.*

Direction	Type of Louver	Spacing Between Vertical or Horizontal Angle of Inclination					Direction of Inclination	Performance	Recommended
		$B = 0°$	$B = 15°$	$B = 30°$	$B = 45°$	$B = 60°$			
D North-East/ North West									
Case 1	*V*	0.36 *P*	0.63 *P*	0.94 *P*	1.36 *P*	2.1 *P*	Towards north away from normal	Winter sun negligible on this facade and summer sun cut-off completely	Type V($B = 30°$)
Case 2	*H*	0.47 *P*	0.74 *P*	1.05 *P*	1.47 *P*	2.2 *P*	Downwards	Cuts-off only after 7 a m	—
E South-East/ South-West									
Case 1	*C* Vertical member	0.36 *P*	0.63 *P*	0.94 *P*	1.36 *P*	2.1 *P*	Southwards away from normal	Completely cuts-off all summer sun and allows winter morning sun partially	Type C
	Hori-zontal member	0.84 *P*	1.1 *P*	1.42 *P*	1.84 *P*	2.57 *P*	Downwards		Combination of types V($B = 30°$) and H($B = 0°$)

NOTE — In Type C, any combination of the angles of inclination of the vertical and horizontal members can be made.

TABLE 10 SPACING DISTANCES BETWEEN VERTICAL OR HORIZONTAL MEMBERS OF LOUVER SYSTEMS (SOUTHERN REGION)

(*Clause* 3.4.3)

Direction	Type of Louver	Spacing Between Vertical or Horizontal Angle of Inclination					Direction of Inclination	Performance	Recommended
		$B = 0°$	$B = 15°$	$B = 30°$	$B = 45°$	$B = 60°$			
A North									
Case 1	*V*	2.75 *P*	Inclining		not desirable		—	Cuts-off sun after 7 am during June and completely in other months	For non-air-conditioned buildings
Case 2	*V*	2.15 *P*	—	—	—	—	—	Cuts-off completely at all times	For air-conditioned buildings
B South									
Case 1	*H*	2.75 *P*	3*P*	3.33 *P*	3.75 *P*	4.5 *P*	Downwards	Cuts-off all summer sun after 15 March to 30 September	Type H(B = 0)
C East/West									
Case 1	*V*		Inclining up to 30° not desirable		0.53 *P*	1.27 *P*	Inclined towards north way from the normal	Cuts-off both summer and winter sun	—
Case 2	*H*	0.27 *P*	0.54 *P*	0.85 *P*	1.27 *P*	2 *P*	Downwards	Cuts-off only after 7 am in summer and winter	Type C
Case 3	*C* Vertical member	Inclining up to 15° not desirable		0.31 *P*	0.73 *P*	1.46 *P*	Inclined towards south away from normal	Completely cuts-off only summer sun but allows winter sun to come partially	Combination of types V(B = 30°) and H(B = 0°)

(*Continued*)

TABLE 10 SPACING DISTANCES BETWEEN VERTICAL OR HORIZONTAL MEMBERS OF LOUVER SYSTEMS (SOUTHERN REGION) — *Contd.*

Direction	Type of Louver	Spacing Between Vertical or Horizontal Angle of Inclination					Direction of Inclination	Performance	Recommended
		$B = 0°$	$B = 15°$	$B = 30°$	$B = 45°$	$B = 60°$			
	Hori-zontal member	0.84 *P*	1.11 *P*	1.42 *P*	1.84 *P*	2.57 *P*	Downwards		
D North-East/ North-West									
Case 1	*V*	0.36 *P*	0.63 *P*	0.94 *P*	1.36 *P*	2.1 *P*	Inclined towards north away from normal	Winter sun negligible on this facade and summer sun is completely cut-off	Type V($B = 30°$)
Case 2	*H*	0.36 *P*	0.63 *P*	0.94 *P*	1.36*P*	2.1 *P*	Downwards	Cuts-off only after 7 am	—
E South-East/ South-West									
Case 1	C Vertical member	0.58 *P*	0.85 *P*	1.15 *P*	1.58 *P*	2.31 *P*	Southwards away from normal	Completely cuts-off all summer sun and allows winter morning sun partially	Type C
	Hori-zontal member	*P*	1.27*P*	1.58 *P*	2 *P*	3.73 *P*	Downwards		Combination of types V(B = 30°) and H($B = 0°$)

NOTE — In Type C above, any combination of the angles of inclination of vertical and horizontal members can be made.

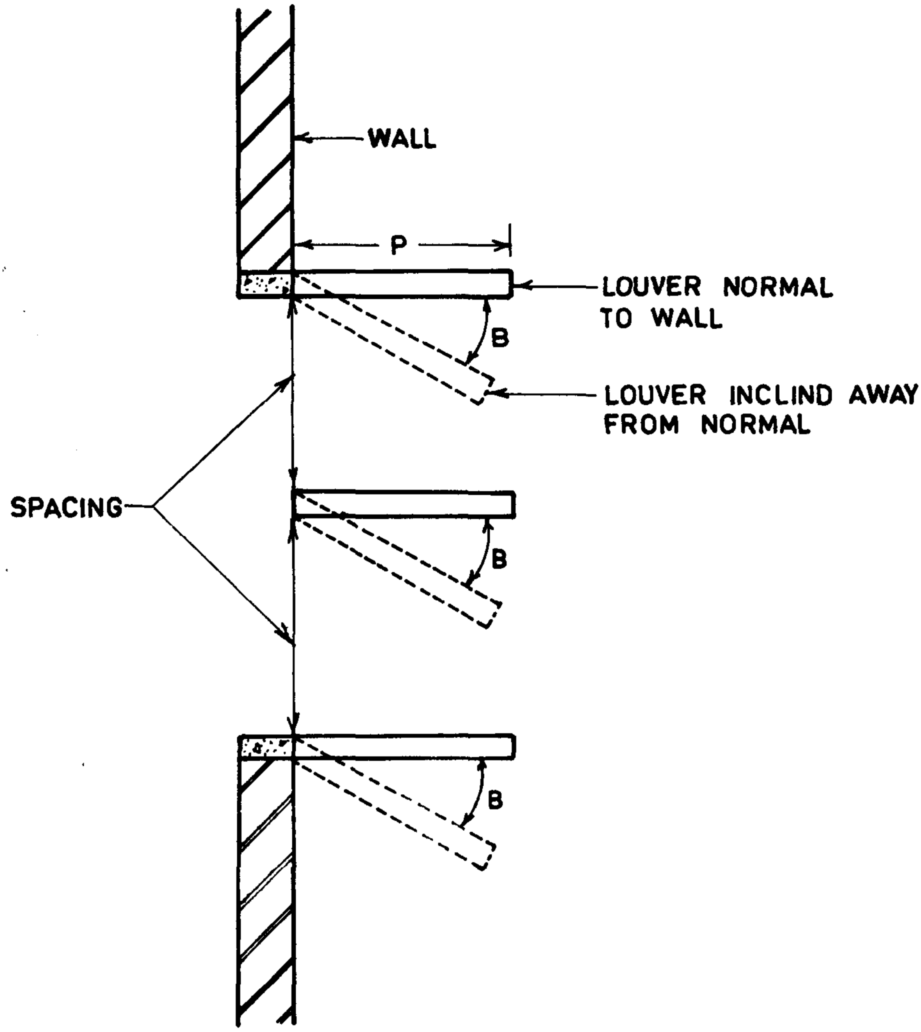


FIG. 13 TYPICAL PLAN OF LOUVER SHOWING THE OUTWARD PROJECTION AND ITS INCLINATION

Suppose it is desired to cut-off the sun completely (for example, in an air-conditioned building) and also to provide vertical members at the two extremities:

From Table 9, item A, Spacing = 2.15 P

Hence 200 = 2.15 P and, therefore,

$$P = \frac{200}{2.15} = 93 \text{ cm.}$$

Alternatively, if this value of P is considered too large, an extra vertical member may be provided at the centre of the window too. Then the spacing = 100 cm and P = 46.5 cm.

3.5.2 *South* — The horizontal member suggested here for a south facade ought to be extended much beyond the window, possibly to other windows at the same level, to avoid sunlight coming partly from the corners. However, instead of extending the horizontal members to any distance beyond the window on either side, two vertical members may be provided at the two extremities. The vertical members can be either rectangular or triangular. The horizontal members can also be inclined downward. If it is desired to provide only one horizontal member at the top, the spacing should be taken as the height of the window and P can then be worked out.

Suppose it is desired to provide only one horizontal member at the top, the spacing becomes equal to 120 cm. From Table 1, the spacing for a horizontal member with $B = 0$ is given as 1.73 P.

Therefore, 1.73 P = 120 cm

$$\text{and } P = \frac{120}{1.73} = 69.4 \text{ cm}$$

3.5.3 *East/West* — In these facades, any of the three types mentioned above can be used. The performance of each is given in the respective columns of the tables. The recommended one is a combination of horizontal and vertical louvers, wherein the horizontal member should have $B = 0$ and the vertical one $B = 30°$, inclined towards the south away from the normal to the wall. This has the advantage of letting in the winter sun during early mornings on the east facade and late evening on the west facade, and also of completely cutting-off the summer sun from morning to evening.

Suppose it is desired to provide an egg-crate type of louver, where the horizontal member has $B = 0$ and the vertical one has $B = 30°$. From Table 9, the spacing for the horizontal members is 0.84 P.

Let us first try only with one horizontal member at the top so that the spacing is equal to the height of the window.

Thus spacing = 0.84 P = 120 cm

$$\text{or } P = \frac{120}{0.84} = 143 \text{ cm},$$

which appears too large an outward projection.

Alternatively, we think of providing two horizontal members. One on top and the other at the middle and hence the spacing = 60 cm and thus P = 71.5 cm. So we now know the likely outward projection of the louver system.

Now for the vertical members, the required spacing is 0.21 P and knowing P to be 71.5 cm, the spacing of the vertical members = 0.21 × 71.5 = 15 cm. In order to determine the number of vertical members needed to cover the 200 cm width of the window when the spacing works out to be small, the likely thickness of the louvers should also be added to the spacing. If then the thickness of each vertical member is say 5 cm, the total separation between corresponding edges of the louvers is 15 + 5 = 20 cm and so the number of spaces needed between vertical louvers is 200/20 = 10, and actually 11 louvers would be needed. But as mentioned earlier, the extreme louver on the southern extremity is not necessary and only 10 vertical louvers inclined by 30° towards the south would be adequate.

3.5.4 *North-East/North-West* — For these facades, either vertical or horizontal type can be used. The vertical members capped by a horizontal member of the same width will cut-off all summer and winter sun completely whereas the horizontal type of louvers will cut-off direct sun only after 7 am throughout the year. Inclining the vertical louvers northwards will reduce the dimensions. The recommended angle of inclination is 30°.

Suppose it is desired to provide vertical members inclined by 30° towards north. Also suppose it is decided to provide only 60 cm of outward projection. From item D of Table 9, it is seen that spacing = 0.94 P.

Hence spacing = 0.94 × 60 = 56 cm.

Considering the thickness of the louver equal to 5 cm, the total distance required for each spacing is 56 + 5 = 61 cm and the number of spaces needed = 200/61 = 3.3. But since this is not a whole number, some changes in the dimensions are needed.

Suppose now it is desired to find the outward projection of the louvers for four spacing. This gives a spacing width of 50 cm between the adjacent members. Reckoning 5 cm as the thickness of louver, the clear spacing distance associated with each member is 45 cm. Therefore spacing = 45 cm = 0.94 P.

$$\text{or } P = \frac{45}{0.94} = 48 \text{ cm nearly.}$$

In a similar way, the outward projection for only three spacings can also be worked out.

Alternatively, if it is decided to provide horizontal type of louvers, projecting by say 60 cm beyond the wall, the spacing from item D of Table 9 for $B = 0°$ is 0.47 P. Hence spacing = 0.47 × 60 = 28 cm and the total distance between the corresponding edges of adjacent louvers is equal to spacing + thickness of louver = 28 + 5 = 33 cm.

The required number of spacings is 120/33, 120 cm being the height of the window. This gives a value slightly less than four. In order to have exact four spacings, the outward projection can be slightly modified. Each spacing will be 120/4 = 30 cm and since 5 cm is the thickness of the louver, the clear spacing distance = 25 cm, which gives:

$$0.47\ P = 25 \text{ cm}$$

$$\text{or } P = \frac{25}{0.47} = 53 \text{ cm nearly.}$$

Therefore, for four spacings, the outward projection should be 53 cm.

3.5.5 *South-East/South-West* — For these facades, only egg-crate type of louvers can be adequate without being unwieldy. A vertical member with any given angle of inclination can be combined with a horizontal member of any given inclination from the tables. The recommended louver system comprises a vertical member with $B = 30°$, inclined towards the south and a horizontal member with $B = 0°$. It has the advantage of intercepting all summer sun and permitting winter sun up to around mid-day on the south-east, and late afternoons on the south-west facades.

Suppose it is decided to employ the recommended Type C system of louvers, where the vertical members are inclined by 30° towards south away from the normal to the wall and horizontal members have $B = 0°$. Also suppose the intended outward projection, P, is around 70 cm.

For the horizontal members from item E of Table 9, the spacing is given as 0.84 P. Therefore, spacing = 0.84 × 70 = 59 cm nearly. As the height of the window is 120 cm, two horizontal members, one at the top and one at the middle are necessary.

For the vertical members ($B = 30°$), the spacing shown is 0.94 P = 0.94 × 70 = 66 cm nearly. For a total width of 200 cm, roughly 3 spacings are indicated and so 4 vertical members are necessary. The last vertical member on the southern extremity of the window is not needed as discussed earlier. Therefore, only 3 vertical members will suffice.

3.5.6 *Concluding Remarks* — The decision for choosing the type and size of the shading device is left entirely to the designer. A little familiarity with the use of Tables 9 and 10 can easily enable the designer to evolve a foolproof shading system for any orientation of the building anywhere in the country.

4. ENERGY REQUIREMENT FOR COOLING AND HEATING

4.1 Introduction — In multi-storey buildings, a substantial amount of energy is consumed for heating and cooling. The amount of energy required will depend upon a number of factors as follows:

a) Limits of comfortable conditions,

b) Cooling and heating load to maintain comfortable temperature, and

c) Type of the system employed for cooling and heating.

4.2 The Limit of Thermal Comfort — It depends upon combination of dry bulb temperature, relative humidity and air velocity. From the survey in this regard, it has been observed that the TSI values for summer comfort ranges between 26.5 and 29.5°C. This corresponds to a dry bulb temperature range of 27 and 30° with different air velocity from 0.5 to 2 m/s. The limits of dry bulb temperature can be very well increased from 25 to 30°C with increased air motion. For summer comfort condition, precise control of indoor temperature is not necessary. Therefore, comfort level can be increased from 25 to 28°C without decreasing the efficiency of personnel. This will certainly reduce energy consumption of cooling appliances. It has also been observed that increasing air motion from 0.5 to 1.5 m/s gives same comfort condition as created by decreasing the air temperature by 3°C. From the point of view of energy conservation, this factor has considerable bearing on the selection of proper cooling devices. During winter, comfortable TSI values range from 21 to 18°C corresponding to dry bulb temperatures of 22 to 18°C. Here also the comfortable temperature limits can be lowered by a certain extent.

4.3 Cooling and Heating Load

4.3.1 The cooling and heating equipments installed must be able to remove heat from or supply heat to the source where it is generated. The equipment must have adequate capacity to maintain the optimum comfort condition inside the room. The capacity of the plant, if designed for the peak load, would require higher capital cost and consume more energy. If, on the other hand, plant capacity is designed for average load, it may fail to meet the load during peak season. Even in such situations, short duration discomfort of reasonable degree may be allowed to save energy consumption. However, there should not be long periods of discomfort. Hence the capacity must be estimated at a value which accounts both for reasonable comfort and minumum energy consumption.

4.3.2 The heat gain of a building falls under the following categories:

a) *Sensible heat gain* — It causes a change in the temperature of air and is due to the heat flow through building fabrics, such as roofs, windows, walls and doors.

b) Heat generated by the occupants, lights, fans and other electrical appliances.

c) Heat received through the ingress of fresh air.

d) Other heat sources which give both sensible and latent heat load.

4.3.3 Cooling Loads — Variation of cooling load of multistoreyed building rooms of a given floor area, with room height as 3 m, with building design variables like percentage of glass area, shading, roof insulation, orientation and for top and intermediate floors have been worked out, both at a comfortable temperature of 25 ± 1°C and 27.5 ± 1°C by CBRI, Roorkee and it has been observed that a good amount of energy could be saved by *raising* the limits of comfortable temperature. It has also been observed that the temperatures swing beyond the comfortable limits only for one or two hours even in worst situations when the unshaded glass window area is 45 percent oriented towards west. If the cooling equipment is selected to meet the cooling load chosen as above, the equipment will be sufficient to provide comfortables temperatures at a *reduced energy consumption.*

4.3.4 *Heating Loads*

4.3.4.1 In winter radiant heaters, convectors and air-conditioners are used to increase the dry bulb temperature up to the range of comfort. Radiant heaters only provide spot heating. The size and number of such devices are not based on any scientific study and as such a large amount of energy is wasted.

4.3.4.2 In general, during winter months of December and January in the northern zone of the country from 10 to 17 h, the indoor air temperature of rooms range from 12 to 13°C. In many cases, with proper utilization of sun shine through adequate window areas and with very little or no shading of the windows, it may be possible to obtain the requisite energy for providing the minimum winter comforts. In view of this, the heating loads for different building design variables have also been worked out by CBRI, Roorkee and it has been observed that the minimum temperature for winter comfort may be reduced from 21 to 18°C. With this aim, heating load has been calculated per unit floor area of rooms both at the temperature of 21 and 18°C. The difference between two corresponding readings *directly* provide the *possible energy saving*.

4.4 Systems Employed for Cooling and Heating

4.4.1 The different systems for mechanical controls which are employed for cooling and heating are:

a) unit air-conditioners,

b) package air-conditioners,

c) evaporative coolers, and

d) radiant heater and heat convector units.

4.4.1.1 *Unit air-conditioners* — These are self-contained factory made units. The unit is generally mounted on a window or wall bracket of the room to be cooled. The capacity of these units varies from 3 000 kcal/h to 4 600 kcal/h. Thermostats are fitted with these units to control the temperature of the room. Working temperature of these thermostats should be adjusted at 28°C.

The thermostats should also be maintained in proper working condition. From the point of view of energy conservation measures, it is advisable to select the units based on higher comfortable temperature, that is, 27.5 ± 1°C. Furthermore, even if a slightly lower capacity unit is chosen for intermediate floors and partially shaded windows, it is found from calculations that it will not materially upset the comfort conditions indoors.

4.4.1.2 *Package air-conditioners* — These are also factory assembled units and are available in sizes ranging in capacity from 5 to 15 tons. Cool air from these units are usually supplied through duct system and circulated to different rooms. It is advisable to use these units when the total load is more than 5 tons as otherwise power consumption per ton of refrigeration will be slightly less as compared to unit air-conditioners. The rooms thermostats should be adjusted to the working temperature of 27.5 ± 1°C in these cases as well.

4.4.1.3 *Evaporative cooling* — Evaporative cooling of air is the cheapest method of cooling residential, office and other buildings. In India, evaporative coolers manufactured are of two types—one of these types are for placement inside the room while the other type is for installation in the window. These coolers employ either blower or exhaust fans. The blower type of coolers consume more power and are less effective as compared to those of exhaust fan type. Both the types of coolers are usually fitted with a pump to lift water from the tank to the cooling pads. Based on certain experimental studies conducted at CBRI, various design parameters have been optimized. The specification and design data for exhaust fan type evaporative coolers are given in Tables 11 and 12. The power consumption in evaporative coolers is significantly less as compared to unit air-conditioners. The

TABLE 11 SPECIFICATION OF EXHAUST FANS

(*Clause* 4.4.1.3)

Sl No.	Diameter	Revoluation Per Minute	Power Consumption	Noise Level	Air Volume	Suitable Application
(1)	(2) (mm)	(3)	(4) (Watts)	(5) (dB)	(6) (m^3/h)	(7)
i)	300	1 400	90	56	1 900	Suitable for houses and small rooms
ii)	400	900	90	52	2 460	
iii)	400	1 400	160	62	4 000	Office and residential building
iv)	450	900	145	56	4 340	
v)	450	1 400	370	66	6 800	Factories
vi)	600	700	240	57	7 900	Cinema halls, laboratories, etc
vii)	600	940	500	63	10 450	Factories

TABLE 12 DESIGN DATA FOR EVAPORATIVE COOLERS

(*Clause* 4.4.1.3)

Sl. No.	Fan Diameter	Pad Area	Water Tank Capacity	Cooling Capacity	Volume of The Room Cooled
(1)	(2) (mm)	(3) (m^2)	(4) (litres)	(5) (tons)	(6) (m^3)
i)	300	1.3	40	1.00	30 to 50
ii)	400	1.5	60	1.2	40 to 60
iii)	400	1.9	80	2.0	80 to 120
iv)	450	2.1	90	2.2	80 to 140
v)	450	4.0	140	3.0	100 to 180
vi)	600	4.8	180	3.2	120 to 200
vii)	600	5.5	200	3.6	150 to 250

performance of these coolers has been compared with the unit air-conditioners and it has been observed that. for same capacity of air-conditioner, the average power consumption in these coolers is found to be 4 to 5 times lower. Thus in this area there exists considerable scope for saving in consumption of electric power. As many unit air-conditioners as found feasible may be replaced by evaporative type of coolers.

4.4.1.4 *Radiant heater and heat convector* – Radiant heaters are normally used in office buildings for spot heating. These are available in capacity ranging from 750 to 2 000 watts. No scientific data are yet available on the performance and coverage area of these heaters. As such it is not possible to specify the floor area covered by a given size of heater. Normally the number of heaters used are far in excess of those considered necessary for maintaining comfortable winter temperature. To a certain extent, the minimum number and size of heaters can be decided from the heating load requirement. This will provide considerable scope for reducing the number of heaters for the given floor area and result in saving of considerable amount of energy. Convective type of heaters are more efficient as compared to radiative heaters, as in the former most of the heating is utilized for heating the room air, rather than being absorbed by building fabrics and furniture.

APPENDIX A

(*Clauses* 1.3.1, 1.3.2 *and* 1.3.4)

SOME REPRESENTATIVE TOWNS UNDER HOT AND ARID, HOT AND HUMID, WARM AND HUMID, AND COLD ZONES

Hot and Arid Zone	*Hot and Humid Zone*	*Warm and Humid Zone*	*Cold Zone*
Agra	Ahmadabad	Cochin	Darjeeling
Ajmer	Asansol	Dwarka	Dras
Akola	Bhavanagar	Guwahati	Gulmarg
Aligarh	Bhuj	Puri	Leh
Allahabad	Bombay	Sibsagar	Mussoorie
Ambala	Calcutta	Silchar	Nainital
Bareilly	Calicut	Tezpur	Ootacamund
Bikaner	Cuttack	Trivandrum	Shillong
Gaya	Dohad	Veraval	Shimla
Jabalpur	Jamnagar		Skardu
Jaipur	Jamshedpur		Srinagar
Kanpur	Madras		
Khandwa	Madurai		
Kota	Mangalore		
Lucknow	Masulipatam		
Ludhiana	Midnapur		
Nagpur	Nellore		
Neemuch	Patna		
New Delhi	Rajkot		
Roorkee	Ratnagiri		
Sambalpur	Salem		
Sholapur	Surat		
Umaria	Tiruchichirapalli		
Varanasi	Vellore		
	Vishakhapatnam		

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PART 2 HEAT INSULATION

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PART 2 HEAT INSULATION

1. INTRODUCTION

1.1 This part of the Handbook is intended to cover heat insulation of buildings, such as dwellings, hospitals, schools and office buildings both for non-air-conditioned and air-conditioned buildings wherein mechanical cooling or heating aids such as air-conditioning plants are used.

In preparing this Part, considerable assistance has been derived from IS : 3792-1978 'Guide for heat insulation of non-industrial buildings (*first revision*)', IS : 7662 (Part 1)-1974 'Recommendations for orientation of buildings : Part 1 Non-industrial buildings', and 'National Building Code of India 1983 : Part VIII Building services, Section 3 Air-conditioning and heating'.

2. TERMINOLOGY

2.1 Absorptivity (*a*) — It is a factor indicating the relative amount of radiation absorbed by a surface as compared to an absorbing black body under the same conditions. Its value is dependent upon the temperature of the source as also that of receiving surface.

2.2 Emissivity (*e*) — It is the ratio of the heat emitted by a surface as compared to that of an absolutely black surface under similar conditions. It varies with the temperature of the emitting surfaces.

2.3 Reflectivity (*r*) — It is the ratio of the reflected heat to that of the total heat incident on a surface at a certain mean temperature range.

2.4 Shade Factor (*S*) — It is defined as

$$S = \frac{\text{Instantaneous heat gain through the shading device}}{\text{Instantaneous heat gain through 3.0 mm plain glass sheet}}$$

Shade factor is expressed in percent.

It takes into account the heat gain through glazing, both by direct transmission and air-to-air transfer.

2.5 Surface Coefficient (*f*) — It is the quantity of heat transmitted by convection, conduction and radiation from unit area of the surface when unit difference of temperature is maintained between the surface and the surrounding medium. Its value depends upon many factors, such as orientation or position of the surface, emissivity of the surface, temperature difference and air velocity. It is expressed in W/(m²K).

2.6 Surface Resistance (1/*f*) — It is the reciprocal of surface coefficient. It is expressed in m²K/W.

2.7 Thermal Conductance (*C*) — Thermal conductance per unit area is the thermal transmission of a single layer structure per unit area divided by the temperature difference between the hot and cold faces. It is expressed in W/(m²K).

Thermal conductance is a measure of the thermal transmission per unit area through the total thickness of the structure under consideration. Thermal conductivity on the other hand refers to unit thickness of a material. Further, this term applies only to a single layer of material and not to a composite insulation or to a structure made up of several layers of materials.

2.8 Thermal Capacity (q_{st}) — It is the amount of heat that will be absorbed by the material before the 'steady state' condition is reached. It is the product of the mass of the material and specific heat.

$$q_{st} = m.c$$

where m and c are the mass and specific heat of the material.

2.9 Thermal Conductivity (*K*) — This is the quantity of heat in the 'steady state' conditions flowing the unit time through a unit area of a slab of uniform material of infinite extent and of unit thickness, when unit difference of temperature is established between its faces. Its unit is W/(mK).

The thermal conductivity is a characteristic property of a material and its value may vary with a number of factors including density, porosity, moisture content, fibre diameter, pore size, type of gas in the material, mean temperature and outside temperature range.

2.10 Thermal Damping (*D*) — It is given as :

$$D = \frac{(T_o - T_i)}{T_o} \times 100$$

where

T_o = outside temperature range, and
T_i = inside temperature range.

It is expressed in percent.

Thermal damping or decreased temperature variation is a characteristic dependent on the thermal resistance of the materials used in the structure.

2.11 Thermal Performance Index (*TPI*) — Thermal performance index of a non-air-conditioned building element is given by :

$$\text{TPI} = \frac{(T_{is} - 30) \times 100}{8}$$

where

T_{is} = peak inside surface temperature.

It is expressed in percent.

A temperature of 8°C has been considered over a base temperature of 30°C. It depends upon the total heat gain through the building section both by steady and periodic part, and is a function of outside surface temperature.

2.12 Thermal Resistance (*R*) — It is reciprocal of thermal conductance. For a structure having plane parallel faces, thermal resistance is equal to thickness (L) divided by thermal conductivity (K) as given below :

$$R = \frac{L}{K}$$

The unit of thermal resistance is $\frac{(\text{m}^2\text{K})}{\text{W}}$

The usefulness of this quantity is that when heat passes in succession through two or more components of the building unit, the resistance may be added together to get the total resistance of the structure.

2.13 Thermal Resistivity (1/*K*) — It is the reciprocal of thermal conductivity. It is expressed in (mK)/W.

2.14 Thermal Time Constant (*T*) — It is the ratio of heat stored (Q) to thermal transmittance (U) of the structure. It is expressed in hour (h).

a) For homogeneous wall of roof, thermal time constant may ·e calculated from the following formula :

$$T = \frac{Q}{U} = \left(\frac{1}{f_o} + \frac{1}{2\text{K}}\right) \text{L}\rho c$$

where

Q = quantity of heat stored,
U = thermal transmittance,
f_o = surface coefficient of the outside surface,
K = thermal conductivity of the material,
L = thickness of the component,
ρ = density of the material, and
c = specific heat of the material.

b) For composite wall or roof, T may be obtained from the formula :

$$T = \Sigma \frac{Q}{U} = \left(\frac{1}{f_o} + \frac{L_1}{2K_1}\right)(L_1 \rho_1 c_1)$$

$$+ \left(\frac{1}{f_o} + \frac{L_1}{K_1} + \frac{L_2}{2\text{K}_2}\right)(L_2 \rho_2 c_2)$$

$$+ \left(\frac{1}{f_o} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{2K_3}\right)(L_3 \rho_3 c_3)$$

2.15 Thermal Transmission or Rate of Heat Flow (*q*) — It is the quantity of heat flowing in unit time under the conditions prevailing at that time. The unit of q is taken as W.

2.16 Thermal Transmittance (*U*) — It is the thermal transmission through unit area of the given building unit divided by the temperature difference between the air or other fluid on either side of the building unit in 'steady state' conditions. It is receiprocal of total thermal resistance. Its unit is W/(m^{2}K).

Thermal transmittance differs from 'Thermal conductance' in so far as temperatures are measured on the two surfaces of material or structure in the latter case and in the surrounding air or other fluid in the former. The conductance is a characteristic of the structure whereas the transmittance depends on conductance and surface coefficients of the structure under the conditions of use.

2.17 Time Lag — It is the time difference between the occurrences of the temperature maximum at the outside and inside when subjected to periodic conditions of heat flow. It is expressed in hour (h).

2.18 Total Thermal Resistance (*R*$_T$) — It is the sum of the surface resistance and the thermal resistance of the building unit itself.

3. REQUIREMENTS

3.1 Indoor thermal conditions up to a certain extent can be improved by judicious selection of building components, optimum orientation of building layout and proper selection of shading devices. The main problems requiring solutions in the design of thermal comfort are concerned with minimizing solar heat gain and reducing wall and roof surface temperatures. Certain minimum thermal performance requirements for building components in three principal climatic zones (hot dry, hot humid and warm humid) of the country has been recommended in IS : 3792-1978. These requirements are given in Table 1. These are the maximum prescribed values and should not be exceeded. Representative towns under different climatic zones are given in **7.5**.

3.2 Heat insulation is usually not needed for buildings situated in places not covered under any of the zones mentioned in Part 1 of the Handbook.

NOTE 1 — Representative towns under this category are Indore, Bangalore, Belgaum, Mysore, Pune, Ranchi and Sagar.

TABLE 1 THERMAL PERFORMANCE STANDARDS

(*Clause* 3.1)

SL No.	BUILDING COMPONENTS	HOT DRY AND HOT HUMID ZONES				WARM HUMID ZONE			
		U, Max	TPI, *Max*	*T, Min*	*D, Min*	*U, Max*	TPI, *Max*	*T, Min*	*D, Min*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		$W/(m^2K)$		h		$W/(m^2K)$		h	
i)	Roof	2.33	100	20	75	2.33	125	20	75
ii)	Exposed wall	2.56	125	16	60	2.91	175	16	60

NOTE 2 — Marginal cases may be dealt with by users themselves in the light of the principles enumerated in this Handbook.

4. HEAT TRANSMISSION THROUGH BUILDING SECTIONS

4.0 Basically there are three aspects which require careful attention in the thermal design of buildings. Firstly, an evaluation must be made of indoor thermal condition most conducive to comfort, health and safety of the occupants. Secondly, it is necessary to describe optimum outside climatic data that must be taken into account when developing the best design to suit specific procedures. Thirdly physical properties of structural materials which can be effectively utilized to ensure the best possible control of living and working environments.

The main factors determining the thermal response of a building are the heat gains or losses through various structural elements, that is, walls, windows, roof and floor, the internal heat loads, and rate of ventilation. The structural heat gains or losses are dependent on certain properties of the elements concerned, for instance heat gain through walls depend upon the colour of the outside surface, the heat storing capacity of the walls and their thermal resistance or insulation property.

4.1 Principles of Heat Transmission

4.1.1 The two basic forms in which heat may appear are sensible and latent heat. The first is associated with a change in temperature of the substance involved. Addition or removal of the sensible heat is, therefore, always accompanied by a change in temperature. Latent heat is the term used to express the thermal energy involved in a change of state without changing temperature. For example, in conversion of ice to water, latent heat is absorbed.

4.1.2 *Models of Heat Transfer Through Solids and Fluids* — The process of heating or cooling imply basically a transfer of thermal energy from one region to another. This transfer of heat from hotter to cooler parts of building due to existence of temperature difference can take place in three ways—by conduction, convection and radiation.

a) *Conduction* — Thermal conduction is the property of heat transfer from the elements of the body at higher temperature to those at lower temperature. All substances which are solid, liquid or gases conduct heat. Some of them conduct more rapidly than others, depending upon the thermal conducting power or thermal conductivity of the substance. The basic equation of heat conduction is :

$$Q = \frac{KA\ (T_h - T_c)}{L}$$

where

K = thermal conductivity of the material in W/mK.
A = area in m^2
L = thickness in m,
T_h = temperature of the hot surface in K,
T_c = temperature of the cold surface in K, and
Q = quantity of heat flow in W.

b) *Convection* — The term thermal convection is used to describe the mechanism whereby heat energy is transferred by mixing one portion of a fluid, that is, gas or liquid with another. Heat transfer by convection takes place at the surface of walls, floor and roofs. The rate of heat transfer by convection can be expressed by the equation as :

$$Q_c = f\ A\ (T_s - T_f)$$

where

Q_c = the quantity of heat flow in W,
f = coefficient of heat transfer in W/m^2K,
A = area in m^2, and
$T_s - T_f$ = temperature difference between the surface and the fluid in K.

The surface coefficient of heat transfer is a variable factor and its numerical value largely depends on the nature of flow velocity of the fluid, physical properties of the fluid and the surface orientation.

c) *Radiation* — Radiation heat transfer is the exchange of heat energy between two or more building surfaces at different temperatures and separated by space. In this mode of heat transfer, the space or medium through which heat waves pass is not heated to any significant extent. An example of this type of heat transfer is the radiation received by the earth from the sun. The intensity of radiation emitted by a body depends upon the nature and temperature of the body. The equation of radiation following Stefan-Boltzman's law is :

$$Q_4 = \sigma A T^4$$

where

Q_r = quantity of heat radiated from surface area A in W,

σ = Stefan-Boltzman radiation constant in W/m^2K,

A = area of the emitting body in m^2, and

T = absolute temperature in K.

Where two or more bodies at different temperatures exchange heat by radiation, heat will be emitted, absorbed and reflected by each body. The net radiation exchange between two surfaces at different temperatures is given by the equation.

$$Q_{rm} = F_c F_e A(T_1^4 - T_2^4)$$

where

Q_{rm} = net heat radiated in W,

F_c = configuration factor,

F_e = emissivity factor, and

T_1 and T_2 = the temperatures of the two surfaces in K.

For two parallel surfaces infinitely large, F_e is given by

$$F_e = \frac{1}{\frac{1}{E_1} + \frac{1}{E_2} - 1}$$

where E_1 and E_2 refer to the two surface emissivities. Radiation from the sun occurs in the short wave region while radiation from heated surfaces normally occur as long wave radiation.

4.1.3 Thermal Quantities

4.1.3.1 Thermal conductivity of a few building and insulating materials are given in Table 2. Air has the lowest conductivity whereas metals have the largest values.

4.1.3.2 Thermal Conductance — Thermal conductance (C) is related to thermal conductivity (K) by :

$$C = \frac{K}{L}$$

where L is thickness of structure.

Thermal resistance (R) is the reciprocal of thermal conductance or

$$R = \frac{1}{C}$$

For a non-homogenous or composite material comprising several layers of conductivities K_1, K_2, etc, and of thicknesses L_1, L_2, etc, the thermal resistance is :

$$R_T = R_1 + R_2 + R_3 + R_4 + \ldots.$$

$$= \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{L_4}{K_4} + \ldots.$$

4.1.3.3 *Surface coefficient* — The symbols f_i and f_o are used to denote respectively the inside and outside surface film coefficients. Values of surface conductance at different wind speed and orientation are given in Table 3. The reciprocal of surface heat transfer coefficient is called surface resistance; it is given by $\frac{1}{f}$

4.1.3.4 *Thermal transmittance (or the overall heat transfer coefficient)* — The overall heat transfer coefficient or the U-value is given by

$$U = 1/R_T$$

where $R_T = \frac{1}{h_i} + \frac{1}{h_o} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \ldots.$

where R_T is the total thermal resistance and h_i and h_o are the inside and outside air heat transfer coefficients.

4.1.3.5 *Thermal conductance of air space* — It is the amount of heat flow through unit area of the air space when unit temperature difference is maintained between the bounding surfaces. Its value is dependent on the temperature difference, orientation or position, air velocity and emissivity of the surface. Typical values are given in Table 4.

4.1.3.6 *Emissivity, absorptivity and reflectivity* — The reflectivity of a surface is related to its absorptivity and emissivity by the equation :

$$\alpha + E + r = 1$$

Average values of the emissivity, absorptivity and reflectivity for some common building surfaces are given in Table 5. In hot and humid climates, the indoor air temperature is not very different from the outside temperature. Therefore, provision of adequate air motion either by natural or mechanical means is the prime need in these climates.

4.1.3.7 *Criteria of thermal performance rating* — Various investigators have attempted use of parameters like, U, Q/U and damping for the assessment of thermal performance of building sections. These are applicable only under steady state conditions. From these it is possible to obtain a realistic comparison between different types of building elements. In a tropical climate, the thermal performance of a building section is also a function of solar temperature which is

TABLE 2 THERMAL PROPERTIES OF BUILDING AND INSULATING MATERIALS AT MEAN TEMPERATURE OF 50°C

(*Clause* 4.1.3.1)

Sl No.	Type of Material	Density	Thermal Conductivity*	Specific Heat Capacity
(1)	(2)	(3)	(4)	(5)
		kg/m³	W/(mK)	kJ/(kg.K)
	Building Materials			
1.	Burnt brick	1 820	0.811	0.88
2.	Mud brick	1 731	0.750	0.88
3.	Dense concrete	2 410	1.74	0.88
4.	RCC	2 288	1.58	0.88
5.	Limestone	2 420	1.80	0.84
6.	Slate	2 750	1.72	0.84
7.	Reinforced brick	1 920	1.10	0.84
8.	Brick tile	1 892	0.798	0.88
9.	Lime concrete	1 646	0.730	0.88
10.	Mud *Phuska*	1 622	0.519	0.88
11.	Cement mortar	1 648	0.719	0.92
12.	Cement plaster	1 762	0.721	0.84
13.	Cinder concrete	1 406	0.686	0.84
14.	Foam slag concrete	1 320	0.285	0.88
15.	Gypsum plaster	1 120	0.512	0.96
16.	Cellular concrete	704	0.188	1.05
17.	AC sheet	1 520	0.245	0.84
18.	GI sheet	7 520	61.06	0.50
19.	Timber	480	0.072	1.68
20.	Timber	720	0.144	1.68
21.	Plywood	640	0.174	1.76
22.	Glass	2 350	0.814	0.88
23.	Alluvial clay (40 percent sands)	1 958	1.211	0.84
24.	Sand	2 240	1.74	0.84
25.	Black cotton clay (Madras)	1 899	0.735	0.88
26.	Black cotton clay (Indore)	1 683	0.606	0.88
27.	Tar felt (2.3 kg/m²)	—	0.479	0.88
	Insulating Materials			
1.	Expanded polystyrene	16.0	0.038	1.34
2.	Expanded polystyrene	24.0	0.035	1.34
3.	Expanded polystyrene	34.0	0.035	1.34
4.	Foam glass	127.0	0.056	0.75
5.	Foam glass	160.0	0.055	0.75
6.	Foam concrete	320.0	0.070	0.92
7.	Foam concrete	400.0	0.084	0.92
8.	Foam concrete	704.0	0.149	0.92
9.	Cork slab	164.0	0.043	0.96
10.	Cork slab	192.0	0.044	0.96
11.	Cork slab	304.0	0.055	0.96
12.	Rock wool (unbonded)	92.0	0.047	0.84
13.	Rock wool (unbonded)	150.0	0.043	0.84
14.	Mineral wool (unbonded)	73.5	0.030	0.92
15.	Glass wool (unbonded)	69.0	0.043	0.92
16.	Glass wool (unbonded)	189.0	0.040	0.92
17.	Resin bonded mineral wool	48.0	0.042	1.00
18.	Resin bonded mineral wool	64.0	0.038	1.00
19.	Resin bonded mineral wool	99.0	0.036	1.00
20.	Resin bonded glass wool	16.0	0.040	1.00
21.	Resin bonded glass wool	24.0	0.036	1.00
22.	Exfoliated vermiculite (loose)	264.0	0.069	0.88
23.	Absestos mill board	1 397.0	0.249	0.84
24.	Hard board	979.0	0.279	1.42
25.	Straw board	310.0	0.057	1.30
26.	Soft board	320.0	0.066	1.30
27.	Soft board	249.0	0.047	1.30
28.	Wall board	262.0	0.047	1.26
29.	Chip board	432.0	0.067	1.26
30.	Chip board (perforated)	352.0	0.066	1.26
31.	Particle board	750.0	0.098	1.30
32.	Coconut pith insulation board	520.0	0.060	1.09
33.	Jute fibre	329.0	0.067	1.09
34.	Wood wool board (bonded with cement)	398.0	0.081	1.13
35.	Wood wool board (bonded with cement)	674.0	0.108	1.13
36.	Coir board	97.0	0.038	1.00
37.	Saw dust	188.0	0.051	1.00
38.	Rice husk	120.0	0.051	1.00
39.	Jute felt	291.0	0.042	0.88
40.	Asbestos fibre (loose)	640.0	0.060	0.84

*The thermal conductivity (K) values have been determined by :

a) Guarded Hot Plate Method, and

b) ASTM Heat Flow Method.

TABLE 3 VALUES OF SURFACE CONDUCTANCE FOR VARIOUS WIND VELOCITIES

(*Clause* 4.1.3.3)

Sl No.	Wind Velocity	Position of Surface	Direction of Heat Flow	Surface Conductance (For Non-reflective Surfaces)
(1)	(2)	(3)	(4)	(5) W/m²K
i)	Still air	Horizontal	Up	9.26
		Sloping 45°	Up	9.08
		Vertical	Horizontal	8.29
		Sloping 45°	Down	7.49
		Horizontal	Down	6.13
ii)	Moving air:			
	a) 24 km/h	Any position	Any direction (for winter)	34.06
	b) 12 km/h	Any position	Any direction (for summer)	22.71

influenced by climate data, surface colour and orientation. Therefore, for arriving at a generalized basis of thermal rating of building sections, it is necessary to compare the peak inside surface temperatures and heatflow. Peak degree hours (PDH) above a temperature of 30°C and peak heat gain factor (PHGF) for an air-conditioned enclosure at 25°C have been taken as the basis for the evaluation of thermal performance of building sections of non-air-conditioned and air-conditioned buildings respectively. These are shown in Fig. 1.

TABLE 4 THERMAL CONDUCTANCE OF AIR GAPS

(*Clause* 4.1.3.5)

Sl No.	Thickness of Air Gaps	Thermal Conductance
(1)	(2)	(3) W/m²K
i)	Closed space, 1.88 cm wide or more:	
	a) Bounded by ordinary building material	5.67
	b) One or both sides faced with reflective insulation	2.84
ii)	Closed space, 0.62 cm wide:	
	a) Bounded by ordinary building material	8.75
	b) One or both sides faced with reflective insulation	5.67
iii)	Open space, 1.88 cm wide or more	8.75
iv)	Closed space, 1.88 cm minimum one faced corrugated	6.33
v)	Closed space between plane and corrugated surfaces in contact	11.35

TABLE 5 AVERAGE EMISSIVITIES, ABSORPTIVITIES AND REFLECTIVITIES FOR SOME SURFACES COMMON TO BUILDING

(*Clause* 4.1.3.6)

Surface	Emissivity or Absorptivity		Reflectivity
	Low Temperature Radiation	Solar Radiation	Solar Radiation
(1)	(2)	(3)	(4)
Aluminium, bright	0.05	0.20	0.80
Asbestos cement, new	0.95	0.60	0.40
Asbestos cement, aged	0.95	0.75	0.25
Asphalt pavement	0.95	0.90	0.10
Brass and copper, dull	0.20	0.60	0.40
Brass and copper, polished	0.02	0.30	0.70
Brick, light puff	0.90	0.60	0.40
Brick red rough	0.90	0.70	0.30
Cement white portland	0.90	0.40	0.60
Concrete, uncoloured	0.90	0.65	0.30
Glass	0.90	0.79	0.10
Marble white	0.95	0.45	0.55
Paint, aluminium	0.55	0.50	0.50
Paint, white	0.90	0.30	0.70
Paint, brown, red, green	0.90	0.70	0.30
Paint, black	0.90	0.90	0.10
Paper, white	0.90	0.30	0.70
Slate, dark	0.90	0.90	0.10
Sleel, galvanized, new	0.25	0.55	0.45
Steel galvanized, weathered	0.25	0.70	0.30
Tiles, red clay	0.90	0.70	0.30
Tiles, black concrete	0.90	0.70	0.10
Tiles, uncoloured concrete	0.90	0.65	0.35

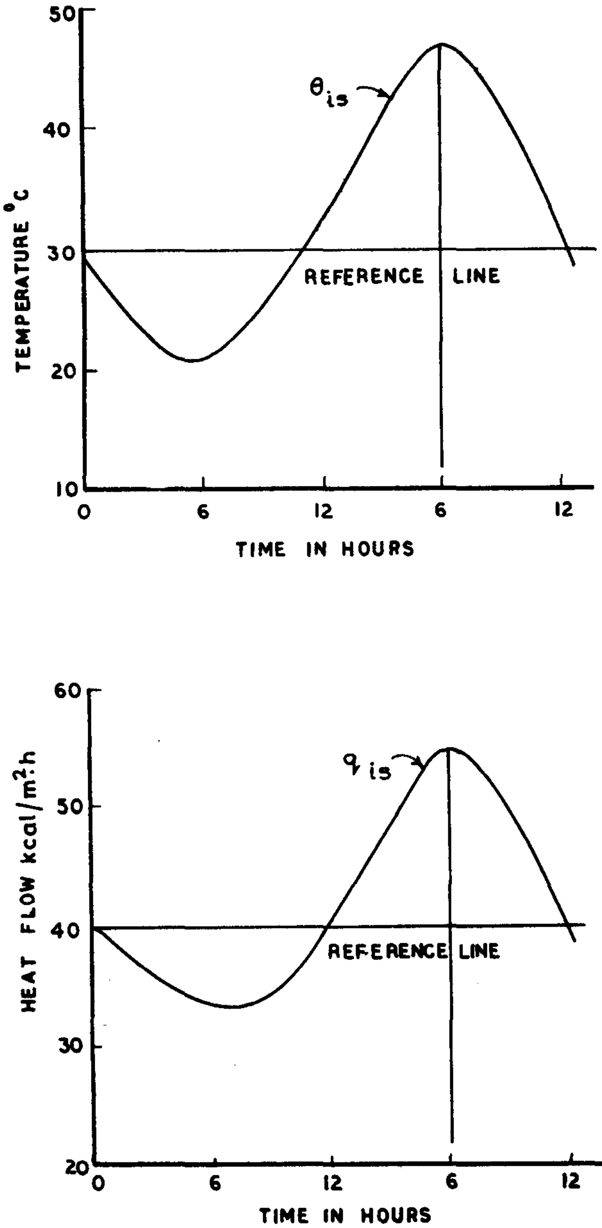


FIG. 1 RELATIONSHIP BETWEEN THERMAL PERFORMANCE

4.1.3.8 *Thermal performance index* — Thermal performance index of a non-air-conditioned building element is given by:

$$TPI = \frac{(T_{is} - 30) \times 100}{8}$$

In this equation, 8°C temperature drop over a base temperature of 30°C is taken as a reference. Here T_{is} is the peak inside surface temperature. These are shown in Fig. 1. *TPI* for air-conditioned building elements is given by:

$$TPI = (q_{is} - 46) \times 2.5$$

Here q_{is} is the peak heat gain factor in W/m², 46 W/m² is taken as a reference heat gain factor. The basis adopted for rating and broad classification for non-air-conditioned and air-conditioned situations are given in Table 6. Performance is best for those graded A and poorest for those rated E.

4.1.3.9 *Heat gain factors and their computation* — Heat gain factors represent the quantity of heat flow per unit area in unit time under the actual temperature difference for a given building section. The unit is W/m². The equations for calculation of heat gain factors both for non-air-conditioned and air-conditioned buildings are given in American Society of Heating, Refrigeration and Air-Conditioning Engineering, 1981. It can be calculated from a knowledge of solar air temperature and periodic thermal characteristics. Its main use is in the estimation of cooling load of air-conditioned buildings. The higher the heat gain factor, greater will be the cooling load. Therefore, reduction of heat gain factors is of prime importance in air-conditioned building design for possible economy in energy consumption.

4.1.3.10 *Heat gain through fenestration* — Glass is one of the most remarkable building material which has been in wide application in buildings for many years. Although glass in sheet form is not very strong structurally, it has several advantages, such as long-term durability, almost perfect surface finish, ability to transmit daylight and clear vision. Glass transmits radiation in varying degrees within the wavelength region of 0.3 to 4.8 μm and is opaque to both very short wave and long wave radiations. The basic difference between glasses lie in their transmission characteristics. The transmission characteristics of various types of glasses are shown in Fig. 2. The percentage transmission for each wavelength is a function of physical and chemical properties of the glass and angle of incidence of the radiant energy. The variation of transmission, absorption and reflection for a 3.0 mm clear plate glass is shown in Fig. 3.

a) *Green-house effect* — Short wave solar radiations entering a building through glazed fenestrations tend to increase the temperature of air and other surfaces. These warm surfaces in turn emit long wave radiations which cannot find their way out to outdoor environment through closed fenestration, because glass is opaque to low temperature radiations. Thus heat energy is trapped within the enclosure, thereby causing indoor temperature to rise. This is known as green house effect.

b) *Mechanism of solar heat gain through glass* — In practice, it is convenient to express the heat gains for different glazing materials and shading devices in terms of shade factor. Shade factor is defined as the ratio of the solar heat gain for the fenestration under consideration to the solar heat gain factor for 3.0 mm plain glass under the same conditions.

Shade factor (S) is given as:

$$S = \frac{\text{Solar heat gain through fenestration}}{\text{Solar heat gain factor through ordinary clear glass}}$$

Solar heat gain factor (SHGF) varies with angle of incidence whereas shade factor remains constant for all practical purposes. Total heat gain (THG) through any fenestration is:

$$\text{THG} = S\,(\text{SHGF for ordinary clear glass}) + U\,(T_o - T_i)$$

where

U = thermal transmittance,
T_o = outside temperature range, and
T_i = inside temperature range.

It is a useful parameter for the comparison of relative efficacies of different shading devices. These can be measured with the help of solar calorimeters. Solar optical properties and shade factors for indigenous glazing and shading materials are given in Table 7.

TABLE 6 BASIS FOR THE THERMAL PERFORMANCE RATING AND CLASSIFICATION

(*Clause* 4.1.3.8)

Thermal Performance Index: Non-air-conditioned		Thermal Performance Index: Air-conditioned		Class	Quality of Performance
⩽ 75		⩽ 50		A	Good
⩾ 75	⩽ 125	⩾ 50	⩽ 100	B	Fair
⩾ 125	⩽ 175	⩾ 100	⩽ 150	C	Poor
⩾ 175	⩽ 225	⩾ 150	⩽ 200	D	Very poor
⩾ 225			⩾ 200	E	Extremely poor

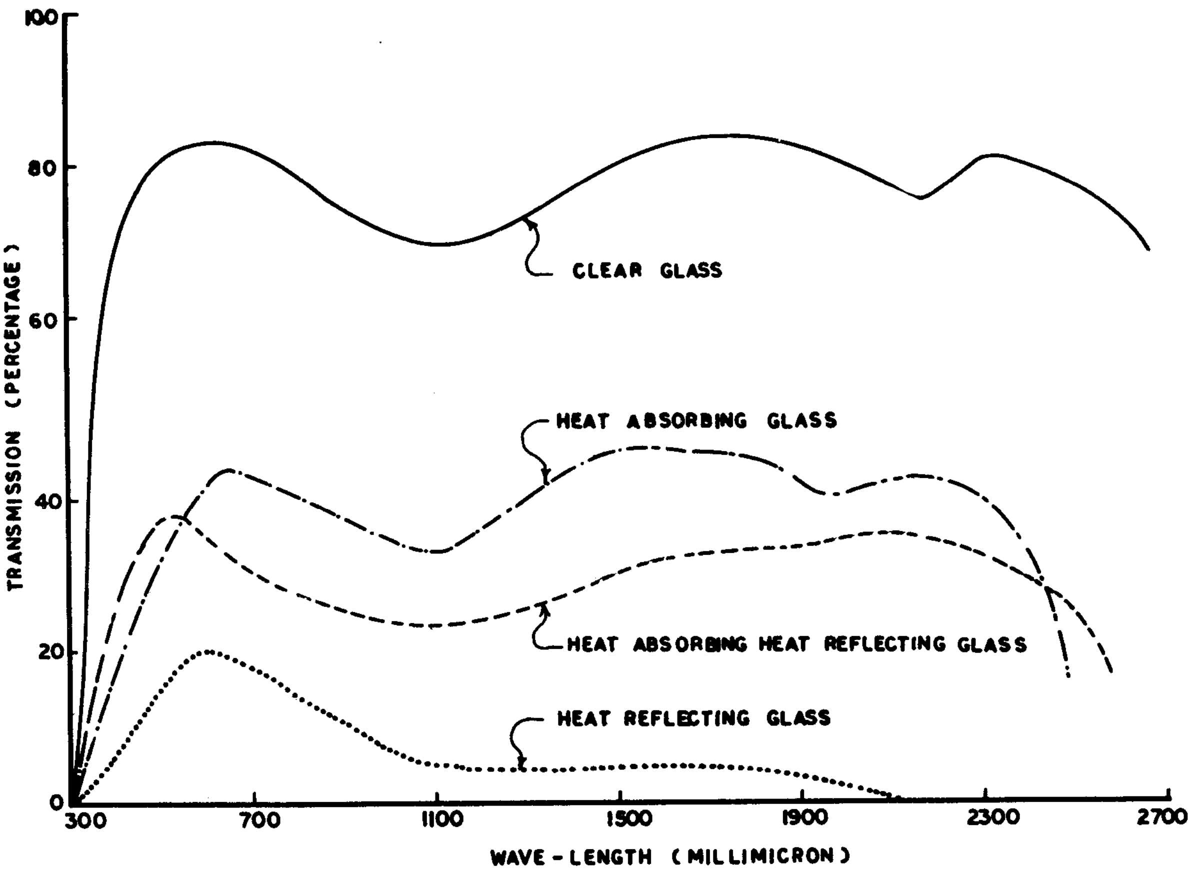


FIG. 2 TRANSMISSION CHARACTERISTICS OF VARIOUS TYPES OF GLASSES

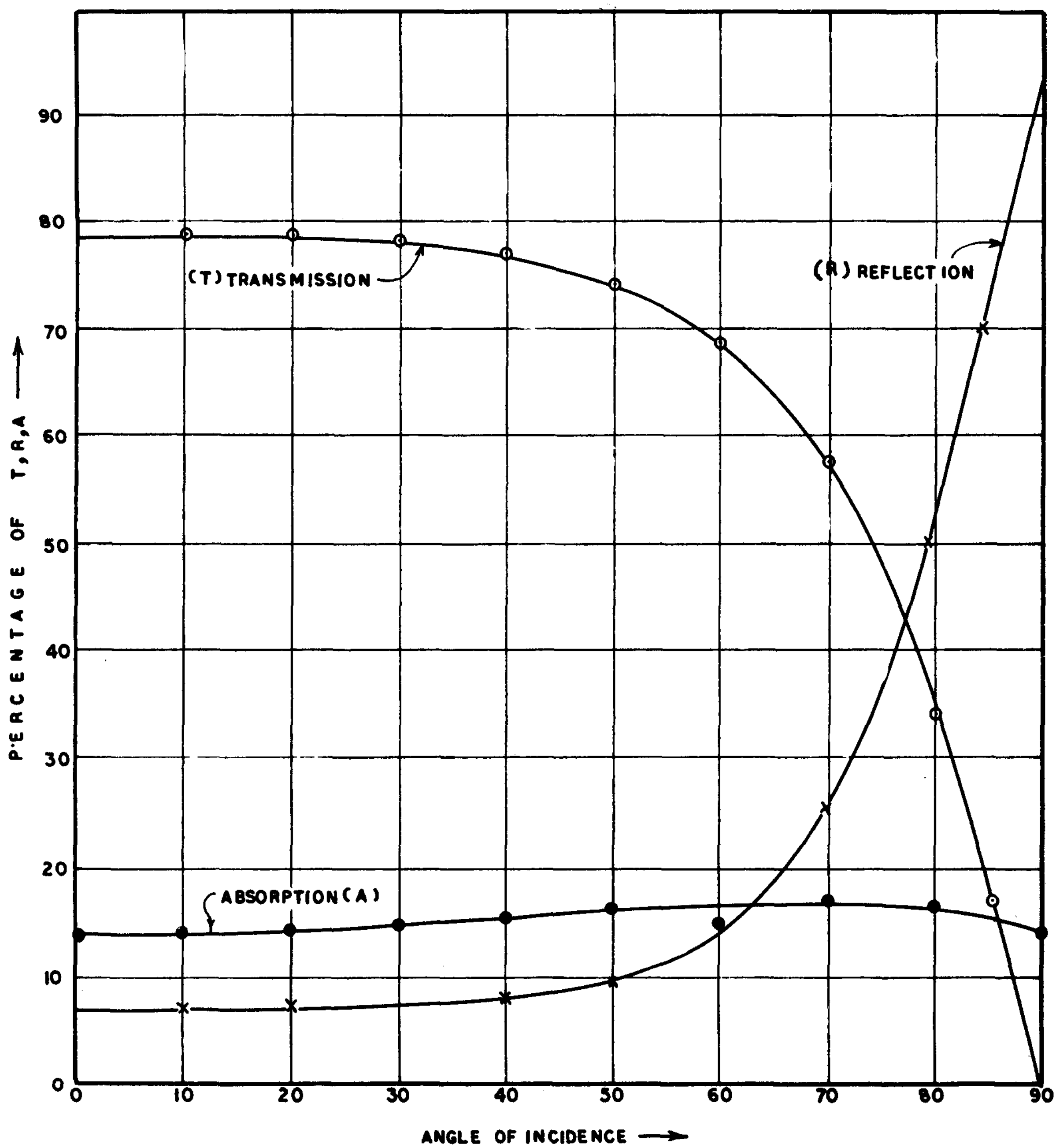


FIG. 3 VARIATION OF TRANSMISSION, ABSORPTION AND REFLECTION FOR 3.0 mm CLEAR PLATE GLASSES

5. THERMAL PERFORMANCE OF BUILDING SECTIONS

5.1 Thermal Performance of Walls and Roofs — Thermal performance of building sections depends upon thermal properties, outside surface finish, orientation and climatic conditions. These properties are represented in two categories: (a) thermal characteristics of the building section, and (b) thermal performance index.

5.2 Computation of Thermal Transmission or *U* Values and Thermal Damping — The *U* values of building sections can be computed with a knowledge of thermal conductivities of the building sections, their thickness and surface resistance. Although there will be slight variation in the *U* values for different cities due to variation in surface resistance, for all practical purposes in building design certain constant values of surface resistance are assumed in *U* value calculation. The

TABLE 7 SOLAR OPTICAL PROPERTIES OF GLAZING MATERIALS

[*Clause* 4.1.3.11(b)]

SL No.	NAME OF MATERIALS	THICKNESS	TRANSMISSION FACTOR	SHADE FACTOR
(1)	(2)	(3) cm	(4) (4)	(5) (5)
i)	Plain glass sheet	0.33	0.79	1.0
ii)	Plain glass sheet	0.56	0.78	0.98
iii)	Wired glass	0.74	0.55	0.70
iv)	White figure glass	0.33	0.75	0.74
v)	Blue colour glass	0.33	0.62	0.62
vi)	Green colour figure glass	0.32	0.70	0.63
vii)	Blue painted glass	0.28	0.65	0.64
viii)	Aluminium painted glass	0.28	0.12	0.08
ix)	Yellow painted glass	0.27	0.31	0.24
x)	Red painted glass	0.27	0.48	0.24
xi)	Plain window glass + wire mesh	0.565	0.52	0.44
xii)	Plain window glass + plastic sheet	0.565	0.55	0.44
xiii)	Dark yellow spotted glass	0.38	0.71	0.68
xiv)	White painted glass	0.28	0.32	0.28
xv)	Heat absorbing glass	0.36	0.15	0.52
xvi)	Heat absorbing glass	0.50	0.14	0.45

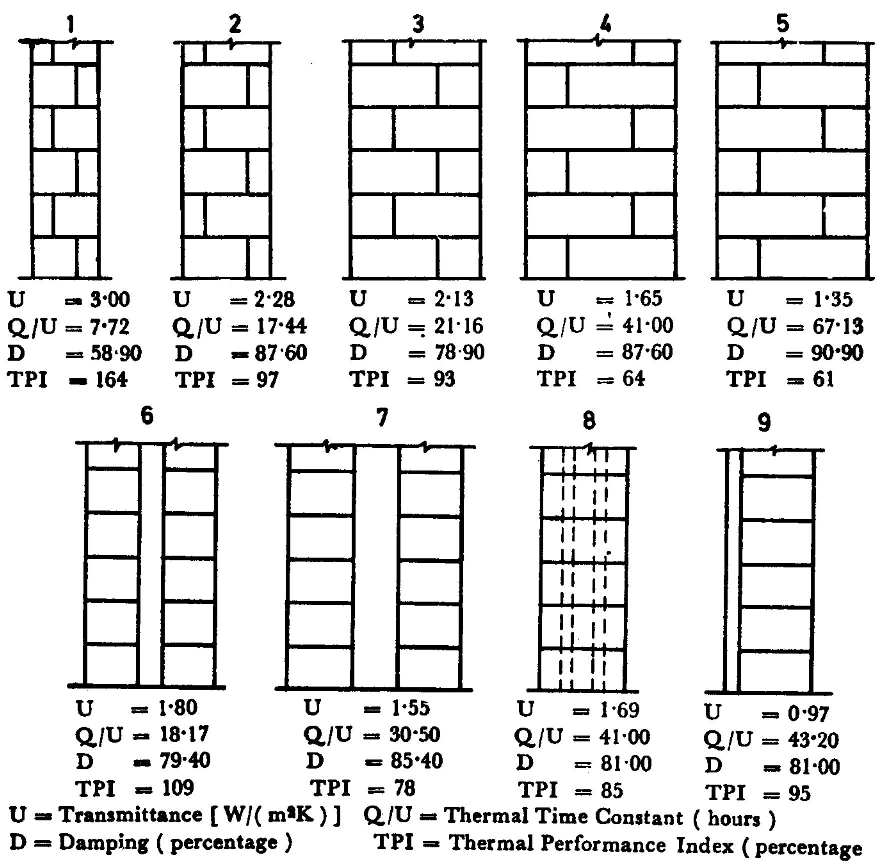
average value of f_i for building material surface is about 9.30 W/m^{2}K for still air and for wind velocity of 8.0 km/h, f_o is 19.90 W/m^{2}K.

5.2.1 The method of computation and few worked out examples are shown in Appendix A. Figure 4 gives values for some typical constructions and building components.

5.2.2 A correlation between thermal damping and *Q*/*U* is shown in Fig. 5 from which damping can be determined once *Q*/*U* is calculated from the basic data. A few worked out examples for calculating thermal damping are given in Appendix A.

5.3 Thermal Performance Index — The *TPI* values given in Tables 8, 9 and 10 are for a typical summer design day with a fixed surface absorption coefficient (α = 0.7). The correction factors are to be applied to the *TPI* values for other climatic zones, orientations and surface finishes. These correction factors are given in Table 11.

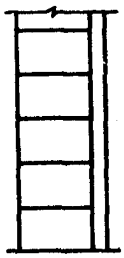
5.3.1 A few worked out examples for application of correction factor applied to thermal performance index are given in Appendix A.



4A THERMAL PERFORMANCE OF WALLS

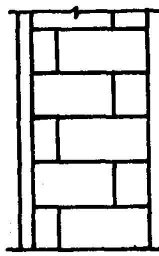
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS—*Contd.*

10



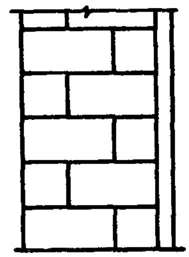
U = 0·97
Q/U = 11·30
D = 89·00
TPI = 92

11



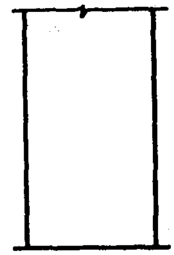
U = 0·85
Q/U = 52·00
D = 85·80
TPI = 79

12



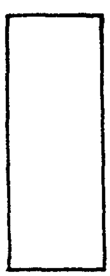
U = 0·85
Q/U = 16·70
D = 92·40
TPI = 82

13



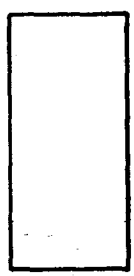
U = 2·09
Q/U = 31·90
D = 75·00
TPI = 102

14



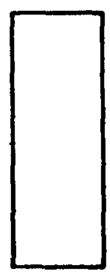
U = 4·12
Q/U = 12·5
D = 41
TPI = 223

15



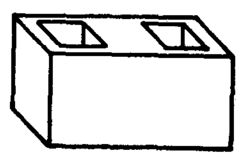
U = 3·29
Q/U = 14·0
D = 56
TPI = 173

16



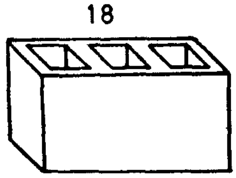
U = 2·12
Q/U = 14·00
D = 57·00
TPI = 112

17



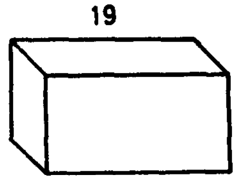
U = 3·01
Q/U = 14·50
D = 61·00
TPI = 136

18



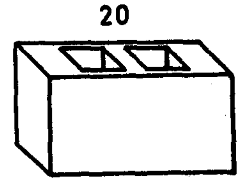
U = 2·79
Q/U = 12·00
D = 67·00
TPI = 131

19



U = 2·90
Q/U = 12·00
D = 49·00
TPI = 193

20

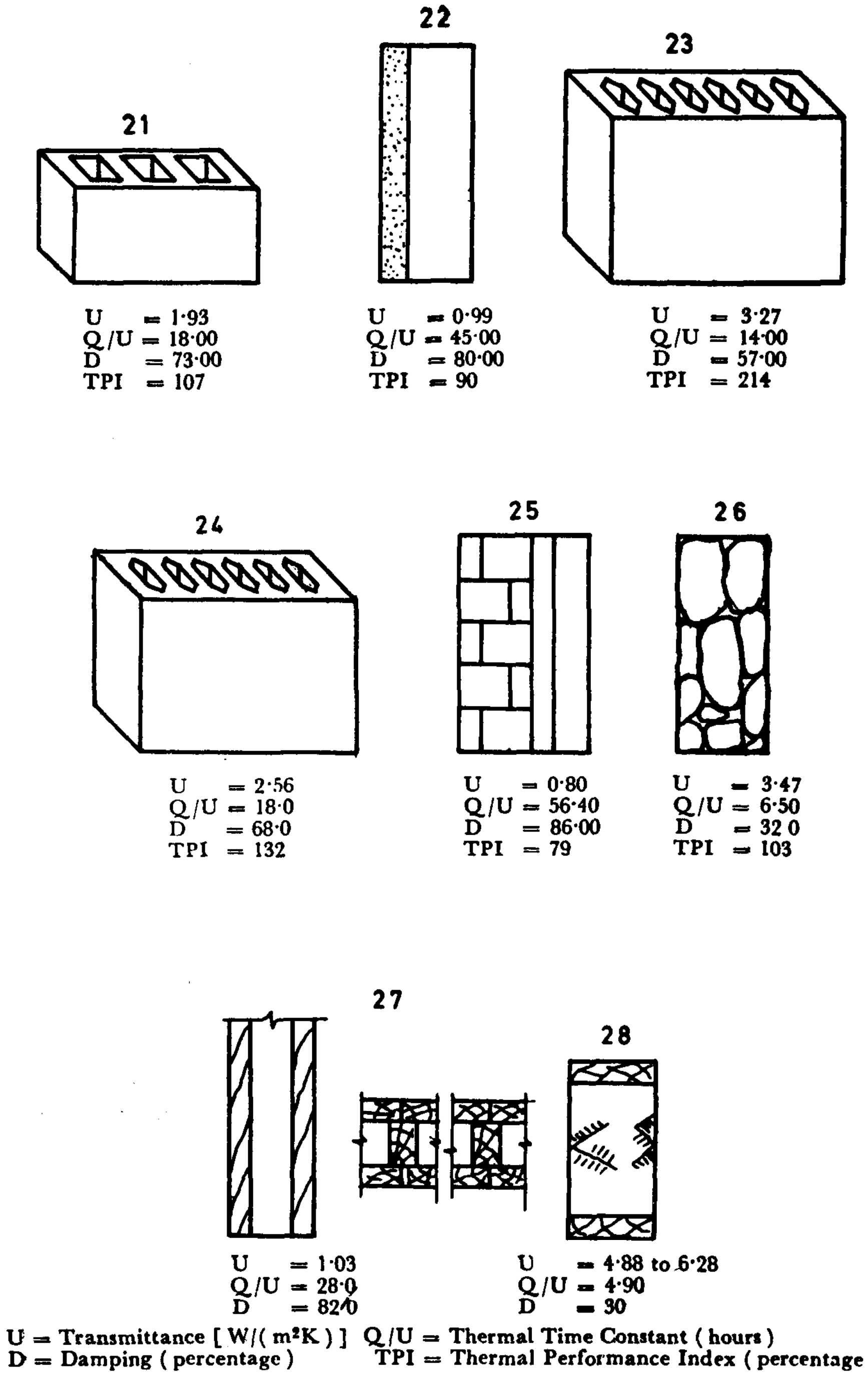


U = 2·07
Q/U = 40·00
D = 81·00
TPI = 101

U = Transmittance [W/(m^{2}K)] Q/U = Thermal Time Constant (hours)
D = Damping (percentage) TPI = Thermal Performance Index (percentage)

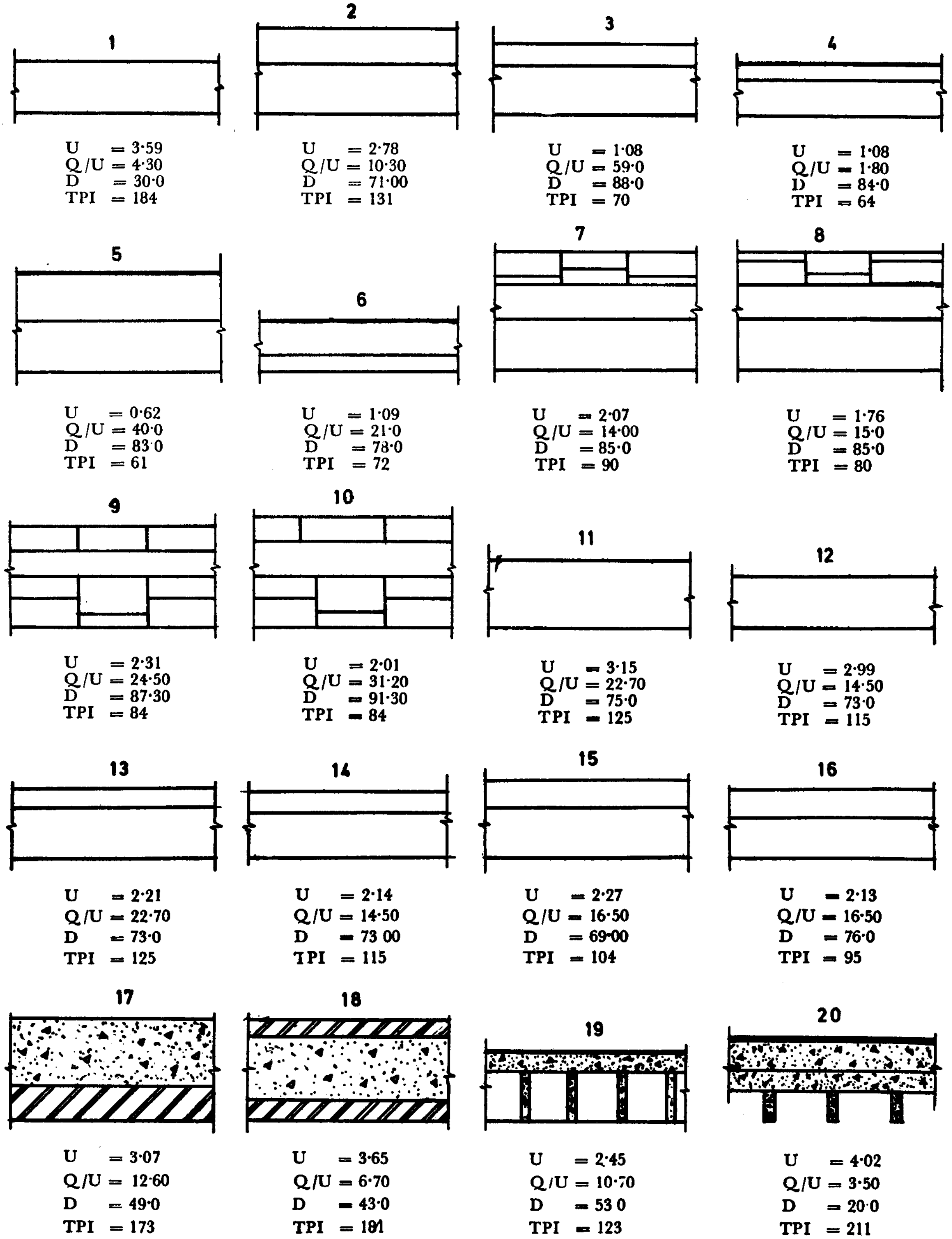
4A THERMAL PERFORMANCE OF WALLS

FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*



4A THERMAL PERFORMANCE OF WALLS

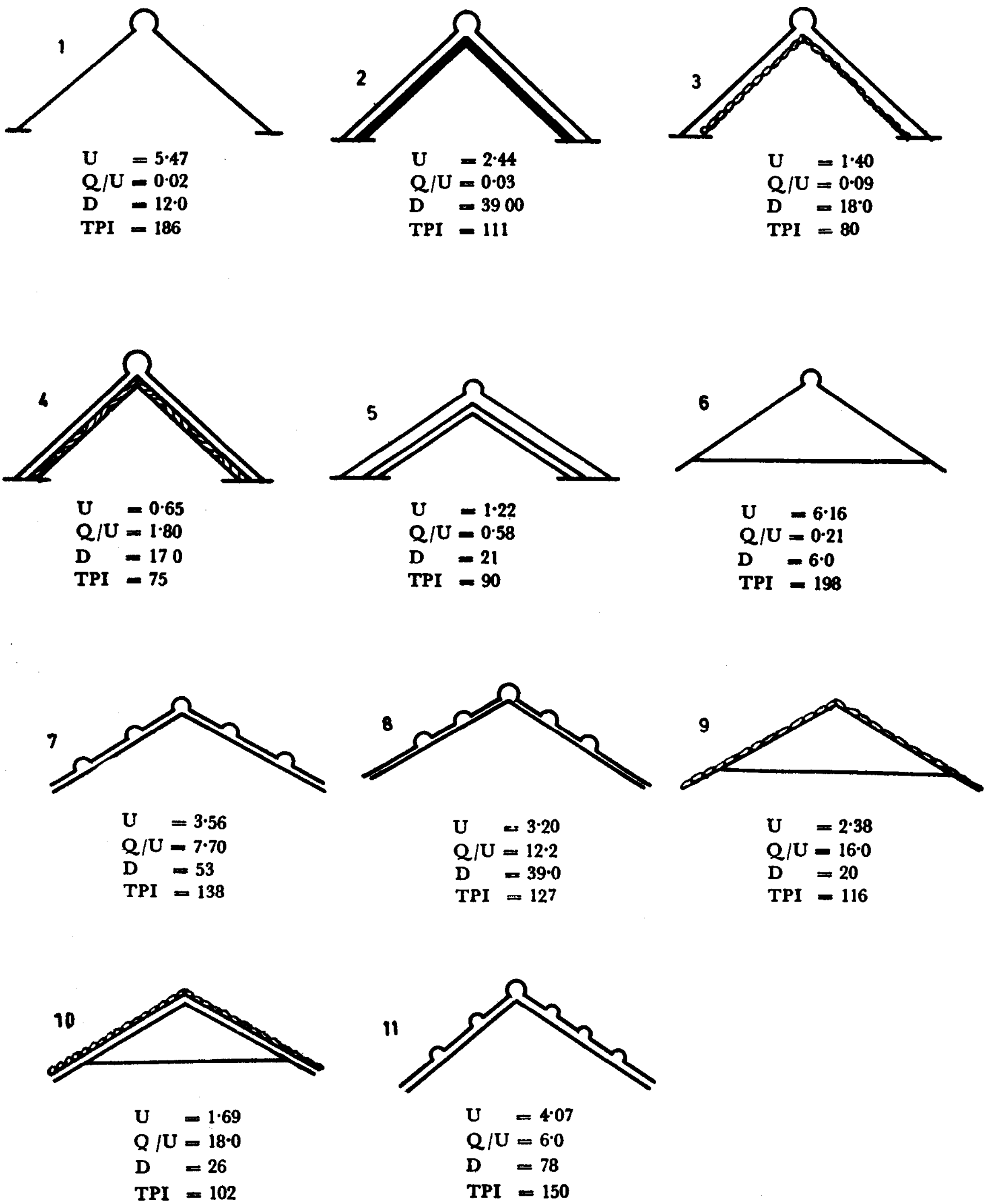
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*



U = Transmittance [$W/(m^2K)$] Q/U = Thermal Time Constant (hours)
D = Damping (percentage) TPI = Thermal Performance Index (percentage)

4B THERMAL PERFORMANCE OF FLAT ROOFS

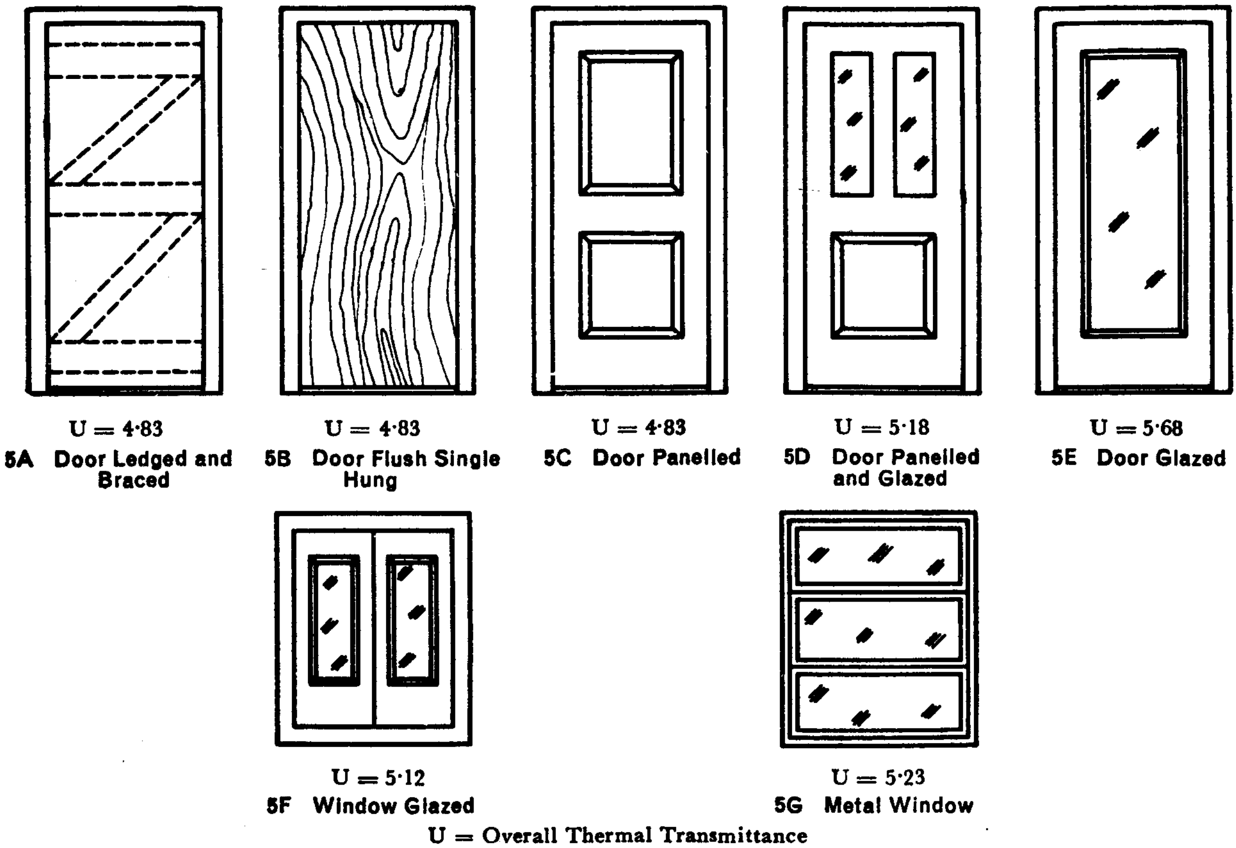
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*



U = Transmittance [W/(m²K)] Q/U = Thermal Time Constant (hours)
D = Damping (percentage) TPI = Thermal Performance Index (percentage)

4C THERMAL PERFORMANCE OF SLOPED ROOFS

FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*



4D THERMAL TRANSMITTANCE OF DOORS AND WINDOWS

FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS

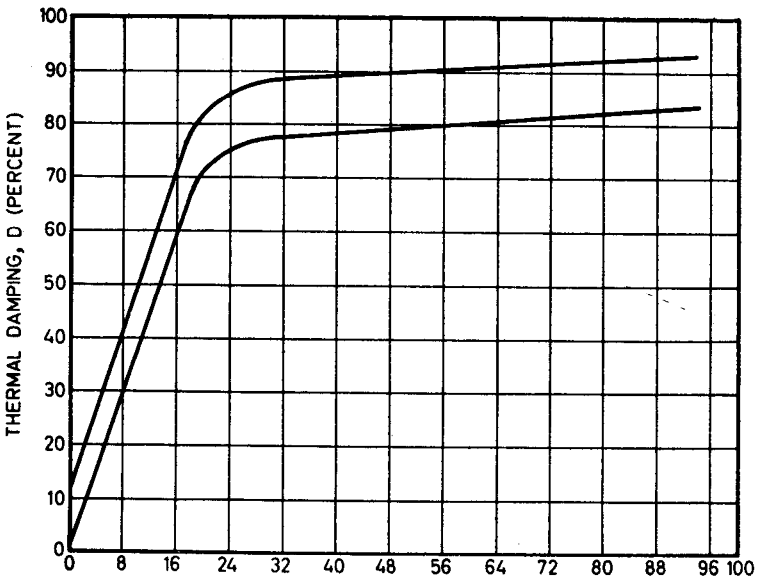


FIG. 5 LIMITING CURVES SHOWING RELATIONSHIP BETWEEN THERMAL TIME CONSTANT IN HOURS AND THERMAL DAMPING IN PERCENT

TABLE 8 THERMAL PERFORMANCE OF WALLS

(*Clause* 5.3)

SL No.	SPECIFICATION OF WALLS	*U* VALUES	THERMAL TIME CONSTANT	DAMPING (*D*)	*TPI*
(1)	(2)	(3) W/(m²·K)	(4) h	(5) percent	(6) percent
i)	1.25 cm PL* + 11.25 cm brick + 1.25 cm PL	3.00	7.72	58.9	164
ii)	1.25 cm PL + 20.00 cm brick + 1.25 cm PL	2.28	17.44	87.6	97
iii)	1.25 cm PL + 22.5 cm brick + 1.25 cm PL	2.13	21.16	78.8	93
iv)	1.25 cm PL + 33.75 cm brick + 1.25 cm PL	1.65	41.0	87.6	64
v)	1.25 cm PL + 45.0 cm brick + 1.25 cm PL	1.35	67.13	90.9	61
vi)	1.25 cm PL + 7.5 cm brick + 5.0 cm air gap + 7.5 cm brick + 1.25 cm PL	1.80	18.17	79.4	109
vii)	1.25 cm PL + 11.25 cm brick + 5.0 cm air gap + 11.25 cm brick + 1.25 cm PL	1.55	30.5	85.4	78
viii)	22.5 cm cavity brick wall	1.69	41.0	81.0	85
ix)	1.25 cm PL + 2.5 cm expanded polystyrene + 11.25 cm brick + 1.25 cm PL	0.97	43.2	81.0	95
x)	1.25 cm PL + 11.25 cm brick + 2.5 cm expanded polystyrene + 1.25 cm PL	0.97	11.3	89.0	92
xi)	1.25 cm PL + 2.5 cm expanded polystyrene + 22.5 cm brick + 1.25 cm PL	0.85	52.0	85.80	79
xii)	1.25 cm PL + 22.5 cm brick + 2.5 cm expanded polystyrene + 1.25 cm PL	0.85	16.7	92.4	82
xiii)	1.25 cm PL + 20 cm cin, con† block + 1.25 cm PL	2.09	31.9	75.0	102
xiv)	10 cm con block	4.12	8.2	41.0	223
xv)	15 cm con block	3.29	14	56	173
xvi)	10 cm cellular con	2.12	14	57	112
xvii)	20 cm dense con-hollow block (2 holes)	3.01	14.5	61	136
xviii)	20 cm dense con-hollow block (3 holes)	2.79	12	67	131
xix)	10 cm light weight con-block	2.90	12	49	193
xx)	20 cm light weight con-block (2 holes)	2.07	40	81	101
xxi)	20 cm light weight con-block (3 holes)	1.93	18	73	107
xxii)	1.25 cm PL + 5 cm foam con + 11.25 cm con + 1.25 cm PL	0.99	45	80	90
xxiii)	10 cm hollow pan	3.27	14	57	214
xxiv)	15 cm hollow pan	2.56	18	68	132
xxv)	1.25 cm PL + 11.4 cm brick wall + 5.08 cm reed board + 3.8 cm cement con plaster	0.80	56.4	86	79
xxvi)	25.4 cm rubble wall + 1.25 cm PL	3.47	6.5	32	103
xxvii)	7.62 × 7.62 cm wooden studs + 3.81 cm wooden boarding with fireproof paint spray on each side	1.03	28.0	82	92
xxviii)	Mud wall based on wooden lacings	4.88 to 6.28	4.9	30	—

*PL = cement plaster   †con = concrete

TABLE 9 THERMAL PERFORMANCE OF FLAT ROOFS

(*clause* 5.3)

Sl No.	Specification of Walls	U Values	Thermal Time Constant	Damping (D)	TPI
(1)	(2)	(3) W/(m².K)	(4) h	(5) percent	(6) percent
i)	10 cm RCC	3.59	4.3	30	184
ii)	10 cm RCC + 10 cm lime concrete	2.78	10.3	71	131
iii)	10 cm RCC + 5 cm foam con + waterproofing	1.08	5.9	88	70
iv)	5 cm RCC + 2.5 cm expanded polystyrene	1.08	1.8	84	64
v)	5 cm expanded polystyrene + 5 cm RCC + waterproofing	0.62	40.0	83	61
vi)	2.5 cm expanded polystyrene + 5 cm RCC	1.09	21.0	78	72
vii)	10 cm RCC + 5 cm cin + 5 cm brick tile	2.07	14.0	81	90
viii)	10 cm RCC + 7.5 cm cin. + 5 cm brick tile	1.76	15.0	85	80
ix)	11.5 cm RCC + 5 cm Mud *Phuska* + 5 cm brick tile	2.31	24.5	87.3	97
x).	11.5 cm RCC + 7.5 cm Mud *Phuska* + 5 cm brick tile	2.01	31.2	91.3	84
xi)	15 cm clay unit	3.15	8.8	52.0	183
xii)	13.75 cm clay unit	2.99	7.7	53.0	170
xiii)	15 cm clay unit + 10 cm lime con	2.21	22.7	75.0	125
xiv)	13.75 cm clay unit + 10 cm lime con	2.14	14.5	73.0	115
xv)	10 cm cellular unit + 8.5 cm lime concrete	2.27	14.0	69.0	104
xvi)	12.5 cm cord unit + 8.5 cm lime concrete	2.13	16.5	76.0	95
xvii)	15.4 cm lime con using stone aggregate + 7.6 cm stone slab	3.07	12.6	49	173
xviii)	8.89 cm concrete using brick aggregate + 2.54 Kota stone slab on each side	3.65	6.7	43	181
xix)	5.08 cm lime con using ballast aggregate + 11.4 cm reinforced brick and bitumen wash on top	2.45	10.7	53	123
xx)	5.08 cm lime con using brick ballast aggregate + 5.08 cm RCC slab + bitmen wash on top surface	4.02	3.5	20	211

TABLE 10 THERMAL PERFORMANCE OF SLOPED ROOFS

(*Clause* 5.3)

Sl No.	Specification of Sloped Roof	U Values	Thermal Time Constant	Damping (D)	*TPI*
(1)	(2)	(3) W/(m².K)	(4) h	(5) percent	(6) percent
i)	0.625 cm AC sheet	5.47	0.015	12	186
ii)	0.625 cm AC sheet + 2.5 cm air space + insulating board	2.44	0.029	39	111
iii)	0.625 cm AC sheet + air space + 5 cm fibre glass + 0.625 hard board	1.40	0.085	18	80
iv)	0.625 cm AC sheet + air space + 5 cm sandwich of fibreboard/expanded polystyrene	0.65	1.8	17	75
v)	0.625 cm AC sheet + air space + 2.5 cm sandwich of fibre board/expanded polystyrene	1.22	0.58	21	90
vi)	0.3 cm GI sheet	6.16	0.21	6	198
vii)	2.5 cm tile + 2.5 cm bamboo reinforcement	3.56	7.7	55	138
viii)	5 cm tile + 2.5 cm bamboo reinforcement	3.20	12.0	39	127
ix)	2.5 cm thatch roof + 2.5 cm bamboo reinforcement	2.38	16.0	26	116
x)	5 cm thatch roof + 2.5 cm bamboo reinforcement	1.69	18.0	20	102
xi)	Mangalore tiles on wooden rafters	4.07	6	78	150

TABLE 11 CORRECTION FACTORS (*C*) FOR THERMAL PERFORMANCE INDEX (*TPI*)

(*Clause* 5.3)

SL No.	CHARACTERISTICS	HOT DAY ZONE	HOT HUMID ZONE	WARM HUMID ZONE
(1)	(2)	(3)	(4)	(5)
i)	Building Component			
	a) Roof	1	0.95	0.92
	b) Wall (W)	1	0.85	0.75
ii)	Orientation of Wall			
	a) N	0.45	0.38	0.34
	b) NE	0.70	0.59	0.54
	c) E	0.85	0.72	0.63
	d) SE	0.67	0.57	0.50
	e) S	0.55	0.47	0.42
	f) SW	0.75	0.64	0.57
	g) NW	0.70	0.68	0.60
iii)	External Surface Finish			
	a) Roof			
	1) Dark	1.00	0.95	0.92
	2) Light	0.75	0.71	0.69
	b) Wall			
	1) Dark	1.00	0.85	0.75
	2) Light	0.78	0.66	0.59
iv)	Shading			
	a) Roof	0.32	0.31	0.30
	b) Wall	0.35	0.30	0.26

6. ORIENTATION OF BUILDINGS

6.0 Although solar heat gain is the main consideration in the selection of optimum orientation of buildings, other factors like the direction of wind, rainfall and site conditions cannot be overlooked in the final choice of the orientation. In most of the cases, building byelaws and other regulations do not permit selection of optimum orientation. Where best orientation is not possible for a building, the next choice for good orientation is to obtain a compromise amongst solar and climatic data available for the place, site conditions and building byelaws. The selection of optimum orientation should be based on the summer conditions or, in other words, the orientation chosen should lead to minimum summer heat into the building.

6.1 Building Shape — For the practical evaluation of correct orientation for any specific building, it is necessary to know its shape, the location of various shading devices, and the shaded and unshaded areas during the day. From this, it is possible to locate the living rooms where other portions of the building provide shade during summer afternoon. Exposed surfaces can be shaded by overhangs or verandah.

6.2 Room Location — Judicious layout of rooms inside a building is also as important as the choice of proper orientation. Discomfort due to ingress of excessive solar heat inside rooms can be offset by favourable breeze during the period of occupancy. Location of window inside the room should ensure desirable wind speed and requisite ventilation. It has been observed by experiments that deviation up to 30° from the direction of optimum wind makes only slight reduction in wind velocity available inside the room. Sun breakers and louvers on windows may also serve as good wind scoops which may be utilized to promote indoor ventilation.

6.3 Evaluation of Best Orientation — The best orientation from solar heat gain point of view requires that the building as a whole should receive maximum solar radiation in winter and minimum in summer. Normally roofs are horizontal, and hence these will receive the same solar heat irrespective of the building orientation. The total amount of solar radiation incident on different vertical surfaces may be calculated for all possible orientations of the building, both for proper orientation on the basis of above criterion.

6.3.1 For practical evaluation, it is necessary to know the duration of sunshine and hourly solar intensity on the various external surfaces on representative days of the seasons. The total direct diurnal solar loads per unit area on different vertical surfaces are given in Table 12 for two days in the year, that is, 16 May and 22 December, representative of summer and winter, for latitudes corresponding to some important cities all over India. From Table 12, the total heat intake can be calculated for all possible orientations of the building for the extreme days of summer and winter.

6.3.1.1 The method of calculating solar load on vertical surface of different orientations is given in Appendix B.

6.3.1.2. An example to illustrate how to workout an orientation of a building from the solar point of view is given in Appendix C.

6.4 Shading of Windows — It has been observed that heat gain through glazed window is many times as compared that through solid wall. The heat gain through fenestration is a function of orientation, window area and shade factor. The heat gain factors for different orientation both for solid wall and glazed window with different percentage of shading, are shown in Table 13. The minimum window area for a given building is mainly worked out based upon adequate daylighting and natural ventilation. The average heat gain factors for 15 percent glazing area are given in Table 14. From this, it is clear that adequate protection against solar heat is essential by shading the windows.

6.4.1 *Types of Shading Devices* — There are different methods of reducing solar heat gains through glasses. Shading devices used are generally classified into three groups:

TABLE 12 DAILY TOTAL DIRECT SOLAR RADIATION ON VERTICAL SURFACES IN W/m² PER DAY FOR TWO REPRESENTATIVE DAYS

(*Clause* 6.3.1)

ORIENTATION	8°N		13°N		19°N		23°N		29°N	
	May 16	Dec 22	May 16	Dec 22	May 16	Dec 22	May 16	Dec 22	May 16	Dec 22
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
North	2 177	—	1 625	—	962	—	741	—	536	—
North-east	2 650	410	2 492	315	2 255	237	2 192	173	2 098	110
East	2 618	2 177	2 697	2 019	2 795	1 830	2 871	1 703	2 950	1 467
South-east	1 167	3 391	1 341	3 423	1 640	3 438	1 845	3 454	2 192	3 265
South	—	4 164	—	4 385	—	4 574	205	4 637	741	4 543
South-west	1 167	3 391	1 341	3 423	1 640	3 438	1 845	3 454	2 192	3 265
West	2 618	2 177	2 697	2 019	2 795	1 830	2 871	1 703	2 950	1 467
North-west	2 650	410	2 492	315	2 255	237	2 192	173	2 098	110

TABLE 13 HEAT GAIN FACTOR THROUGH GLASS WITH DIFFERENT PERCENTAGE OF SHADING IN W/m²

(*Clause* 6.4)

ORIENTATION	WITH 100 PERCENT SHADING	WITH 75 PERCENT SHADING	WITH 50 PERCENT SHADING	WITH 0 PERCENT SHADING	SOLID WALL 23 cm
(1)	(2)	(3)	(4)	(5)	(6)
North	67.1	82.9	121.6	176.2	25.6
North-east	74.2	171.3	267.5	462.9	29.1
East	88.4	193.6	298.9	509.4	30.2
South-east	91.1	153.7	217.0	341.9	24.4
South	86.6	119.1	151.2	215.7	20.9
South-west	95.9	186.5	276.8	457.6	27.9
West	95.7	203.8	311.2	444.6	33.7
North-west	214.6	278.0	341.3	468.1	34.9

a) External shading, such as louvers, sun breakers, verandahs, etc;
b) Internal shading, like curtain, venetian blind, etc; and
c) Translucent materials, like heat absorbing or heat reflecting glass, plastics, painted glass, etc.

The effectiveness of these shading devices are evaluated in terms of shade factors. The measured values of shade factors for various types of shading devices are given in Table 15.

The maximum shade factor and U values for windows has been recommended in IS : 3792-1978. These are given in Table 15. From this, it is evident that air-conditioned buildings need full protection from solar heat through window. For non-air-conditioned buildings, this requirement can be fulfilled by proper orientation and selection of economical shading devices.

6.5 Design of Shading Devices — Design of external shading devices for a given percentage of window area can be worked out with a knowledge of solar chart and shadow angles. These are discussed in detail in Part 1 of the Handbook. Selection of proper shading devices can be made based on cost as well as performance standard, both for non-air-conditioned and air-conditioned building.

TABLE 14 AVERAGE HEAT GAIN FACTOR IN 23 cm BRICK WALL WITH AND WITHOUT 15 PERCENT GLASS WINDOW IN W/m²

(*Clause* 6.4)

ORIENTATION	SOLID WALL	WITH 100 PERCENT SHADED WALL	WITH 100 PERCENT SHADED WINDOW	WITH 75 PERCENT SHADED WINDOW	WITH 0 PERCENT SHADED WINDOW	WITH SHADED WINDOW
(1)	(2) cm	(3)	(4)	(5)	(6)	(7)
North	22.0	Long	31.4	36.0	40.7	48.3
		Short	32.6	38.4	44.2	57.2
North-east	25.0	Long	33.7	45.9	58.1	82.6
		Short	36.0	50.6	66.3	97.7
East	26.0	Long	36.6	56.4	75.6	112.8
		Short	39.5	64.0	87.2	136.1
South-east	21.0	Long	39.0	50.0	61.1	87.8
		Short	43.0	57.0	71.5	100.5
South	18.0	Long	40.7	46.5	55.2	64.0
		Short	46.5	54.1	46.5	75.6
South-west	24.0	Long	46.5	68.0	87.8	131.4
		Short	52.3	79.1	105.8	150.0
West	29.0	Long	50.0	69.8	87.8	125.6
		Short	55.8	79.1	102.9	152.3
North-west	30.0	Long	49.4	67.5	84.9	119.8
		Short	54.1	76.8	98.3	144.2

TABLE 15 THERMAL PERFORMANCE OF DIFFERENT SHADING DEVICES

(*Clause* 6.4.1)

SL NO.	NAME OF THE SHADING DEVICE	TRANS-MITTANCE U-VALUE	SHADE FACTOR
(1)	(2)	(3) W/(m²K)	(4)
i)	Plain glass sheet (3.0 mm thick)	5.23	1.00
ii)	Plain glass + wire mesh outside	5.00	0.65
iii)	Painted glass		
	a) White paint	5.22	0.35
	b) Yellow paint	5.22	0.37
	c) Green paint	5.22	0.40
iv)	Heat absorbing glass	4.65	0.45
v)	Plain glass sheet + venetian blind inside	3.72	
	a) Light colour		0.35
	b) Dark colour		0.40
vi)	Flain glass sheet + curtain inside	3.14	
	a) Light colour		0.35
	b) Dark colour		0.40
vii)	Plain glass sheet	5.23	
	a) 100 percent shaded		0.14
	b) 75 percent shaded		0.34
	c) 60 percent shaded		0.56

7. BUILDING CHARACTERISTICS FOR VARIOUS CLIMATES

7.0 Buildings are characterized by the climate in which these are located. Characteristics of the buildings in the four climatic zones are given below.

7.1 Hot Dry Climate

7.1.1 *General* — The characteristic features of hot dry climate are that it is hot during summer, cool to very cold during winter and warm humid during monsoon season. Maximum day time summer temperature goes as high as 45°C and relative humidity as low up to 20 percent. Exclusion of sun during day time is required. Sunlight penetration is desirable during winter. Adequate provision for air change and comfort ventilation in monsoon period is required. Heavy massive structures with thick walls and roof are preferred as compared to thin concrete walls and asbestos cement roof. Building axis (that is, axis parallel to the longer side of the building) should fall East-West to minimize heat gains through walls in summer and maximize the same in winter. Location of rooms to be judiciously determined. Ceiling height more than 2.9 metres is not recommended.

7.1.2 *External Walls* — These should be constructed of bricks or similar locally available materials. The thickness of external wall should not be less than 22.5 cm. The building materials used should satisfy the requirements of strength, water absorption and durability as prescribed in relevant Indian Standards. Cavity walls, hollow block, etc, can also be used. The empty air space can be filled with loose insulating materials to improve the thermal performance.

7.1.3 *Unexposed Walls* — These should be constructed of suitable building materials and their thickness should not be less than 11.15 cm. Precast concrete panels, hollow blocks and lightweight cellular concrete blocks can also be used.

7.1.4 *Partition Walls* — These should be constructed of brick or other suitable materials. Structural and noise reduction requirements should be given due consideration.

Roof: Roof may be either a flat roof or sloping with asbestos cement.

7.1.5 *Flat Roof* — It should be of 10 cm RCC or reinforced brick cement (RBC) over which 7.5 cm thick mud *phuska* or cinder or any other equivalent insulting material is laid. It should be waterproofed with 7.5 cm of lime concrete or 5.9 cm of brick tiles or with 2 layers of tarfelt according to relevant Indian Standard.

7.1.6 *Sloped Roof* — It may be of either 6.0 mm asbestos cement sheets or of thatch or bricktile according to Indian Standards. In the former type roof, false-ceiling should be provided to improve thermal performance. For false ceiling, 2.5 cm of wood-wool board or other equivalent insulating materials should be used.

7.1.7 *Glazing* — Fenestrations having 15 to 20 percent of floor area should be used for ventilation and daylighting. Shutters, if used, should be capable of being closed tightly during summer days or winter nights. Shutters should be made of steel, aluminium or treated timber. Windows should be protected by external louvers, sun-breakers, etc. Internal shading like curtains, heat resistant glasses, double and painted glasses can also be used to avoid excessive solar heat penetration.

7.1.8 *Special Needs* — Outdoor sleeping areas for summer nights are essential. Cooling of building during summer months by spraying water on roofs, white washing and shading is needed. Use of ceiling fans is most desirable. Desert coolers, should be used in summer, if required. Unit type room heaters are also needed during winter months.

7.2 Hot and Humid Climate — Regions, where mean daily maximum dry bulb temperature is above 32°C and relative humidity above 40 percent prevail during the hottest month of the year and where the altitude is not more than 500 m above mean sea level, may be classified as hot and humid zones.

The thermal characteristic for hot arid zone and hot-humid zone are almost identical except that desert coolers are not suitable for hot-humid zone.

7.3 Warm Humid Climate — This climate is not excessively hot. Mean maximum temperature during summer does not rise beyond 32°C. Relative humidity ranges between 70 and 90 percent. Ventilation mainly determine thermal comfort. Fans are essential almost all the time and particularly during calm and rainy days. Ceiling height more than 2.7 metre is not recommended.

7.3.1 *Walls* — These should be of 11.25 cm brick or equivalent. Light weight concrete blocks, panels and hollow blocks of 10 cm are preferred. These should be suitably waterproofed for rain protection. Many municipal byelaws state that external walls must be of 22.5 cm thick brick or equivalent RCC so as to provide adequate protection against rain.

7.3.2 *Roofs* — Lightweight roof with AC sheet or precast flat roof is preferred. False ceiling is helpful but not essential. Protection against heavy rainfall is necessary.

7.3.3 *Glazing* — Windows having 15 to 20 percent of floor area for ventilation and daylighting should be located on walls in the direction of available wind. Windows longer in the horizontal direction and having low still height are preferred. Good arrangement of cross ventilation is essential.

7.3.4 *Special Needs* — Building axis to be preferably located along E-W or NE-SW axis to reduce solar heat gains by walls and improve wind movements. Good rain-water drainage is essential. Desert coolers are not suitable in these areas.

7.4 Cold Climate — Regions, where the mean daily dry bulb temperature of 6°C or less prevail during the months of December and January, and altitude is more than 1 200 m above mean sea level, may be classified as zones of cold climate. Main requirement in this region is heating during winter months. Walls and roof should be protected against heavy rain and snowfall.

7.4.1 *Walls* — These may be made of 11.25 cm brick with 2.5 cm of insulation on the inner side. Different kinds of insulation materials given in Table 2 can be used. The insulation should be protected against the risk of condensation by providing sufficient vapour barrier on the warm side. Vapour barrier like 2 coats of bitumen, polyethylene sheet 300 to 600 guage or aluminium foil can be used. Hollow and lightweight concrete blocks are also quite suitable.

7.4.2 *Roofs* — Roofs of houses in cold climate may be made from asbestos cement or GI sheets backed by false ceiling of wood, 2.5 cm wood-wool board or equivalent material. The roof should have sufficient slope for quick drainage of rain-water. Vapour barrier should be used depending upon location and possible wind pressure

7.4.3 *Glazing* — Windows of up to 25 percent floor area may be provided. Longer axis should be faced N-S to receive more solar heat during winter months. Double glazing is preferable to avoid heat losses during winter nights.

7.4.4 *Special Needs* — Artificial heating is essential during winter months. Ceiling fans are not normally required, but may be used during summer on special occasions. Outdoor sleeping space is not required.

7.5 Representative Towns — Some representative towns falling under various zones are as follows:

Hot and Arid Zone	*Hot and Humid Zone*	*Warm and Humid Zone*	*Cold Zone*
Agra	Ahmadabad	Cochin	Darjeeling
Ajmer	Asansol	Dwarka	Dras
Akola	Bhavanagar	Guwahati	Gulmarg
Aligarh	Bhuj	Puri	Leh
Allahabad	Bombay	Sibsagar	Mussoorie
Ambala	Calcutta	Silichar	Nainital
Bareilly	Calicut	Tezpur	Ootacamund
Bikaner	Cuttack	Trivandrum	Shillong
Gaya	Dohad	Veraval	Shimla
Jabalpur	Jamnagar		Skardu
Jaipur	Jamshedpur		Srinagar
Kanpur	Madras		
Khandwa	Madurai		
Kota	Mangalore		
Lucknow	Masulipatam		
Ludhiana	Midnapur		
Nagpur	Nellore		
Neemuch	Patna		
New Delhi	Rajkot		
Roorkee	Ratnagiri		
Sambalpur	Salem		
Sholapur	Surat		
Umaria	Tiruchichirapalli		
Varanasi	Vellore		
	Vishakhapatnam		

8. THERMAL DESIGN OF BUILDINGS

8.0 Indoor thermal conditions can be improved to a certain extent by a judicious selection of building components, optimum orientation, required glazing area and proper selection of shading devices. The main consideration of the design are given in **8.1** to **8.8**.

8.1 Optimum Orientation — The orientation of the building should be chosen according to the recommendations given in IS : 7662 (Part 1)-1974 'Recommendations for orientation of buildings : Part 1 Non-industrial buildings', if the site and other conditions are favourable. There is a need to avoid excessive heat in summer and heat losses in winter. At the same time, advantage of prevalent wind direction should also be taken to achieve desirable air motion indoors. It has been found that inclinations of apertures up to 30° with the expectable wind direction do not result in large deterioration in internal air motion. Therefore, in situations where there is conflict between solar heat gain and air motion, the actual site requirement should be the deciding factor for orientation.

8.2 Required Glazing Area — The minimum glazing area for any building should be decided for adequate daylight illumination indoors in accordance with IS : 2440-1975 'Guide for daylighting of building (*second revision*)'. Wherever possible, this area should also be adequate for comfortable ventilation.

The recommendations in IS : 3362-1977 'Code of practice for natural ventilation of residential buildings (*first revision*)', should be satisfied in the design of glazing for lighting and ventilation. Proper attention should be given for sufficient air motion in hot humid and warm humid climate. In such areas, fans are essential as a means of providing comfortable air motion indoors. Fenestrations having 15 to 20 percent of floor area are found adequate both for ventilation and daylighting in hot dry and hot humid regions.

8.3 Proper Selection of Shading Devices — It is always desirable to exclude much of the solar heat by shading windows. Shading devices used may be either external or internal or combination of both. The thermal performance of different shading devices are given in Table 15. From this, it is possible to select proper shading devices consistent with economics and performance for non-air-conditioned building. In hot dry and hot humid climate, shade factor of windows with shading device should be less than 0.5, whereas for air-conditioned buildings, it should be less than 0.3. The design for external shading like louvers, sun breakers, etc, is given in Part 1 of the Handbook. For non-air-conditioned buildings, landscaping element like trees, creepers, etc, provide sufficient protection against solar heat. They provide shade to walls and roof as well. Internal shading like curtains and plastic paints are equally effective and cheaper than venetian blinds.

8.4 Selection of Building Components — The thermal performance of a building depends upon thermal properties of the constituent wall and roof sections, outside surface finish, orientation and climatic condition. The required thermal performance standard, both for air-conditioned and non-air-conditioned buildings in three zones are given in Table 1. These are the maximum prescribed values and should not be exceeded. Computed *TPI* values of typical wall and roof sections for hot dry region are given in Tables 8, 9 and 10. The *TPI* values have been worked out for a typical summer design day with a fixed surface absorption coefficient ($\alpha = 0.7$). The list includes various types of wall and roofing elements, brick and stone masonry, hollow blocks, lightweight, and heavyweight roofs with and without insulation. Some designer may be interested in having a knowledge of expected surface temperatures and quantum of heat flow. These can be easily calculated from the equations given below:

Peak surface temperature $= 30 + 0.08 \times TPI$ (°C)

Peak heat gain $= 0.46 \times TPI$ (W/m^2)

8.5 Correction Factors — The correction factors, *C*, for calculating *TPI* values for various climatic zones due to effect of orientation and surface finish are given in Table 11. Corrected *TPI* values for non-air-conditioned and air-conditioned buildings are obtainable respectively from the following simple equations:

a) For non-air-conditioned buildings: Corrected $TPI = (TPI\text{-}50) \times C + 50$

b) For air-conditioned buildings: Corrected $TPI = C \times TPI$.

8.6 Heat Insulation of Roofs — Heat gain through roofs can be reduced by adopting the following techniques :

a) Heat insulating materials can be applied externally on roofs. In case of external application, insulating materials should be protected by waterproofing treatments. For internal application, these materials can be applied directly on the ceiling by an adhesive or applied in the form of a false ceiling with an air gap. Optimum thickness of various types of insulating materials, both for air-conditioned and non-air-conditioned buildings, are given in Table 16 alongwith range of densities, and maximum recomended thermal conductivity values. This will provide ready reference data for selection of insulating material and its thickness;

b) White washing the roof before the onset of summer;

TABLE 16 OPTIMUM THICKNESS OF INSULATION FOR ROOFS IN HOT DRY CLIMATE

[*Clause* 8.6(a)]

Sl No.	Name and Type of Insulating Material	Density Range Min	Density Range Max	Maximum Thermal Conductivity Value	Optimum Thickness Flat Roof UC	Optimum Thickness Flat Roof C	Optimum Thickness Sloped Roof UC	Optimum Thickness Sloped Roof C
(1)	(2)	(3) kg/m³	(4) kg/m³	(5) W/mK	(6) cm	(7) cm	(8) cm	(9) cm
i)	Cellular concrete	320.0	350.0	0.081	5.0	7.5	—	10.0
ii)	Coconut pitch concrete	500.0	600.0	0.087	5.0	7.5	—	10.0
iii)	Light weight bricks	400.0	450.0	0.081	5.0	7.5	—	10.0
iv)	Vermiculite concrete	480.0	560.0	0.105	5.0	10.0	—	12.5
v)	Wood-wool board	350.0	450.0	0.076	2.5	5.0	2.5	7.5
vi)	Foamtex	150.0	200.0	0.046	2.5	5.0	2.5	5.0
vii)	Thermocole	16.0	20.0	0.041	2.5	3.5	2.5	5.0
viii)	Fibreglass	24.0	32.0	0.041	2.5	3.5	2.5	5.0
ix)	Mineral wool	48.0	64.0	0.041	2.5	3.5	2.5	5.0
x)	Fibre insulation board	200.0	250.0	0.053	1.5	2.5	1.5	20.5

UC — Non-air-conditioned C — Air-conditioned

c) Spraying of water on roof. Loss due to evaporation can be compensated by sprinkling water at fixed intervals of time;

d) Shining and reflecting materials may be used on roof top.

The hourly heat flow and ceiling surface temperatures due to these treatments on roofs are shown respectively in Fig. 6 (A and B). From these, it is observed that ceiling temperatures can be reduced to an extent to satisfy conditions specified in Indian Standards. If the ceiling temperature is reduced below body temperature (37°C), ceiling acts as a heat receiver, and thus radiant load on the human body is reduced. The same is also true in case of intermediate floors of multistoreyed buildings where ceiling temperatures are most of the time below those of body and room air.

8.7 Ceiling Height — The minimum ceiling height from the point of view of thermal comfort is based upon three factors:

a) Required ceiling surface temperature,
b) Radiation load on the occupants, and
c) Safety requirement and minimum clear space for fixing ceiling fans.

If the ceiling temperature is reduced below the body temperature (37°C), ceiling acts as a heat receiver and this produces comfortable conditions. The same is true in case of intermediate floors of multistoreyed buildings where ceiling temperature is most of the time below that of body temperature.

Experiments conducted have shown negligible effect on indoor air temperatures due to variation of ceiling height from 2.4 to 3.3 m. The extent of reduction of temperature with increasing ceiling height is of the order of 0.3°C for increased height by every 30 cm for single storeyed buildings. The rise in air temperature due to lower ceiling height can be compensated by improving the thermal performance of roof. For intermediate floors in multistoreyed buildings, reduced ceiling height may even be more comfortable.

8.8 Heat Insulation of Exposed Walls — Brick walls 22.5 cm thick satisfy the requirement of IS : 3792-1978. A wall may be constructed of material with suitable thickness having *TPI* value less than 125. *TPI* values of traditional walls are given in Table 8. Thermal performance can be improved by: (a) increasing wall thickness, (b) providing cavity walls and hollow bricks, and (c) constructing the wall with suitable lightweight material like cellular concrete and cinder ash blocks provided structural requirements are satisfied. Light colour distemper may also be applied on the exposed side of the wall. Use of thermal insulating material on walls is not recommended, usually due to its cost.

9. INFLUENCE OF DESIGN PARAMETERS

9.0 Thermal design of buildings is influenced by various parameters, such as buildings materials and fabric specification, orientation, glass area, insulation, shading, fenestration, heating and cooling loads, ventilation rates, and location of rooms. It may not be possible by thermal design alone to create comfortable conditions indoors, and thus mechanical devices such as evaporative coolers and air-conditioners may be needed to pull down the thermal loads.

In this context, the buildings can be categorized into three types:

a) those which do not utilize any heating and cooling device, and use electrical energy for indoor lights and air motion;

b) the buildings in which heating and cooling devices such as unit air-conditioner, evaporative coolers, radiative and convective heaters are used; and

c) those buildings in which heating and cooling plants are employed to achieve thermal comfort.

Majority of our buildings fall either in first or second category.

9.1 Building Index — The thermal environment in a building depends upon the heat flow through fabric, distribution pattern of air, radiation exchanges between the various components of an enclosure and relative humidity. Of all these parameters, heat flow contributes the most. It is, therefore, obvious that thermal behaviour of a building can be judged by the total peak heat flow resulting on account of individual heat flows. An index known as 'Building Index' has thus been defined as the ratio of total maximum heat gain averaged over entire surface area of the building envelope to the acceptable limit of heat gain for achieving comfortable conditions indoors. The acceptable limit of heat gain has been taken as 46.00 W/m². The maximum limits of building index for different thermal comfort conditions and the corresponding indoor air temperature with fan are given in Table 17. It is clear from this table that a building index (BI) up to 50 gives comfortable conditions.

9.2 Thermal Performance of Buildings

9.2.1 Thermal performance of buildings depends upon three factors, namely, climate of the place, thermal design and usage of the building.

9.2.2 The effect of various design variables, for example, orientation, exposure of wall and roof, insulation, multistorey construction, white wash, glass area, ventilation rates, water spray on roof and night ventilation on building index was studied. The data on about 50 cases covering these factors was obtained for a typical summer day in hot dry region of the country. The general feature of building considered are given below:

Walls — 23 cm brick with plaster on both sides,
Roof — 7.5 cm lime concrete over 10 cm RCC slab,
Intermediate floor — 15 cm RCC slab,
Window — 3 mm glass,
Door — 2.5 cm teak wood,
Ventilation — 3 air changes per hour, and
Aspect ratio — 1 : 1.5.

9.2.3 The data on building index and comfort conditions for typical cases with different design variables are given in Table 18.

Wherever conditions are not specified in Table 18, the following features have been assumed:

Glass area	15 percent of floor area
Orientation	Longer axis of the building along East-West, and
Exposure	Only one wall.

9.3 Influence of Design Factors

9.3.1 The variations in BI values due to change in orientation can be seen from first four cases, it varies from 85 to 125 and the comfort conditions deteriorates as expected. The results indicate that, for any building, the wall with maximum glass area should face North/South direction, however, slight change in orientation is possible depending on the wind direction and site conditions. Cases 5 and 7 give the effect of multistorey construction and BI reduces considerably in case of ground floor.

9.3.2 The effect of glass area under similar conditions is evident from cases 2, 5 and 6. The increase in glass area enhances the heat intake and thereby indoor air temperatures. Therefore, minimum glass area should be provided, if other design conditions such as daylight and ventilation permit. The glass area can be increased to accommodate daylight and ventilation but in that case adequate shading should be provided over the glass area.

TABLE 17 LIMITS OF BUILDING INDEX CORRESPONDING TO AIR TEMPERATURE AND COMFORT CONDITIONS

(*Clause* 9.1.1.)

SL No.	BUILDING INDEX	INDOOR AIR TEMPERATURE °C	COMFORT CONDITIONS WITH FAN
i)	0-50	32	Comfortable
ii)	51-100	32-36	Slightly warm
iii)	101-150	36-40	Hot

9.3.3 Insulation against heat and evaporative surfaces help in reduction of heat input to the buildings. Light, medium and heavy insulation, white wash and water spray on roof have been considered. As is reflected from BI values (cases 8 to 14), these treatments improve indoor condition. The BI varies from 62 to 100.

9.3.4 The exposure of walls to prevent solar heat and reduction in thickness of the wall, increases the building index from 73 to 87 whereas increase in thickness of wall and reduced exposure of walls to solar heat helps in overall improvement of thermal environment indoors.

9.4 Reduction in Peak Cooling Load — To make a building thermally comfortable for human living, heating or cooling of buildings is required. It is important to assess the reduction in energy requirements using the suggested treatments. The extent of reduction in energy requirement can be assessed with the help of data given in Table 18.

10. MECHANICAL CONTROLS

10.1 In most of the cases, it may not be possible to control to desirable extent an internal environment by natural means alone. In such cases, one must preferably adopt mechanical means for controlling internal conditions.

10.2 Types of Mechanical Controls

10.2.1 A large number of mechanical controls are available. The type of the mechanical controls to be employed is decided by the following considerations:

a) Type of building, whether residential, office, hospital or industrial;
b) Size of the building and occupancy;
c) Whether year round air-conditioning is required; and
d) Outside climatic conditions of the place.

10.2.2 The different systems of mechanical controls available are:

a) Unit room air-conditioners or spot coolers,
b) Packaged air-conditioners,
c) Radiant cooling panels,
d) Evaporative cooling, and
e) Central air-conditioning plant.

10.3 Unit Room Air-Conditioners or Spot-Coolers

10.3.1 These are self-contained air-conditioning units, comprising a compressor, evaporator fan and air-cooled condenser. This unit is used for single rooms having limited occupancy. These are suited for bedrooms, office cabins, general office areas, hotel rooms and hospitals, and similar applications where normal comfort conditions are required.

10.3.2 *Capacity* — Room air-conditioners are available in nominal capacities of 1 500, 2 250, 3 000, 3 750, 4 500, 5 250, 6 000, 7 500 and 9 000 kcal/h.

10.3.3 *Factors Affecting Cooling Load Estimates*

a) *Occupancy* — Number of people smoking and non-smoking.
b) *Extent of glazing and orientation.*
c) *Exposure* — Roof, ceiling, floor, walls, partitions.
d) *Internal Load* — Lighting and other heat generating sources like equipment and machinery.
e) *Ventilation* — Requirement for fresh air.

10.3.4 *Location* — Room air-conditioner shall be mounted at the window sill level on an external wall where hot air from the air cooled condenser can be discharged to outside without causing a nuisance. There should not be any obstruction to the inlet of air for the condenser.

10.3.5 *Installation* — The opening for the air-conditioner shall preferably be made a part of window or wall construction from the planning stage.

10.3.6 *Limitations* — These are not generally recommended for:

a) operation theatres where 100 percent fresh air is needed and fire hazard exists, depending on the type of anaesthesia being used.
b) width of the area exceeds 6 m;
c) area requiring close control of temperature and relative humidity;
d) internal zones where no exposed wall is available for the installation of room air-conditioners;
e) sound recording rooms where criteria for acoustics are stringent; and
f) special applications like sterile rooms for hospitals and clean room applications where high filtration efficiency is desired;

10.4 Packaged Air-Conditioners

10.4.1 Window air cooled packaged units are available up to a limited capacity. Floor mounted self-contained packaged units are made to meet the requirements for large capacities. This unit comprises a compressor, condenser (water-cooled or air-cooled), evaporator, fans, filter and controls. It may also include means for heating, humidifying or ventilating air. These units are designed for application in residences and in the smaller commercial market-shops, restaurants, small office suits, etc.

10.4.2 *Capacity* — Commercial packaged air-conditioners are available in sizes of the nominal cooling capacity 10 000 W (approximately 9 000 kcal/h) and above.

10.4.3 Factors affecting cooling load estimates as specified in **10.3.3** shall be taken into account while making the heat calculation.

TABLE 18 BUILDING INDEX AND COMFORT CONDITIONS IN VARIOUS SITUATIONS

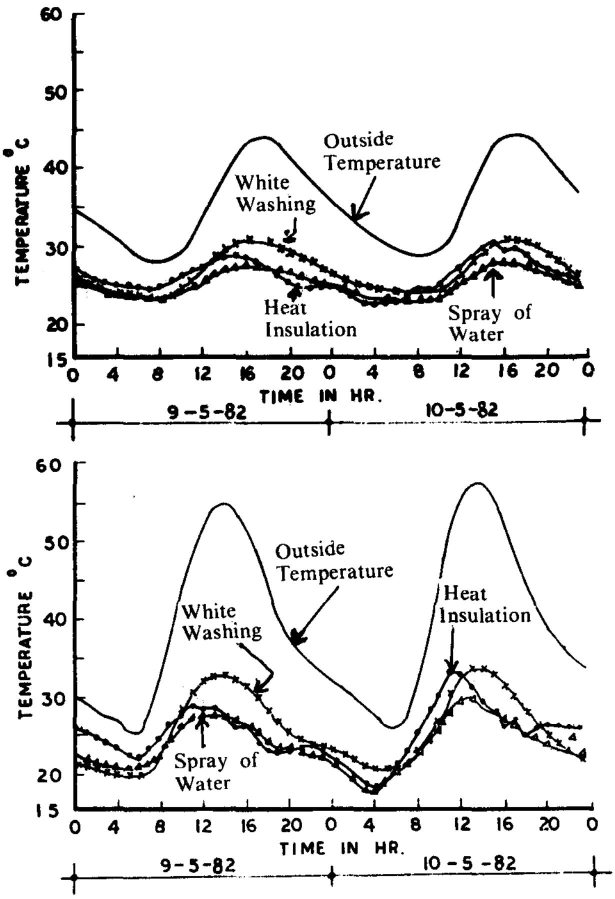
(*Clause* 9.4)

Sl No.	Type of Treatment	Building Index	Comfort Conditions with Fan
(1)	(2)	(3)	(4)
	Multistoreyed Construction		
i)	Top floor unshaded glass area (15 percent of floor area), North orientation	85	SW
ii)	Same as (1), South orientation	87	SW
iii)	Same as (1), East orientation	112	H
iv)	Same as (1), West orientation	125	H
v)	Same as (2) but glass area shaded	73	SW
vi)	Same as (5) but glass area 30 percent of floor area	85	SW
vii)	Same as (5) but ground floor	56	C-SW
	Single Storey Construction		
viii)	Light insulation on roof, glass area shaded	100	H
ix)	Same as (8) medium insulation on roof	78	SW
x)	Same as (8) heavy insulation on roof	69	SW
xi)	Same as (8) roof white washed	85	SW
xii)	Same as (9) roof white washed	62	SW
xiii)	Water spray on bare roof (RCC)	62	SW
xiv)	Water spray with gunny bags on bare roof (RCC)	40	C
xv)	One wall exposed	73	SW
xvi)	Two wall exposed	78	SW
xvii)	Three walls exposed	87	SW
xviii)	11.5 cm brick wall, one wall exposed	79	SW
xix)	33.75 cm brick wall, one wall exposed	70	SW

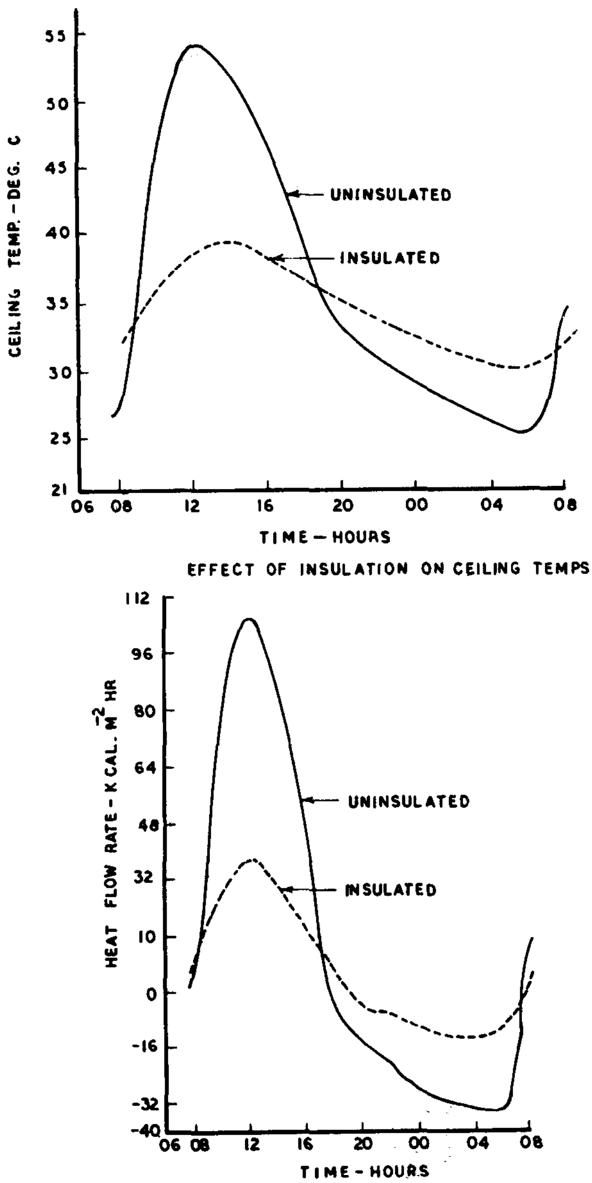
H = Hot, SW = Slightly warm, C = Comtortable.

10.4.4 *Location* — The packaged units can be mounted within the air-conditioned space or remote in a separate enclosure. Provision shall be kept for proper servicing facility around the unit.

10.4.5 *Installation* — The packaged units are normally mounted on a resilient pad which prevents vibration of the compressor from being transmitted to the building.



6A EFFECT OF VARIOUS TREATMENTS ON FLAT ROOFS



6B EFFECT OF INSULATION ON INDUSTRIAL ROOF

FIG. 6 HOURLY HEAT FLOW AND CEILING SURFACE TEMPERATURES DUE TO HEAT INSULATION TREATMENT ON ROOFS

10.5 Radiant Cooling Panels — Cooling panels with perimetric location are best for radiant heating/cooling. The pipes above the aluminium panels are supplied with chilled water. The temperature of the panel should be greater than the dew point temperature of the room air, otherwise condensation will take place on the panel. Radiant cooling is very efficient, clean and healthy with complete elimination of draft, and circulation of dust. Radiant cooling is most economical when the same panel is also used for winter heating. A heat pump can then be used to provide hot water in winter and cold water in summer to the radiating panel.

10.6 Evaporative Cooling

10.6.1 In view of the rise in energy cost, the use of evaporative coolers has become necessary, particularly for the hot and arid region. In areas where the air is very hot and dry, it is possible to reduce the dry bulb temperature by passing air over a wetted surface. This type of coolers cannot be used in damp climates because the moisture content of the air leaving the coolers is very high, thus raising the humidity above comfort level.

10.6.2 Fresh outside air should be used with no recirculation because by recirculating the air leaving the evaporating cooler, the wet bulb temperature shall continue to increase and shall result in unsatisfactory conditions.

10.6.3 *Capacity* — The nominal capacities of the evaporative air coolers based on the delivery of air at 'zero' static pressure shall be as under:

750, 1 000, 1 200, 1 500, 1 800, 2 000, 2 500, 3 000, 4 000, 5 000, 6 000 and 8 000 m^3/h.

10.7 Central Air-Conditioning Plant

10.7.1 In this system, the equipment, such as fan, cooling coils, filters and cooling tower are designed for assembly in the field. The refrigeration equipment is located at one place. The cool air is carried to different rooms by means of supply ducts and returned back to central plants by return ducts.

10.7.2 Advantages of the central system are:

a) lower investment cost as compared to the total cost of separate units,
b) better accessibility for maintenance,
c) space occupied is negligible as compared to room units, and
d) noise from mechanical vibrations of the equipment is eliminated or reduced.

Figure 7 and Fig. 8 show the block diagram of a central system in different parts of a typical building.

10.7.3 Depending on the refrigeration load, the system normally employed in majority of cases are as follows:

Capacity in Tons	*System Used*
0 to 10 tons	Unit air-conditioners located in the room to be air-conditioned
0 to 25 tons	Factory assembled packaged units using duct work
25 to 100 tons	Central cooling plants with duct work using reciprocating compressors
100 tons and above	Central system using centrifigual compressors (chilled water plants and fan coil or induction units).

10.8 Air-Conditioning

10.8.1 Air-conditioning is the application of methods for controlling the temperature of internal environments for the purpose of: (a) promoting human health and comfort, (b) improving working efficiency, (c) maintaining materials in the most suitable conditions for storage and manufacturing operations, and (d) supplying conditioned air (hot or cold) for industrial process. Multistoreyed office, hotel and other buildings are air-conditioned to increase working efficiency and to provide optimum thermal comfort of the occupants. Thermal comfort depends on proper combination of dry bulb temperature, relative humidity and air velocity.

10.8.2 Some of the factors that need consideration in air-conditioning are:

a) cleaning the air to make it free from dust, dirt and other impurities;
b) control of inside temperature to the optimum value either for summer cooling or for winter heating,
c) control of humidity to the desired level, and
d) control of air motion which includes the distribution of air as well. This is necessary to keep uniform temperature distribution throughout the room.

10.8.3 For deriving the necessary comfort from 'Comfort Air-Conditioning', the inside dry bulb and wet bulb temperature may be adopted as given in Table 19 for summer and Table 20 for winter.

TABLE 19 INSIDE DESIGN CONDITIONS FOR SUMMER

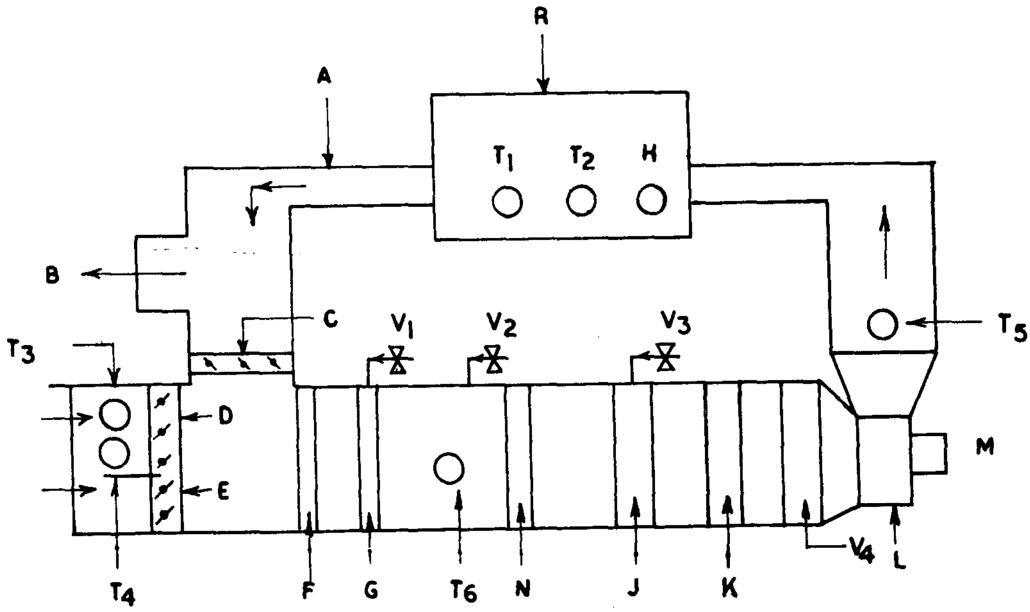
(*Clause* 10.8.3)

Sl No.	Optimum Conditions		Maximum Conditions	
	Dry Bulb Temperature	Wet Temperature	Dry Bulb Temperature	Wet Bulb Temperature
(1)	(2) °C	(3) °C	(4) °C	(5) °C
i)	23.3	19.4	25.9	21.8
ii)	23.9	18.4	26.1	21.6
iii)	24.4	17.6	26.7	20.9
iv)	25.0	16.8	27.2	20.1
v)	25.6	16.0	27.8	19.4
vi)	26.1	15.2	28.3	18.8
vii)	--	—	28.9	18.1
viii)	—	—	29.4	17.5

TABLE 20 INSIDE DESIGN CONDITIONS FOR WINTER

(*Clause* 10.8.3)

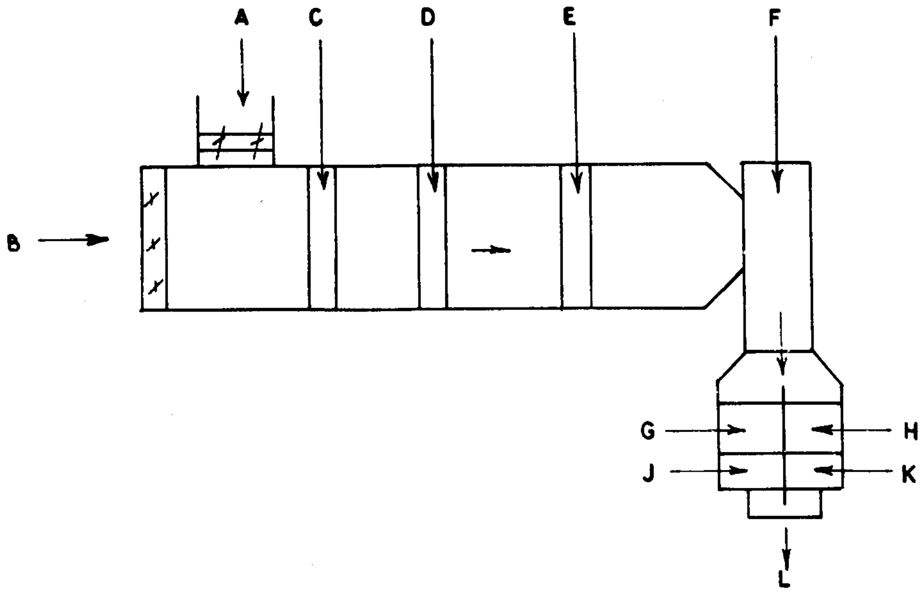
Sl No.	Optimum Conditions		Maximum Conditions	
	Dry Bulb Temperature	Wet Temperature	Dry Bulb Temperature	Wet Bulb Temperature
(1)	(2) °C	(3) °C	(4) °C	(5) °C
i)	21.4	17.8	18.3	15.0
ii)	21.7	17.3	18.9	13.4
iii)	22.2	16.4	19.4	12.0
iv)	22.8	15.3	19.7	10.8
v)	23.3	14.4	—	—
vi)	23.6	13.4	—	—



A: RETURN AIR
B: EXHAUST FAN
C: RETURN AIR DAMPER
D: MAX. OUTDOOR DAMPER
E: MIN. OUTDOOR DAMPER
F: FILTERS
G: TEMPERING COIL
H: HUMIDISTAT
J: REHEATING COIL
K: HUMIDIFIER
L: AIR FAN
M: MOTOR
N: COOLING COIL

T_1: ROOM THERMOSTAT FOR HEATING
T_2: ROOM THERMOSTAT FOR COOLING
T_3: OUTDOOR AIR DUCT DIRECT ACTING THERMOSTAT
T_4: OUTDOOR AIR DUCT INDOOR ACTING THERMOSTAT
T_5: LOW LIMIT DISCHARGE THERMOSTAT
T_6: DUCT THERMOSTAT
V_1 V_2 V_3 V_4 VALVES
R: ROOM

FIG. 7 BLOCK DIAGRAM OF A CENTRAL SYSTEM OF A TYPICAL BUILDING



A: RETURN DUCT
B: OUT DOOR DUCT
C: FILTER
D: TEMPERING COIL
E: HUMIDIFIER
F: FAN
G: HEATING COIL
H: COOLING COIL
J: HOT CHAMBER
K: COLD CHAMBER
L: DUCT FOR ANY ONE ZONE

FIG. 8 BLOCK DIAGRAM OF A CENTRAL SYSTEM OF A TYPICAL BUILDING

10.8.4 The outside design conditions for 16 cities of India based on 2.5 percent exceeded temperature values over a period of ten years collected by the India Meteorological Department are given in Table 21. These should be used for the purpose of air-conditioning design load calculations.

10.8.5 For air-conditioning systems, other than comfort, design condition as required by the process involved may be adopted. Adequate movement of air shall always be provided in air-conditioned enclosure. The air velocity shall be within 15 to 30 m/min in the zone between floor and 1.5 m above this.

10.8.6 The total minimum outside fresh air introduced in the building by an air-conditioning plant shall be related to the number of occupants smoking or non-smoking and the type of building. The minimum outside fresh air requirements are given in Table 22.

10.8.7 *Planning of Air-conditioned Building*

10.8.7.1 The plans for air-conditioning systems shall include all details and data necessary for review of installation. These are:

a) building name, type and location;
b) owner's name;
c) orientation, north point on plans;
d) general plans, dimensions and height of all rooms;
e) intended use of all rooms;
f) detail or description of wall construction including insulation and finish;
g) detail or description of roof, ceiling and floor construction including insulation and finish;
h) detail or description of windows and outside doors including size, weather stripping, storm sash, sills, storm doors, etc;
j) layout showing the location, size and construction of the cooling tower (apparatus), ducts, distribution system;

k) information regarding location, sizes and capacity of air distribution system, refrigeration and heating plant, and air handling equipment;
m) information regarding type of dampers used in air-conditioning supply grille system;
n) chimney or gas vent size, shape and height;
p) internal equipment load, such as number of people, motor, heaters and lighting load; and
q) location and grade of the required fire separations.

10.8.8 *Pre-planning* — In the event of buildings not being air-conditioned at the time of construction and proposed to be air-conditioned at a later stage, provisions for structural and other requirements of the system shall be made at the planning stage (*see* **10.8.8.1** to **10.8.8.7**).

10.8.8.1 *Equipment room for central air-conditioning plant*

a) In selecting the location for plant room, the aspects of efficiency, economy and good practice should be kept in mind and, where possible, it shall be made contiguous with the building. This room shall be located as centrally as possible with respect to the area to be air-conditioned and shall be free from obstructing columns.

   In the case of large installations (500 ton and above), it is advisable to have a separate isolated equipment room, where possible. The clear headroom below soffit of beam should be a minimum of 3.6 m from finished floor level. In the case of smaller plants, this may be reduced to 3 m.

b) The floors of the equipment rooms should be of light colour and finished smooth. For floor loading, the air-conditioning engineer shall be consulted.

c) Generally, in the case of all plants, structural provisions shall be made for supporting the water pipes from the floor/ceiling slabs.

d) All equipment rooms, wherever necessary, shall have provision for mechanical ventilation. For space requirements, air-conditioning engineer shall be consulted.

e) Adequate floor drain for disposal of waste water from the equipment room shall be provided.

f) Wherever required, the structure of the equipment room should be windowless to prevent noise transmission. Wherever possible and necessary, acoustic treatment should be given to prevent transmission of equipment noise. The plant machinery shall be founded on anti-vibratory supports.

g) Pipe supports shall be such that they are isolated from the structure and do not transmit vibration to the building.

10.8.8.2 *Risers*

a) In the case of centralized air handling units, catering for a number of floors, air risers for supply ducts and return air are necessary. The risers shall commence from the roof of the air handling room and shall extend up to the slab of the last floor.

TABLE 21 OUTSIDE DESIGN CONDITIONS FOR SUMMER

(*Clause* 10.8.4)

City	Temperature, °C							
	Dry Bulb				Wet Bulb			
	1 percent	2.5 percent	5 percent	10 percent	1 percent	2.5 percent	5 percent	10 percent
Ahmadabad	42.8	41.7	40.7	39.5	27.6	27.2	26.9	26.4
Amritsar	42.5	41.5	40.3	38.4	27.9	26.9	26.3	25.3
Bhopal	41.7	40.8	39.8	38.5	25.3	24.8	24.4	23.8
Bombay	34.5	33.8	33.6	32.8	28.4	28.0	27.8	27.4
Calcutta	39.5	38.3	37.4	35.6	29.3	29.2	28.8	28.4
Coimbatore	36.7	35.9	34.9	33.7	28.3	27.4	26.7	25.9
Delhi	43.0	41.9	41.4	40.3	28.1	27.2	26.4	25.8
Hyderabad	39.5	38.7	37.9	36.7	25.3	24.4	23.9	23.5
Jodhpur	43.5	42.5	41.3	40.0	27.9	27.2	26.5	25.8
Lucknow	42.8	41.9	41.0	39.5	28.3	27.7	27.2	26.5
Madras	39.2	37.8	36.9	35.5	28.5	28.2	27.8	27.4
Nagpur	42.9	42.0	41.1	39.9	27.5	26.2	25.6	25.1
Patna	42.4	41.1	39.9	38.3	28.1	27.8	27.4	27.1
Roorkee	42.5	41.4	40.6	39.2	27.8	26.9	26.1	25.6
Trivandrum	32.9	32.4	31.8	31.0	27.2	26.9	26.7	26.4
Vishakhapatnam	38.4	37.0	36.0	35.1	30.4	29.7	29.3	28.8

b) The walls of risers in the corridor/space shall be constructed only up to 1 m from finished floor level. They shall be built up to the ceiling only after installation of ducts.

10.8.8.3 *Openings for supply air ducts and return air*

a) For supply air ducts and return air, openings are necessary on each floor. They are connected through an opening to the riser. Adequate clearance shall be provided for the installation of supply and intake duct, and their connection to the risers.

b) Duct supports in the form of recessed anchors of projecting mild steel flats with holes drilled for support belts shall be cast with the ceiling slab.

c) False ceiling shall be provided after the ducts are laid. The supports for the duct and the false ceiling shall be independent.

d) Where a duct penetrates the masonry wall, it shall either be lined on outside with felt to isolate it from the masonry, or an air gap shall be left around it.

10.8.8.4 *Supply and return air opening* — For side and ceiling outlets, provision in walls and ceiling shall be left in consultation with an air-conditioning engineer.

10.8.8.5 *Shaft for pipes* — Provision shall be made for a suitable shaft for condenser chilled water and refrigeration pipes from the main equipment room to the air handling unit room and/or cooling tower, where necessary.

10.8.8.6 *Glazing* — In view of high energy cost, adequate protection shall be provided by keeping away the heat load through glazing and other methods.

The window area required in a building is based on daylighting consideration. Windows should be

TABLE 22 MINIMUM FRESH AIR REQUIREMENTS

(*Clause* 10.8.6)

SL NO.	APPLICATION	SMOKING	AIR REQUIREMENT, m³/min		
			Recommended	Minimum	Per m² of Floor Area
(1)	(2)	(3)	(4)	(5)	
i)	Apartments	Some	0.56	0.28	—
ii)	Banking space	Occasional	0.28	0.21	—
iii)	Board rooms	Very heavy	1.40	0.56	—
iv)	Department stores	None	0.21	0.14	0.015
v)	Directors' rooms	Very heavy	1.40	0.84	—
vi)	Drug stores*	Considerable	0.28	0.21	—
vii)	Factories†	None	0.28	0.21	0.03
viii)	Garages	—	—	—	0.30
ix)	Hospitals:				
	a) Operating rooms (all fresh air)	None	—	—	0.60
	b) Private rooms	None	0.84	0.70	0.10
	c) Wards	None	0.56	0.28	—
x)	Hotel rooms	Heavy	0.84	0.70	0.10
xi)	Kitchens:				
	a) Restaurant	—	—	—	1.20
	b) Residence	—	—	—	0.60
xii)	Laboratories*	Some	0.56	0.42	—
xiii)	Meeting rooms	Very heavy	1.40	0.84	0.38
xiv)	Offices:				
	a) General	None	0.42	0.28	—
	b) Private	some	0.70	0.42	0.08
		Considerable	0.84	0.70	0.08
xv)	Restaurants:				
	a) Cafeteria*	Considerable	0.34	0.28	—
	b) Dining room	Considerable	0.42	0.34	—
xiv)	Retail shop	None	0.28	0.21	—
xvii)	Theatre	None	0.21	0.14	—
		Some	0.42	0.28	—
xviii)	Toilets (exhaust)	—	—	—	0.60

*In case exhaust air required is more than fresh air specified, fresh air requirements will take exhaust considerations into account.

†May be governed by local byelaws (*see also* National Building Code : Part VIII Building Services, Section 1 Lighting and ventilation).

located preferably in south and north orientation to prevent excessive heat flow. Whenever this is not feasible, double glazing or heat resistant glass should be used. The design of external louvers should be done in such a way as to obtain a shade factor of window less than 0.3. Windows which are completely shaded externally gives a shade factor less than 0.3.

10.8.8.7 *Roof insulation* — The exposed roof should be insulated with suitable insulating materials. The insulation should be properly waterproofed to prevent loss of insulating properties.

The overall thermal transmittance from the exposed roof should be kept as minimum as possible and under normal conditions, the desirable value should not exceed 0.58 W/(m^2°C).

The ceiling surface of floors which are not to be air-conditioned shall be suitably insulated to give an overall thermal transmittance not exceeding 1.16 W/(m^2°C).

10.8.9 *Inspection and Maintenance* — No air-conditioning, refrigerating or ventilating system requiring a permit shall be put in commission until it has been tested and found safe by the Competent Authority. All tests shall be conducted in accordance with the standard specifications. After testing, a certificate shall be issued by the Authority upon request.

10.8.10 *Calculation of Cooling Load* — The cooling or heating equipment installed must be able to remove or add heat at the rate at which it is produced or removed and thereby maintain the given comfort conditions inside the room. The capacity of the plant, if designed for peak load, would require higher capital cost. If the capacity is designed for average loads, there may be long periods of discomfort and plant may not work satisfactorily during peak seasons. Hence the capacity must be estimated at a value which wisely accounts both the energy requirements and thermal comfort conditions.

10.8.11 *Reduction of Refrigeration Plant Capacity* — Solar heat gain through buildings is a major component of the total cooling load. All possible ways to reduce this must be given due consideration at the design stage itself.

a) Direct solar radiation entry through glass areas should be minimized by providing appropriate external shading devices, for example, louvers, sunbreakers, etc;

b) It can also be reduced by using internal shading devices like venetian blinds, curtains, double glazing, and heat absorbing and reflecting glasses;

c) Glass areas on East and West facades should be minimum. The external exposed surfaces of buildings may be of light colour;

d) By providing suitable insulating materials on the roof, entry of solar heat into the building may be reduced. Roof spray and white wash can be utilized to a great advantage in reducing solar heat gains through roofs;

e) Thermal capacity of the buildings can also be utilized to some advantage by providing swing of 1 or 2°C in indoor air temperature; and

f) Contribution to cooling load from lights can be reduced by designing the building fenestration for adequate daylight.

APPENDIX A

(*Clause* 5.2.1)

WORKED OUT EXAMPLES

A-1. CALCULATION OF REDUCTION IN HEAT GAIN

Example 1

Calculate the reduction in heat gain through a window 3 × 2 m for 20 percent glazed area.

a) When orientation is changed from West to South, and
b) When the plain glass window is covered by venetian blind.

Given

i) Heat Gain Factor (HGF) for West orientation = 116.3 W/m^2

ii) Heat Gain Factor for South orientation = 58.1 W/m^2

iii) Shade Factor (SF) of plain glass window = 1.0

iv) Shade Factor of plain glass window covered with venetian blind = 0.4

Solution

a) Reduction in heat gain

through the window = Area × HGF
= 6 × 58.1
= 348.6 W

b) Reduction in heat gain in West orientation = SF × Area × HGF
= 0.4 × 6 × 116.3
= 279.3W

Net reduction due to venetian blind = (6 × 116.3 − 279.3)
= 418.5 W

Similarly, net reduction in heat gain in South orientation = (6 × 58.1 − 0.4 × 6 × 58.1)
= (348.6 − 139.4)
= 209.2 W

Example 2

Calculate the reduction in heat gain through a roof of 10 × 6 m if 10 cm RCC + 8.5 cm lime terracing roof is insulated with 5 cm of foamed concrete.

Given

a) HGF of 10 cm RCC + 8.5 cm lime terracing = 64.96 W/m^2

b) HGF of the above roof if insulated with 5 cm of foam concrete = 27.86 W/m^2

Solution

Reduction in heat gain due to insulation = Area × Difference in HGF
= (10 × 6) × (64.96 − 27.86)
= 60 × 37.1
= 2 226 W

Example 3

Calculate the total amount of air required to remove the heat from a building when: (a) sensible load is 11 630 W and (b) latent heat load 3 489 W.

Solution

a) From equation

$$Q_s = \frac{2.976\,8\ K_s}{t}$$

where

Q_s = quantity of air in m^3/h,
K_s = sensible load in W, and
t = difference in temperature in °C between outside and inside and is of the order of 4°C

Here

$$K_s = 11\,630 \text{ W} \qquad t = 4°\text{C}$$

$$Q_s = \frac{2.976\,8 \times 11\,630}{4}$$

$$= 8\,655 \text{ m}^3/\text{h}.$$

b) Quantity of air required to remove latent heat load from the equation

$$Q_l = \frac{K_l}{814\ (w_o - w_i)}$$

where

Q_l = quantity of air in m^3/h,
K_l = latent heat load in W, and
$(w_o - w_i)$ = difference in the specific humidity between outside and inside.

Here

K_l = 3 489 W
$(w_o - w_i)$ = 0.004 kg/kg of dry air, difference in the moisture content from 50 to 80 percent relative humidity.

$$Q_l = \frac{3\,489}{814 \times 0.004} = 1\,072 \text{ m}^3/\text{h}$$

Therefore, total quantity of air required is

$$Q_T = Q_s + Q_l$$
$$= 8\,655 + 1\,072$$
$$= 9\,727 \text{ m}^3/\text{h}$$

A-2. CALCULATION OF THERMAL TRANSMITTANCE (U) FOR TYPICAL CASES

A-2.1 Procedure

a) Calculate thermal resistance R of each uniform material which constitutes the building unit as follows:

$$R = \frac{L}{k}$$

where

L = thickness of material in m, and
k = thermal conductivity in

$$\frac{\text{W}}{\text{mK}}$$

b) Find the total thermal resistance R_T as follows:

$$R_T = \frac{1}{f_o} + \frac{1}{f_i} + R_1 + R_2 + R_3 + \ldots\ldots$$

where

f_o = outside surface conductance (*see* Note),

f_i = inside surface conductance (*see* Note), and

R_1, R_2, R_3 = thermal resistance of different materials.

NOTE — The following values of surface heat transfer coefficient and air conductance have been taken for the computation of various parameters:

a) Outside film coefficient at an air velocity of 8.0 km/h (f_o)	19.86 W/(m²K)	
b) Inside film coefficient at still air (f_i)	9.36 W/(m²K)	
c) Enclosed air space conductance [W/(m²K)]	For E = 0.82	For E = 0.2
1) Vertical closed air space thickness greater than 2.0 cm at 50°C	6.22	2.72
2) Horizontal air space thickness greater than 2.0 cm at 50°C (heat flow downwards)	6.22	2.04

$$U = \frac{1}{RT}\ \mathrm{W/(m^2K)}$$

Example 4

To find U for 19 cm thick brick outside wall provided with 1.00 cm thick plaster on both sides.

Solution

1) $k_1 = 0.721\ \mathrm{W/(mK)}$

$k_2 = 0.811\ \mathrm{W/(mK)}$

$k_3 = 0.721\ \mathrm{W/(mK)}$

$L_1 = 0.01$ m, $L_2 = 0.19$ m, $L_3 = 0.01$ m

$$R_1 = \frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.19}{0.811} = 0.234\,3$$

$$R_3 = \frac{L_3}{k_3} = \frac{0.01}{0.721} = 0.013\,9$$

$$\frac{1}{f_i} = \frac{1}{9.36} = 0.106\,8$$

$$\frac{1}{f_o} = \frac{1}{19.86} = 0.050\,4$$

2) $R_T = \frac{1}{f_o} + \frac{1}{f_i} + R_1 + R_2 + R_3 = 0.419\,3$

3) $U = \frac{1}{R_T} = \frac{1}{0.419\,3} = 2.385\ \mathrm{W/(m^2K)}$

Example 5

To find U for outside wall of two layers of 9.00 cm brick with 5 cm air gap in between and plastered with 1.00 cm thick cement plaster on both sides.

Solution

1) $k_1 = k_5 = 0.721\ \mathrm{W/(mK)}$

$k_2 = k_4 = 0.811\ \mathrm{W/(mK)}$

$L_1 = 0.01$ m, $L_2 = 0.09$ m, $L_4 = 0.09$ m, $L_5 = 0.01$ m

$C_3 = 6.22\ \mathrm{W/(m^2K)}$ (for emissivity = 0.82)

$$R_1 = \frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.09}{0.811} = 0.111\,0$$

$$R_3 = \frac{1}{C_3} = \frac{1}{6.22} = 0.160\,8$$

$$R_4 = \frac{L_4}{k_4} = \frac{0.09}{0.811} = 0.111\,0$$

$$R_5 = \frac{L_5}{k_5} = \frac{0.01}{0.721} = 0.013\,9$$

$$\frac{1}{f_i} = \frac{1}{9.36} = 0.106\,8$$

2) $R_T = 0.567\,8$

3) $U = \frac{1}{R_T} = \frac{1}{0.567\,8} = 1.761\ \mathrm{W/(m^2K)}$

Example 6

To find U for 19.00 cm brick outside wall insulated with 2.50 cm expanded polystrene and finished on both sides with 1.00 cm cement plaster.

Solution

1) $k_1 = k_2 = 0.721\ \mathrm{W/(mK)}$

$k_2 = 0.811\ \mathrm{W/(mK)}$

$k_3 = 0.035\ \mathrm{W/(mK)}$

$L_1 = 0.01$ m, $L_2 = 0.19$ m, $L_3 = 0.025$ m, $L_4 = 0.01$ m

$$R_1 = \frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.19}{0.811} = 0.234\,3$$

$$R_3 = \frac{L_3}{k_3} = \frac{0.025}{0.035} = 0.714\,3$$

$$R_4 = \frac{L_4}{k_4} = \frac{0.01}{0.721} = 0.013\,9$$

$$\frac{1}{f_i} = \frac{1}{9.36} = 0.106\,8$$

$$\frac{1}{f_o} = \frac{1}{19.86} = 0.050\,4$$

2) $R_T = 1.133\,6$

3) $U = \frac{1}{R_T} = \frac{1}{1.133\,6} = 0.882 \text{ W/(m}^2\text{K)}$

Example 7

To find U for a 15 cm thick RCC roof slab plastered on both sides with 1 cm thick cement plaster.

Solution

1) $k_1 = k_3 = 0.721$ W/(mK)

$k_2 = 1.58$ W/(mK)

$L_1 = 0.01$ m, $L_2 = 0.15$ m, $L_3 = 0.01$ m

$$R_1 = \frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.15}{1.58} = 0.094\,9$$

$$R_3 = \frac{L_3}{k_3} = \frac{0.01}{0.721} = 0.013\,9$$

$$\frac{1}{f_i} = \frac{1}{9\,36} = 0.106\,8$$

$$\frac{1}{f_o} = \frac{1}{19.86} = 0.050\,4$$

2) $R_T = 0.279\,9$

3) $U = \frac{1}{R_T} = \frac{1}{0.279\,9} = 3.573 \text{ W/(m}^2\text{K)}$

Example 8

To find U for a 15 cm thick RCC roof slab insulated with 5 cm thick expanded polystyrene and finished with 4 cm thick brick tiles on the top and 1 cm thick cement plaster on the bottom.

Solution

1) $k_1 = 0.798$ W/(mK)

$k_2 = 0.035$ W/(mK)

$k_3 = 1.58$ W/(mK)

$k_4 = 0.721$ W/(mK)

$L_1 = 0.04$ m, $L_2 = 0.05$ m, $L_3 = 0.15$ m, $L_4 = 0.01$ m

$$R_1 = \frac{L_1}{k_1} = \frac{0.04}{0.798} = 0.050\,1$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.05}{0.035} = 1.428\,6$$

$$R_3 = \frac{L_3}{k_3} = \frac{0.15}{1.58} = 0.094\,9$$

$$R_4 = \frac{L_4}{k_4} = \frac{0.01}{0.721} = 0.013\,9$$

$$\frac{1}{f_i} = \frac{1}{9.36} = 0.106\,8$$

$$\frac{1}{f_o} = \frac{1}{19.86} = 0.050\,4$$

2) $R_T = 1.7447\,7$

3) $U = \frac{1}{R_T} = \frac{1}{1.744\,7} = 0.573 \text{ W/(m}^2\text{K)}$

Example 9

To find U for a roof of construction as in Example 4 and having a false ceiling made of two layers of 1.2 cm soft board with an air gap of 2 cm.

Solution

1) $k_1 = k_3 = 0.721$ W/(mK)

$k_2 = 1.58$ W/(mK)

$k_5 = k_7 = 0.047$ W/(mK)

$C_4 = C_6 = 6.22$ W/(mK)^2 (fo82)

$L_1 = 0.01$ m, $L_2 = 0.15$ m, $L_3 = 0.01$ m, $L_5 = 0.012$ m,

$L_7 = 0.012$ m

$$R_1 = \frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_2 = \frac{L_2}{k_2} = \frac{0.15}{1.58} = 0.094\,9$$

$$R_3 = \frac{L_3}{k_3} = \frac{0.01}{0.721} = 0.013\,9$$

$$R_4 = \frac{1}{C_4} = \frac{1}{6.22} = 0.160\,8$$

$$R_5 = \frac{L_5}{k_5} = \frac{0.012}{0.047} = 0.255\,3$$

$$R_6 = \frac{1}{C_6} = \frac{1}{6.22} = 0.160\,8$$

$$R_7 = \frac{L_7}{k_7} = \frac{0.012}{0.047} = 0.255\,3$$

$$\frac{1}{f_i} = \frac{1}{9.36} = 0.106\,8$$

$$\frac{1}{f_o} = \frac{1}{19.86} = 0.050\,4$$

2) $R_T = 1.112\,1$

3) $U = \frac{1}{R_T} = \frac{1}{1.112\,1} = 0.899 \text{ W/(m}^2\text{K)}$

A-3. CALCULATION OF THERMAL TIME CONSTANT (T) FOR TYPICAL CASES

A-3.1 Procedure — Thermal time constant for homogeneous or composite wall or roof may be calculated from the formula given in **2.14.**

Example 10

To find T for 19 cm thick brick wall provided with 1.00 cm thick cement plaster on both sides.

Solution

1) For cement plaster

$$L = 0.01 \text{ m}$$
$$k = 0.721 \text{ W/(mK)}$$
$$\rho = 1\,648 \text{ kg/m}^3$$
$$c = 0.84 \text{ kJ/(kgK)}$$

2) For brick

$$L = 0.19 \text{ m}$$
$$k = 0.811 \text{ W/(mK)}$$
$$\rho = 1\,820 \text{ kg/m}^3$$
$$c = 0.88 \text{ kJ/(kgK)}$$

3) For plaster

$$L_1 \rho_1 c_1 = 0.01 \times 1\,648 \times 0.84$$
$$= 13.843 \text{ kJ/(m}^2\text{K)}$$
$$= 13\,843 \text{ Ws/(m}^2\text{K)}$$
$$\frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9 \text{ m}^2\text{K/W}$$

4) For brick

$$L_2 \rho_2 c_2 = 0.19 \times 1\,820 \times 0.88$$
$$= 304.304 \text{ kJ/(m}^2\text{K)}$$
$$= 304/304 \text{ Ws/m}^2.\text{K}$$
$$= \frac{0.19}{0.811} = 0.234\,3 \text{ m}^2\text{K/W}$$

5) $T = \dfrac{Q}{U}$

$$= \frac{1}{f_o} + \frac{L_1}{2k_1} (L_1 \rho_1 c_1) + \frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{2k_2} \times$$
$$(L_2 \rho_2 c_2) + \frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{2k_3} \times (L_3 \rho_3 c_3)$$
$$= (0.050\,4 + 0.006\,95) \times 13\,843 + (0.050\,4 + 0.013\,9 + 0.117\,15) \times 304\,304 + (0.050\,4 + 0.013\,9 + 0.234\,3 + 0.006\,95) \times 13\,843$$
$$= 0.057\,4 \times 13\,843 + 0.181\,5 \times 304\,304 + 0.305\,6 \times 13\,843$$
$$= 794.59 + 55\,231.18 + 4\,230.42$$
$$= 60\,256.19 \text{ seconds}$$
$$\cong 17 \text{ hours}$$

Example 11

To find T for a sloped roof of 6.25 mm AC sheets with an air gap and false ceiling of softboard 12 mm thick.

Solution

1) For AC sheet

$$L_1 = 0.006\,25 \text{ m}$$
$$k_1 = 0.245 \text{ W/(mK)}$$
$$\rho_1 = 1\,520 \text{ kg/m}^3$$
$$c_1 = 0.84 \text{ kJ/(kgK)}$$
$$\frac{L_1}{k_1} = \frac{0.006\,25}{0.245} = 0.025\,5$$
$$L_1 \rho_1 c_1 = 0.006\,25 \times 1\,520 \times 0.84$$
$$\doteq 7.98 \text{ kJ/(m}^2\text{K)} = 7\,980 \text{ Ws/(m}^2\text{K)}$$

2) For air gap

$$(L_2 \rho_2 c_2) = 0$$

3) For softboard

$$L_3 = 0.012 \text{ m}$$
$$k_3 = 0.047 \text{ W/(mK)}$$
$$\rho_3 = 249 \text{ kg/m}^3$$
$$c_3 = 1.30 \text{ kJ/(kgK)}$$
$$\frac{L_3}{k_3} = \frac{0.012}{0.047} = 0.255\,3$$
$$L_3 \rho_3 c_3 = 0.012 \times 249 \times 1.3$$
$$\doteq 3.884\,4 \text{ kJ/(m}^2\text{K)}$$
$$\doteq 3\,884.4 \text{ Ws/(m}^2\text{K)}$$

4) $T = \Sigma \dfrac{Q}{U} = \left(\dfrac{1}{f_o} + \dfrac{L_1}{2k_1}\right) (L_1 \rho_2 c_1) +$

$$\left(\frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{2k_2}\right) (L_2 \rho_2 c_2) +$$
$$\left(\frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{2k_3}\right) (L_3 \rho_3 c_3)$$
$$= (0.050\,4 + 0\,012\,75) \times 7\,980 + 0 + (0.050\,4 + 0.025\,5 + 0 + 0.127\,65) \times 3\,884.4$$
$$= 0.063\,2 \times 7\,980 + 0.203\,6 \times 3\,884.4$$
$$= 503.94 + 790.86$$
$$= 1\,294.8 \text{ seconds}$$
$$\cong 0.36 \text{ hours}$$

A-4. CALCULATION OF CORRECTED THERMAL PERFORMANCE INDEX (*TPI*)

A.4.1 Procedure — Corrected *TPI* values for non-air-conditioned and air-conditioned buildings may be calculated from equations given in **8.5**.

Example 12

Find the corrected *TPI* values for South orientation, both in hot dry and hot humid regions for a 22.5 cm brick wall with 1.25 cm thick cement plaster on both the sides. *TPI* values for West oriented walls are 93 and 102.

Solution

The correction factors (c) for hot dry region and hot humid region from Table 11 are 0.55 and 0.47 respectively.

(a) *Non-air-conditioned Building*

1) Corrected *TPI* in hot dry region $= (TPI - 50) \times c + 50$

$= (93 - 50) \times 0.55 + 50$
$= 73.7$

2) Corrected *TPI* in hot humid region $= (93 - 50) \times 0.47 + 50$
$= 20.2 + 50$
$= 70.2$

(b) *Air-conditioned Building*

1) Corrected *TPI* in hot dry region $= (TPI) \times c$
$= 102 \times 0.55$
$= 56.1$

2) Corrected *TPI* in hot humid region $= 102 \times 0.47$

$= 47.9$

Thus 22.5 cm brick wall plastered on either side satisfies the requirements specified in **3**. Its *TPI* values is much below the permissible maximum values.

A-4.2 Effect of Surface Colour

Example 13

Determine the corrected *TPI* of a roof having $TPI = 122$ if white wash treatment is given at exposed side. The correction factor is 0.75 for hot dry region and 0.71 for hot humid region.

Solution

i) Corrected *TPI* for non-air-conditioned building in hot dry region $= (122 - 50) \times 0.75 + 50$

$= 54 + 50$

$= 104$

ii) Corrected *TPI* for non-air-conditioned building in hot humid region $= (122 - 50) \times 0.71 + 50$

$= 51 + 50$

$= 101$

A-4.3 Peak surface temperature and heat gain can be calculated from formula given in **8.4**.

Example 14

Calculate the peak surface temperature and heat flow for a roof whose *TPI* values are 134 and 143 respectively.

Peak surface temperature $= 30 + 0.08 \times TPI$

$= 30 + 0.08 \times 134$
$= 40.7°C$

Peak heat gain $= 0.46 \times TPI$

$= 0.46 \times 143$
$= 65.8\ \text{W/m}^2$

A-5. CALCULATION OF REDUCTION IN PEAK COOLING LOAD

A-5.1 The reduction in heat intake may be calculated as given in **9.1**.

Example 15

A building has Building Index (BI) value of 80. It is brought to comfortable range (BI = 50) by using insulation and other treatments. What will be the peak value of saving in energy if building has a surface area of 1 000 m^2.

Solution

Total heat flow (when BI is 80) $= \dfrac{80 \times 46}{100}$

$= 36.8\ \text{W/m}^2$

Total heat flow (when BI is 50) $= \dfrac{50 \times 46}{100}$

$= 23.0\ \text{W/m}^2$

The reduction in heat intake $= (36.8 - 23.0) \times$ surface area

$= 13.8 \times 1\,000$ W

$= 13\,800$ W

Therefore, the peak load is reduced by 13 800 W, if building is to be air-conditioned.

APPENDIX B

(*Clause* 6.3.1.1)

METHOD OF CALCULATING SOLAR LOAD ON VERTICAL SURFACES OF DIFFERENT ORIENTATION

B-1. DETAILS OF CALCULATION

B-1.1 The solar energy above the earth's atmosphere is constant and the amount incident on unit area normal to sun's rays is called solar constant (2 g/cal/cm^2/min). This energy, in reaching the earth's surface, is depleted in the atmosphere due to scattering by air molecules, water vapour, dust particles, and absorption by water vapour and ozone. The depletion varies with varying atmospheric conditions. Another important cause of depletion is the length of path traversed by sun's rays through the atmosphere. This path is the shortest when the sun is at the zenith and, as the altitude of the sun decreases, the length of path in the atmosphere increases. Figure 9 gives the computed incident solar energy/hour on unit surface area normal to the rays under standard atmospheric conditions* for different altitudes of the sun.

B-1.2 In order to calculate the solar energy on any surface other than normal to the rays, the altitude of the sun at that time† should be known. The corresponding value of direct solar radiation (I_N) should then be found out with the help of Fig. 9. The solar radiation incident on any surface (I_S) is given by:

$$I_S = I_N (\sin \beta \sin \phi + \cos \beta \cos \alpha \cos \phi)$$

where

β = solar altitude,

ϕ = angle tilt of the surface from the vertical (*see* Fig. 10), and

α = wall solar azimuth angle.

*The standard atmospheric conditions assumed for this computation are: cloud-free, 300 dust particles per cm^3, 15 mm of precipitable water, 2.5 mm of ozone, at sea level.

†These are given for every hour at different latitudes in 'Climatological and Solar Data for India published by the Central Building Research Institute, Roorkee.

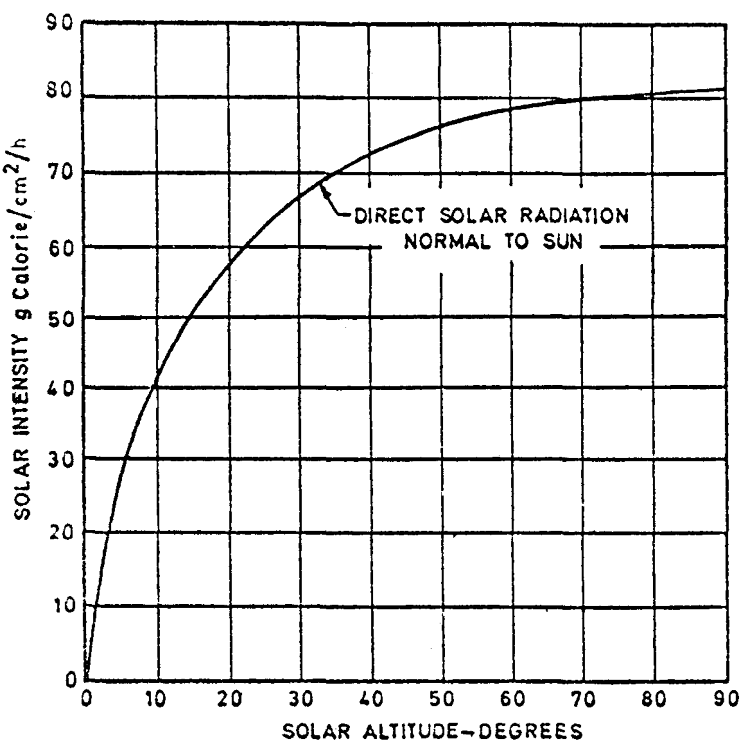


FIG. 9 DIRECT SOLAR INTENSITIES NORMAL TO SUN AT SEA LEVEL FOR STANDARD CONDITIONS (COMPUTED)

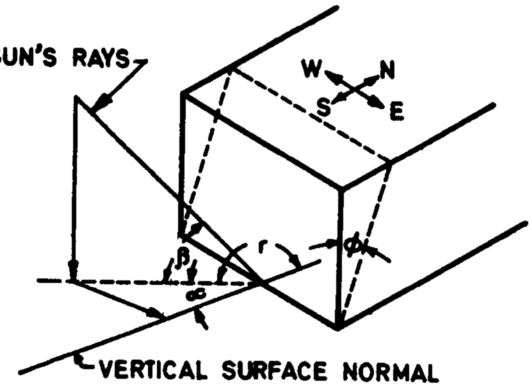


FIG. 10 DEFINITION OF SOLAR ANGLES

APPENDIX C

(*Clause* 6.3.1.2)

EXAMPLE TO FIND OUT ORIENTATION ON THE BASIS OF SOLAR ROAD

C-1. EXAMPLE

C-1.1 As an example, a simple building with flat roof, 10 m × 20 m, and 4 m high is dealt with below. For the sake of generalization, no shading device or verandah is taken.

C-1.2 As the roof is horizontal, it will receive the same solar heat in any orientation.

C-1.3 The area of the vertical surfaces are 4 m × 10 m = A (say) and 4 m × 20 m = 2 A. Since the external wall surfaces are not in shade except when the sun is not shining on them, the total solar load in a day on a surface can be obtained by multiplying the total load per unit area per day (Table 12) by the area of the surface. For four principal orientations of the building, the total solar load on the building is worked out in Table 23.

C-1.4 From Table 23, it can be seen that for the above type of building, orientation 3 (longer surfaces facing North and South) is appropriate as it affords maximum solar heat gain in winter and in summer. This is true for all places of India from the point of solar heat gain. By further increasing the length to breadth ratio, the advantage of this orientation will be more pronounced. It may also be noted that in higher altitudes, the relative merit of this orientation is more.

C-1.5 It is also seen that the total solar heat on the building is the same for orientation 2 and 4. But if the site considerations require a choice between these two, orientation 2 should be preferred at places north of latitude 23°N and orientation 4 at southern places. This is so because the total solar load per unit area in summer on the north-western wall decreases with the increase in latitude and that on the south-western wall increases. It would, therefore, be advantageous to face only the smaller surface of the building to greater solar load in the summer afternoons, when the air temperature also is higher.

C-1.6 At hill stations, winter season causes more discomfort and so sole criterion for optimum orientation should be based on receiving maximum solar energy on building in winter.

TABLE 23 SOLAR HEAT GAINED DUE TO ORIENTATION OF BUILDINGS

(*Clause* B-1.3)

		8°N Trivandrum		13°N Madras	
		May 16	Dec 22	May 16	Dec 22
1.	North	2 177 × A = 2 177A	—	1 625 × A = 1 625A	—
	East	2 618 × 2A = 5 236A	2 177 × 2A = 4 354A	2 697 × 2A = 5 394A	2 019 × 2A = 4 038A
	South	—	4 164 × A = 4 164A	—	4 385 × A = 4 385A
	West	2 618 × 2A = 5 236A	2 177 × 2A = 4 354A	2 697 × 2A = 5 394A	2 019 × 2A = 4 038A
	Total	12 649A	12 872A	12 413A	12 461A
2.	NE	2 650 × A = 2 650A	410 × A = 410A	2 492 × A = 2 492A	315 × A = 315A
	SE	1 167 × 2A = 2 334A	3 391 × 2A = 6 782A	1 341 × 2A = 2 682A	3 423 × 2A = 6 846A
	SW	1 167 × 2A = 2 334A	3 391 × A = 3 391A	1 341 × A = 1 341A	3 423 × A = 3 423A
	NW	2 650 × 2A = 5 300A	410 × 2A = 820A	2 492 × 2A = 4 984A	315 × 2A = 630A
	Total	12 618A	11 403A	11 499A	11 214A
3.	North	2 177 × 2A = 4 354A	—	1 625 × 2A = 3 250A	—
	East	2 618 × A = 2 618A	2 177 × A = 2 177A	2 697 × A = 2 697A	2 019 × A = 2 019A
	South	—	4 164 × 2A = 8 328A	—	4 385 × 2A = 8 770A
	West	2 618 × A = 2 618A	2 177 × A = 2 177A	2 697 × A = 2 697A	2 019 × A = 2 019A
	Total	9 590A	12 602A	8 644A	12 808A
4.	NE	2 650 × 2A = 5 300A	—	2 492 × 2A = 4 984A	315 × 2A = 630A
	SE	1 167 × A = 1 167A	2 177 × A = 2 177A	1 341 × A = 1 341A	3 423 × A = 3 423A
	SW	1 167 × 2A = 2 334A	4 164 × 2A = 8 328A	1 341 × 2A = 2 682A	3 423 × 2A = 6 846A
	NW	2 650 × A = 2 650A	2 177 × A = 2 177A	2 492 × A = 2 492A	315 × A = 315A
	Total	11 451A	12 682A	11 499A	11 214A

TABLE 23 SOLAR HEAT GAINED DUE TO ORIENTATION OF BUILDINGS (Contd)

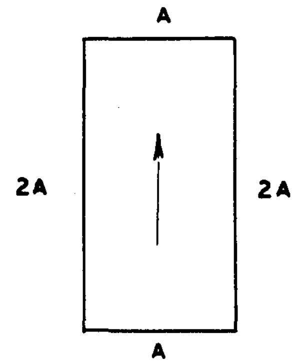
(*Clause* B-1.3)

		19°N Bombay		23°N Calcutta	
		May 16	Dec 22	May 16	Dec 22
1.	North	962 × A = 962A	—	741 × A = 741A	—
	East	2 795 × 2A = 5 590A	1 830 × 2A = 3 660A	2 871 × 2A = 5 742A	1 703 × 2A = 3 406A
	South	—	4 574 × A = 4 574A	205 × A = 205A	4 637 × A = 4 637A
	West	2 795 × 2A = 5 590A	1 830 × 2A = 3 660A	2 871 × 2A = 5 742A	1 703 × 2A = 3 406A
	Total	12 142A	11 894A	12 430A	11 449A
2.	NE	2 255 × A = 2 255A	237 × A = 237A	2 192 × A = 2 192A	173 × A = 173A
	SE	1 640 × 2A = 3 280A	3 438 × 2A = 6 876A	1 845 × 2A = 3 690A	3 454 × 2A = 6 908A
	SW	1 640 × A = 1 640A	3 438 × A = 3 438A	1 845 × A = 1 845A	3 454 × A = 3 454A
	NW	2 255 × 2A = 4 510A	237 × 2A = 474A	2 192 × 2A = 4 384A	173 × 2A = 3 152A
	Total	11 685A	11 025A	12 111A	10 881A
3.	North	962 × 2A = 1 924A	—	741 × 2A = 1 482A	—
	East	2 795 × A = 2 795A	1 830 × A = 1 830A	2 871 × A = 2 871A	1 703 × A = 1 703A
	South	—	4 574 × 2A = 9 148A	205 × 2A = 410A	4 637 × 2A = 9 274A
	West	2 795 × A = 2 795A	1 830 × A = 1 830A	2 871 × A = 2 971A	1 703 × A = 1 703A
	Total	7 514A	12 808A	7 634A	12 680A
4.	NE	2 255 × 2A = 4 510A	237 × 2A = 474A	2 192 × 2A = 4 384A	173 × 2A = 346A
	SE	1 640 × A = 1 640A	3 438 × A = 3 438A	1 845 × 2A = 1 845A	3 454 × A = 3 454A
	SW	1 640 × 2A = 3 280A	3 438 × 2A = 6 876A	1 845 × 2A = 3 690A	3 454 × 2A = 6 908A
	NW	2 255 × A = 2 255A	237 × A = 237A	2 192 × A = 2 192A	173 × A = 173A
	Total	11 685A	11 025A	12 111A	10 881A

TABLE 23 SOLAR HEAT GAINED DUE TO ORIENTATION OF BUILDINGS (Contd.)

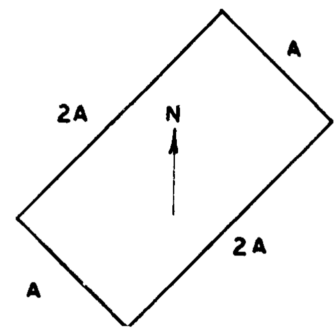
(*Clause* B-1.3)

		29°N Delhi	
		May 16	Dec 22
1.	North	536 × A = 536A	—
	East	2 950 × 2A = 5 900A	1 467 × 2A = 2 934A
	South	741 × A = 741A	4 543 × A = 4 543A
	West	2 950 × 2A = 5 900A	1 467 × 2A = 2 934A
	Total	13 077A	10 411A



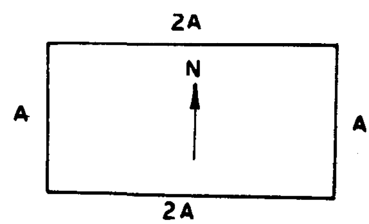
TYPE I

		May 16	Dec 22
2.	NE	2 098 × A = 2 098A	110 × A = 110A
	SE	2 192 × 2A = 4 384A	3 265 × 2A = 6 530A
	SW	2 192 × A = 2 192A	3 265 × A = 3 265A
	NW	2 098 × 2A = 4 196A	110 × 2A = 220A
	Total	12 870A	10 125A



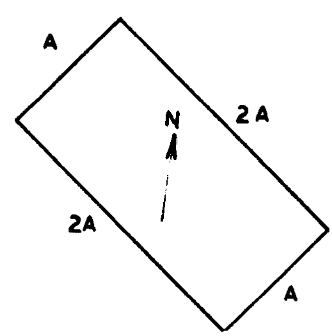
TYPE II

		May 16	Dec 22
3.	North	536 × 2A = 1 072A	—
	East	2 950 × A = 2 950A	1 467 × A = 1 467A
	South	741 × 2A = 1 482A	4 543 × 2A = 9 086A
	West	2 950 × A = 2 950A	1 467 × A = 1 467A
	Total	8 454A	12 020A



TYPE III

		May 16	Dec 22
4.	NE	2 098 × 2A = 4 196A	110 × 2A = 220A
	SE	2 192 × A = 2 192A	3 265 × A = 3 265A
	SW	2 192 × 2A = 4 384A	3 265 × 2A = 6 530A
	NW	2 098 × A = 2 098A	110 × A = 110A
	Total	12 870A	10 125A



TYPE IV

PART 3 VENTILATION

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PART 3 VENTILATION

1. INTRODUCTION

1.1 Ventilation is generally defined as the replacement of stale air by fresh air. As the satisfactory ventilation should provide a refreshing, healthy and comfortable environment; an exchange of fresh air is not necessarily the only factor involved and air movement can be important under certain conditions. Hence it would be appropriate to define the term ventilation as supply of outside air to the interior for air motion and replacement of vitiated air.

Ventilation, being a predominant contributor to thermal and hygienic environment in buildings, warrants due consideration in the design of buildings. A faulty design resulting in inadequate ventilation adds to the cost as attempts are made subsequently to ameliorate the indoor conditions. Therefore, provision for adequate ventilation should invariably be provided right at the design stage of buildings. To accomplish this, the ventilation requirements of different seasons, for the different types of occupancies should be determined first and then a suitable design of ventilation system to meet the required performance standards should be worked out. This part of the Handbook provides detailed information on the requirements of ventilation and design guidelines for achieving desired ventilation rates. Basic principles of ventilation, which act as useful tool for the designers to evolve the ventilation designs for numerous typical cases likely to come across, are also discussed. Design factors governing pattern and velocity of air flow indoors are also covered.

2. TERMINOLOGY

2.1 Air Change Per Hour — The amount of air leakage into or out of a building or room in terms of the number of building volumes or room volumes exchanged.

2.2 Contaminants — Dusts, fumes, gases, mists, vapours and such other substances present in air as are likely to be injurious or offensive to the occupants.

2.3 Dilution Ventilation — Supply of outside air to reduce the airborne concentration of contaminants in the building.

2.4 Dry Bulb Temperature — The temperature of the air, read on a thermometer, taken in such a way as to avoid errors due to radiation.

2.5 Effective Temperature (ET) — An arbitrary index which combines into a single value the effect of temperature, humidity and air movement on the sensation of warmth or cold felt by the human body and its numerical value is that of the temperature of still saturated air which would induce an identical sensation.

2.6 Exhaust of Air — Removal of air from a building and its disposal outside by means of a mechanical device such as a fan.

2.7 General Ventilation — Ventilation, either natural or mechanical or both so as to improve the general environment of the building, as opposed to local exhaust ventilation for contamination control.

2.8 Humidity, Absolute — The weight of water vapour per unit volume.

2.9 Humidity, Relative — The ratio of the partial pressure or density of the water vapour in the air to the saturated pressure or density respectively of water vapour at the same temperature.

2.10 Indoor Wind Speed — The average of wind speeds measured at symmetrically distributed points on a horizontal plane in the normally occupied zone (a region lying between 0.6 to 1.2 m above the floor).

2.11 Mechanical Ventiolation — Supply of outside air, either by positive ventilation or by infiltration by reduction of pressure inside due to exhaust of air, or by a combination of positive ventilation and exhaust of air.

2.12 Natural Ventilation — Supply of outside air into a building through window or other openings due to wind outside and convection effects arising from temperature or vapour pressure differences (or both) between inside and outside of the building.

2.13 Openings — These are openings in the buildings provided for ventilation purposes.

2.14 Positive Ventilation — The supply of outside air by means of a mechanical device such as a fan.

2.15 Stack Effect — Convection effect arising from temperature or vapour pressure difference (or both) between outside and inside of the room and the difference of height between the outlet and inlet openings.

2.16 Threshold Limit Value (TLV) — Refers to airborne concentration of contaminants currently accepted by the American Conference of Governmental Industrial Hygienists and represents conditions under which it is believed that nearly all occupants may be repeatedly exposed, day after day, without adverse effect.

2.17 Ventilation — Supply of outside air to the interior for air motion and replacement of vitiated air.

2.17.1 *Comfort Ventilation* — The ventilation necessary only during certain weather conditions for the purpose of improving thermal comfort.

2.17.2 *Permanent Ventilation* — The ventilation needed under all weather conditions.

2.18 Wet Bulb Temperature — The steady temperature finally given by a thermometer having its bulb covered with gauze or muslin moistened with distilled water and placed in an air stream of not less than 4.5 m/s.

3. VENTILATION REQUIREMENTS

3.1 Requirements of ventilation are two fold: (a) for health and (b) for comfort. To meet the first requirement, the quality of air in buildings is maintained above a certain minimum level by replacing indoor air by fresh outdoor air to maintain certain levels of CO_2 and oxygen in air and for control of odours or for removal of products of combustion during occupancy. Ventilation to meet this requirement is essentially needed under all climatic conditions, hence it is termed as health ventilation. The comfort conditions necessitate ventilation for providing such thermal environment as to increase heat loss from the body and prevent discomfort due to moist skin, and also to cool the indoor space itself when the indoor temperature exceeds outdoor temperature. This type of ventilation is known as comfort ventilation.

3.2 Requirements of Permanent Ventilation — Factors necessitating ventilation in non-industrial buildings are as given below:

a) *Maintenance of Carbon Dioxide Concentration of Air within Safe Limits and to Provide Sufficient Oxygen Content in Air for Respiration* — It is well known that, in the process of breathing, oxygen is taken in and carbon dioxide is given off. Since an average adult, when seated, gives only about 0.016 8 m^3 of carbon dioxide per hour and the concentration of carbon dioxide in atmospheric air is only about 0.04 percent, hence the amount of fresh air required to maintain the concentration of carbon dioxide within safe limits is very small. In rooms, concentration of carbon dioxide rarely exceeds 0.5 to 1 percent and is, therefore, incapable of producing any ill effects. The change in oxygen content is also too small under normal conditions to have any ill effects; the oxygen content may vary quite appreciably without noticeable effect, if the carbon dioxide concentration is unchanged. The concentration of carbon dioxide or reduction in oxygen content is thus not sufficiently critical to provide a basis for fixing rates of ventilation for non-industrial buildings.

b) *Control of Odours* — All persons give off odours in the form of sweat, sebaceous secretions, foul breath, etc. The amount of odours given off varies with such factors as race, socio-economic status and temperature. Although odour may not be harmful, it may be objectionable and, when present, it causes headache and loss of appetite. It is, therefore, desirable to provide such rate of ventilation as to remove noticable body odour and other odours such as from tobacco smoke, cooking, etc.

c) *Removal of Products of Combustion* — Products of combustion discharged from *chullahs*, stoves, gas appliances, etc. used in a kitchen are likely to accummulate there and may also permeate into other rooms. Similarly *angihitis* used for heating rooms in certain colder parts of the country result in the production of carbon monoxide and other gases. Natural ventilation can play here significant role in controlling concentration of these products of combustion.

3.3 Requirements of Comfort Ventilation — As the term implies, the purpose of comfort ventilation is to provide satisfactory thermal conditions indoors. Environmental factors like air temperature, humidity and air speed together with some other factors, such as clothing, level of activity, food, etc, have a direct influence upon bodily processes. Maintenance of thermal equilibrium of the body is very essential for securing thermal comfort and for avoiding heat stress. Heat transfer between human body and the environment occurs through conduction, convection, radiation and evaporation; the relative magnitude of each process varying with changes in ambient conditions. However, under hot environments, evaporation is most important process of heat loss from the human body for securing thermal comfort. As the air around the body becomes nearly saturated due to humidity, it becomes more difficult to evaporate perspiration and a sense of discomfort is felt. A combination of high humidity and high air temperature proves very oppressive. In such circumstances, even a slight movement of air near the body gives relief. It would, therefore, be desirable to consider a rate of ventilation which may produce necessary air movement or the air movement may be augmented by circulating fans inside the building.

3.4 Ventilation in non-industrial buildings due to stack effect, unless there is a significant internal load, could be neglected, except in cold regions, and wind action may be assumed to be predominant.

3.4.1 In hot arid regions, the main problem in summer is to provide protection from sun's heat during day so as to keep the indoor temperatures lower than those outside under the sun and for this purpose windows and other openings are generally kept closed and only minimum ventilation is provided for the control of odours or for removal of products of combustion.

3.4.2 In hot humid and warm humid regions, the problem in the design of non-industrial buildings is to provide free passage of air to keep the indoor temperatures as near to those outside in the shade as possible, and for this purpose the buildings are oriented to face the direction of prevailing winds and windows and other openings are kept open on both windward and leeward sides.

3.4.3 Adequate number of circulating fans should be installed to serve all interior working areas during summer months in the hot arid and hot/warm humid regions to provide necesary air movement at times when ventilation due to wind action alone does not afford sufficient relief.

3.4.4 In winter months in cold regions, the windows and other openings are generally kept shut, particularly during night; and ventilation, necessary for the control of odours and for the removal of products of combustion can be achieved either by stack action or by some infilteration of outside air due to wind action.

4. MINIMUM STANDARDS FOR VENTILATION

4.1 Standards for Permanent Ventilation — Since the amount of fresh air required to maitain the carbon dioxide concentration of air within safe limits and to provide sufficient oxygen content in the air for respiration is very small, the minimum standards of ventilation are based on the control of body odours or the removal of products of combustion depending on the requirement of each case. Where no contaminants are to be removed from air, the amount of fresh air required for dilution of inside air to prevent vitiation by body odours, depends on the air space available per person and the degree of physical activity; the amount of air required decreases as the air space per person increases; and it may vary from 20 to 30 m^3 per person per hour. In rooms occupied by only a small number of persons, such an air change will automatically be attained in cool weather by normal leakage around windows and other openings and this may easily be secured in warm weather by keeping the openings open.

4.2 The following standards of general ventilation are recommended based on maintenance of required oxygen, carbon dioxide and other quality levels and for the control of body odours when no products of combustion or other contaminants are present in air:

Air Change Schedule

Space to be Ventilated	*Air Changes per Hours*
*Assembly hall/auditoria	3-6
*Bed rooms/living rooms	3-6
Bath rooms/toilets	6-12
*Cafes/restaurants	12-15
Cinemas/theatres (non-smoking)	6-9
Class rooms	3-6
*Factories (medium metal work)	3-6
*Garages	12-15
*Hospital wards	3-6
*Kitchens (common)	6-9
*Kitchens (domestic)	3-6
Laboratoeis	3-6
*Offices	3-6

*Smoking

4.3 Standards for Comfort Ventilation — Air movement is necessary in hot and humid weather for body cooling. Specially in hot weather, when thermal environment inside the room is worsened by heat given off by machinery, occupants and other sources, the prime need for ventilation is to provide such thermal environment as will assist in the maintenance of heat balance of the body in order to prevent discomfort and injury to health. Excess of heat either from increased metabolism due to physical activity of persons or gains from a hot environment, has to be offset to maintain normal body temperature (37°C). Heat exchange of the human body with respect to the surroundings is determined by the temperature and humidity gradient between the skin and the surroundings and other factors, such as age of persons, clothing, etc, and the latter depends on air temperature (dry bulb temperature), relative humidity, radiation from the solid surroundings and rate of air movement. The volume of outside air to be circulated through the room is, therefore, governed by the physical considerations of controlling the temperature, air distribution or air movement. Air movement and air distribution may, however, be achieved by recirculation of the inside air rather than bringing in all outside air. However, fresh air supply or the circulated air will reduce heat stress by dissipating heat from body by evaporation of the sweat, particularly when the relative humidity is high and the air temperature is near the body temperature.

4.3.1 *Limits of Comfort and Heat Tolerance* — Thermal comfort is that condition of thermal environment under which a person can maintain a bodily heat balance at normal body temperature and without perceptible sweating. Limits of comfort vary considerably according to studies carried out in India and abroad. In terms of effective temperature, the upper limit of comfort may be 27.5°C for every day work. This is also the temperature for most efficient productivity. Air movement is necessary in hot and humid weather for body cooling. A certain minimum desirable wind speed is needed for achieving thermal comfort at different temperatures and relative humidities. Such wind speeds are given in Table 1. These are applicable to sedentary work in offices and other places having no noticable sources of heat gain. Where somewhat warmer conditions are prevalent, such as in godowns, work is of lighter intensity and higher temperatures can be tolerated without much discomfort, minimum wind speeds for just acceptable warm conditions are given in Table 2.

TABLE 1 DESIRABLE WIND SPEEDS FOR THERMAL COMFORT CONDITIONS

(*Clause* 4.3.1)

Dry Bulb Temperature	Relative Humidity (Percent)						
°C	30	40	50	60	70	80	90
	Wind Speed, m/s						
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	1.47	2.10
32	0.20	0.46	0.94	1.59	2.26	3.04	+
33	0.77	1.36	2.12	3.00	+	+	+
34	1.85	2.72	+	+	+	+	+
35	3.2	+	+	+	+	+	+

*None
+Higher than those acceptable in practice.

TABLE 2 MINIMUM WIND SPEEDS FOR JUST ACCEPTABLE WARM CONDITIONS

(*Clause* 4.3.1)

Dry Bulb Temperature	Relative Humidity (Percent)						
°C	30	40	50	60	70	80	90
	Wind Speed, m/s						
28	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*
31	*	*	*	*	*	0.06	0.23
32	*	*	*	0.09	0.29	0.60	0.94
33	*	0.04	0.24	0.60	1.04	1.85	2.10
34	0.15	0.46	0.94	1.60	2.26	3.05	+
35	0.68	1.36	2.10	3.05	+	+	+
36	1.72	2.70	+	+	+	+	+

*None
+Higher than those acceptable in practice.

For obtaining values of indoor wind speed above 2.0 m/s, mechanical means of ventilation may have to be adopted.

4.4 Volume of Air Required — In context with thermal comfort, the other function of ventilation in hot weather is to prevent an under rise of indoor air temperature due to solar and other heat gains. The desired rate of ventilation shall be calculated by using both the sensible heat or latent heat as the basis. The larger of the two figures obtained shall be used in actual practice.

4.4.1 When the amount of sensible heat given off by different sources, namely, the sun, the occupants, the appliances and other sources is known and a suitable value of allowable temperature rise is assumed, the volume of outside air to be provided for removing the sensible heat may be calculated from the equation:

$$Q_1 = \frac{2.976\,8\ K_s}{t} \qquad \ldots (1)$$

where

Q_1 = quantity of air in m^3/h,
K_s = sensible heat gained in W, and
t = allowable temperature rise in °C.

4.4.2 The temperature rise refers mainly to the difference between the air temperatures at the outlet and inlet openings. An attempt should be made to limit the temperature rise to a reasonably low value.

4.4.3 If the latent heat gained from the occupants and the processes being carried out indoors is also known, and a suitable value for the allowable rise in the vapour pressure is assumed, the volume of air required for removing latent heat is calculated by the equation

$$Q_2 = \frac{4\,127.26 \times K_1}{h} \qquad \ldots (2)$$

where

Q_2 = quantity of air in m^3/h,
K_1 = latent heat gained in W, and
h = allowable vapour pressure difference in mm Hg.

It is mentioned that, in majority of the cases, the sensible heat gain will far exceed the latent heat gain and hence the amount of outside air to be drawn by ventilating system can be calculated in most cases on the basis of equation (1).

5. VENTILATION DESIGN

5.1 The first step in ventilation design of building is to establish the adequate ventilation requirements pertaining to that building. Once this is done, the second step is to evolve a system to meet the required performance standard. The systems of ventilation can broadly be divided into two groups, namely, natural and mechanical or the combination of the two. Although present discussion is mainly concerned with natural ventilation, some account is also given of the use of mechanical system.

5.2 Design for Natural ventilation — The design of natural ventilation system necessitates knowledge of the mechanism of air flow through buildings and also of factors which have a bearing on air flow patterns indoors. Detailed discussion on these aspects has been given in Appendix A.

5.2.1 A few important rules of natural ventilation and some of the guidelines for designing buildings for best possible utilization of outdoor wind indoors are given below:

a) *Size of Openings for Permanent Ventilation* — Openings with size given by equation (3) should be provided on wind facing wall and also on the opposite wall.

$$A = \frac{Q}{KV} \qquad \ldots (3)$$

where

A = area of openings provided on wall (assumed equal for each wall) in m^2,
Q = desired rate of air flow in m^3/h,
V = prevailing outdoor wind speed in m/h, and
K = the coefficient of flow which may be taken as 0.6 for wind perpendicular to the openings and 0.3 for winds incident at 45°.

When areas of inlet and outlet openings are to be kept unequal, say A_1 and A_2, then their values should be so chosen as to satisfy equation (4).

$$\frac{2}{A^2} = \frac{1}{A_1^2} + \frac{1}{A_2^2} \qquad \ldots (4)$$

For rooms having windows on one external wall only, the required area of opening may also be determined from equation (3) assuming the value of K as 0.025.

5.3 Design Guidelines for Comfort Ventilation

5.3.1 A building need not necessarily be oriented perpendicular to the prevailing outdoor wind; it may be oriented at any convenient angle between 0° and 30° without losing any beneficial aspect of the breeze. If the prevailing wind is from East or West, building can be oriented at 35° to the incident wind so as to diminish the solar heat compromising with slight reduction in air motion indoors.

5.3.2 Inlet openings in the buildings should be well distributed and should be located on the windward side at a low level, and outlet openings should be located on the leeward side. Inlet and outlet openings at high levels may only clear the top air at that level without producing air movement at the level of occupancy.

5.3.2 Maximum air movement at a particular plane is achieved by keeping the sill height of the opening at 85 percent of the critical height (such as head level). The following levels of occupancy are recommended:

a) For sitting on chair = 0.75 m

b) For sitting on bed = 0.60 m

c) For sitting on floor = 0.40 m

5.3.3 Inlet openings should not, as far as possible, be obstructed by adjoining buildings, trees, sign boards or other obstructions or by partitions inside in the path of air flow.

5.3.4 In rooms of normal size having identical windows on opposite walls the average indoor air speed increases rapidly by increasing the width of window up to two-thirds of the wall width; beyond that the increase is in much smaller proportion than the increase of the window width. The air motion in the working zone is maximum when window height is 1.1 m. Further increase in window height promotes air motion at higher level of window, but does not contribute additional benefits as regards air motion in the occupancy zones in buildings.

5.3.5 Greatest flow per unit area of openings is obtained by using inlet and outlet openings of nearly equal areas at the same level.

5.3.6 For a total area of openings (inlet and outlet) of 20 to 30 percent of floor area, the average indoor wind velocity is around 30 percent of outdoor velocity. Further increase in window size increases the available velocity but not in the same proportion. In fact, even under most favourable conditions, the maximum average indoor wind speed does not exceed 40 percent of outdoor velocity.

5.3.7 Where the direction of wind is quite constant and dependable, the size of the inlet should be kept within 30 to 50 percent of the total area of openings and the building should be oriented perpendicular to the incident wind. Where direction of the wind is quite variable, the openings may be arranged so that as far as possible there is approximately equal area on all sides. Thus no matter what the wind direction be, there would be some openings directly exposed to wind pressure and others to air suction and effective air movement through the building would be assured.

5.3.8 Windows of living rooms should open directly to an open space. In places where building sites are restricted, open space may have to be created in the buildings by providing adequate courtyards.

5.3.9 In the case of rooms with only one wall exposed to outside, provision of two windows on that wall is preferred to that of a single window.

5.3.10 Windows located diagonally opposite to each other with the windward window near the upstream corner give better performance than other window arrangements for most of the building orientations.

5.3.11 Horizontal louvers, that is, a sunshade (Fig. 1A), atop a window deflects the incident wind upward and reduces air motion in the zone of occupancy. A horizontal slot between the wall and horizontal louver prevents upward deflection of air in the interior of rooms. Provision of inverted L type (Γ) louver increases the room air motion provided that the vertical projection does not obstruct the incident wind.

5.3.12 Provision of horizontal sashes inclined at an angle of 45° in appropriate direction helps to promote the indoor air motion. Sashes projecting outward are more effective than projecting inward.

5.3.13 Air motion at working plane 0.4 m above the floor can be enhanced by 30 percent using a pelmet type wind deflector (Fig. 1B).

5.3.14 Roof overhangs help promoting air motion in the working zone inside buildings.

5.3.15 Verandah open on three sides is to be preferred since it causes an increase in the room air motion for most of the orientations of the building with respect to the outdoor wind.

5.3.16 A partition placed parallel to the incident wind has little influence on the pattern of the air flow, but when located perpendicular to the main flow, the same partition creates a wide shadow. Provision of a partition with spacing of 0.3 m underneath, helps augmenting air motion near floor level in the leeward compartment of wind span buildings.

5.3.17 Air motion in a building unit having windows tangential to the incident wind is accelerated when another unit is located at end-on position on down stream side (*see* Fig. 2).

5.3.18 Air motion in two wings oriented parallel to the prevailing breeze is promoted by connecting them with a block on downstream side.

5.3.19 Air motion in a building is not affected by constructing another building of equal or smaller height on the leeward side; but it is slightly reduced if the leeward building is taller than the windward block.

5.3.20 Air motion in a shielded building is less than that in an unobstructed building. To minimize shielding effect, the distances between two rows should be 8 *H* for semi-detached houses and 10 *H* for long row houses. However, for smaller spacings, the shielding effect is also diminished by raising the height of the shielded building.

5.3.21 Hedges and shrubs deflect the air away from the inlet openings and cause a reduction in indoor air motion. These elements should not be planted up to a distance of about 8 m from the building because the induced air motion is reduced to minimum in that case. However, air motion in the leeward part of the building can be enhanced by planting a low hedge at a distance of 2 m from the building.

5.3.22 Trees with large foliage mass having trunk bare of branches up to the top level of window, deflect the outdoor wind downwards and promote air motion in the leeward portion of buildings.

5.3.23 Ventilation conditions indoors can be ameliorated by constructing buildings on earth mound having a slant surface with a slope of 10° on upstream side.

6. ENERGY CONSERVATION IN VENTILATING SYSTEMS

6.1 Introduction — Ventilation is an important consideration in the design of buildings. The factors necessitating ventilation of a space are two fold:

a) for health; and

b) for comfort.

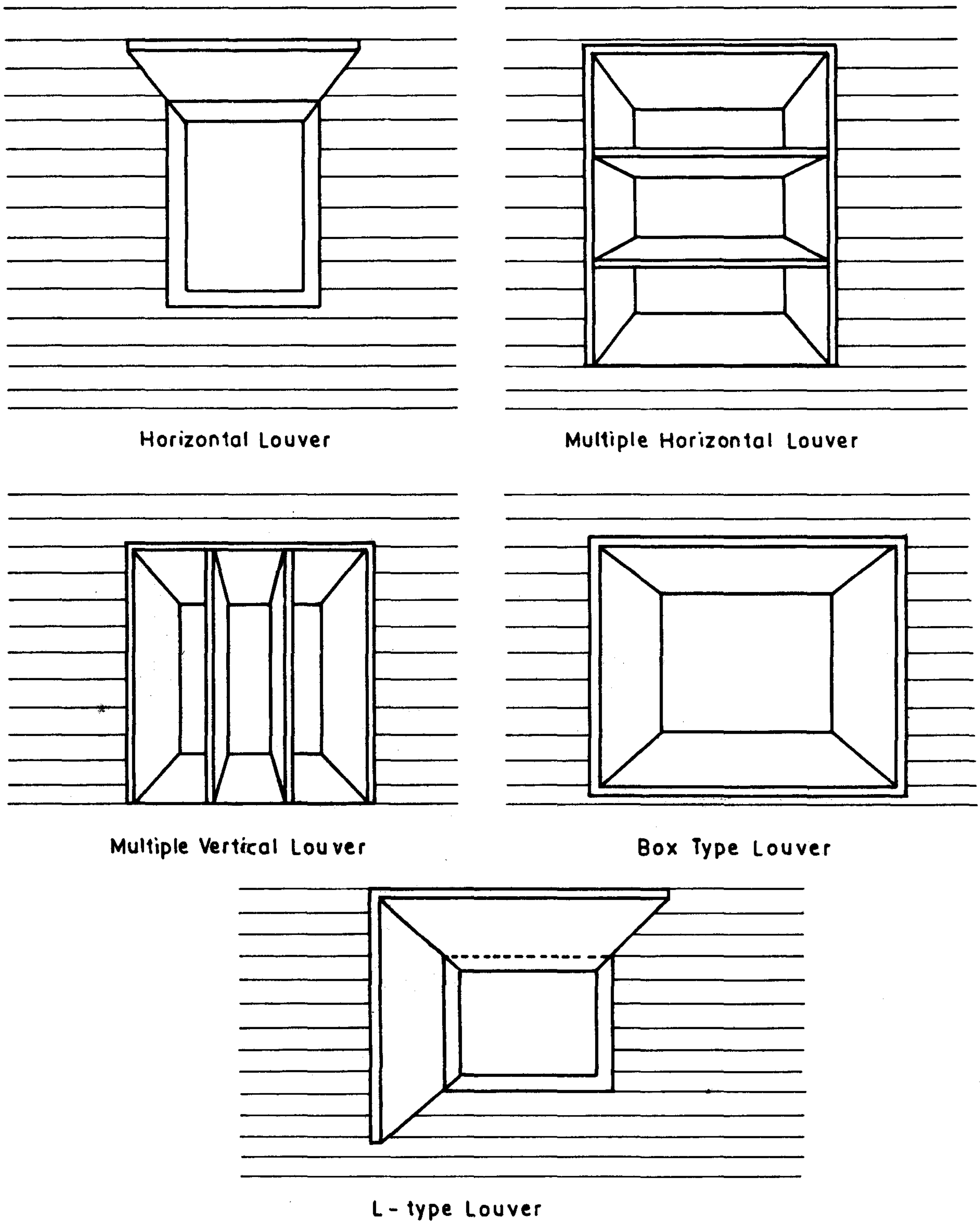


FIG. 1A VARIOUS TYPES OF LOUVERS

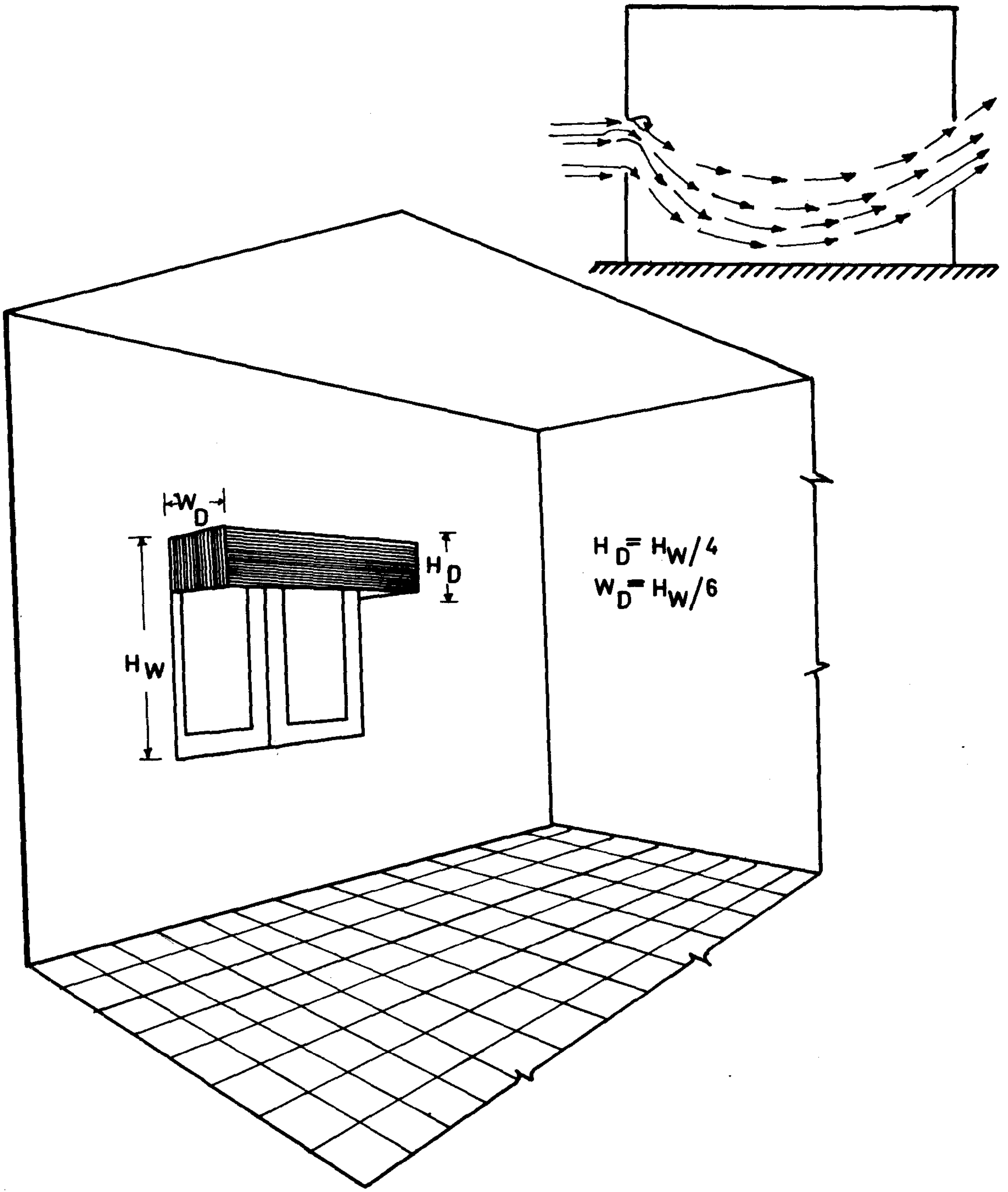
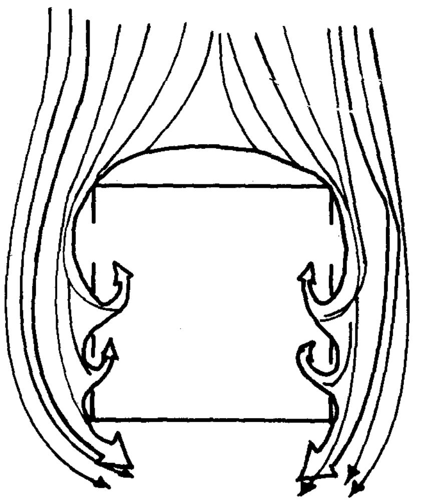


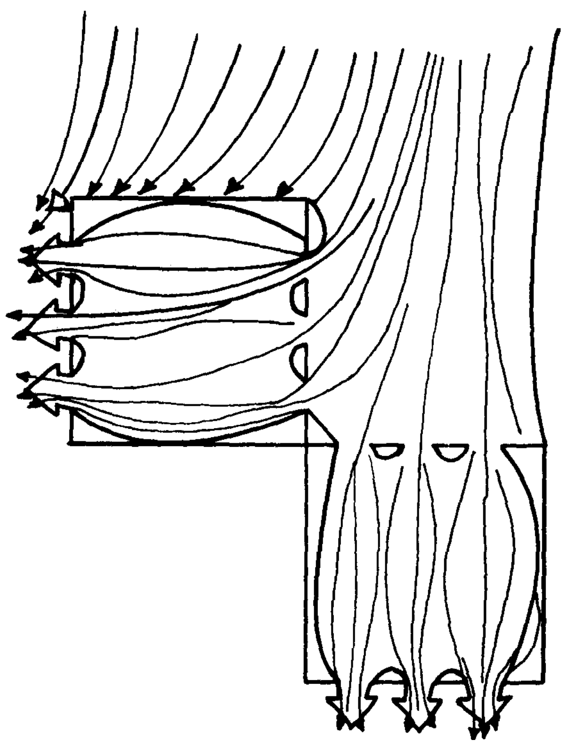
FIG. 1B SKETCH OF A PELMET TYPE WIND DEFLECTOR

(H_w — Window height, H_D — Deflector height, W_D — Deflector width)



Isolated building unit

Air motion in a building unit having windows tangential to the incident wind is accelerated when another unit is located at end-on position on downstream side.



Two units located at end-on position

FIG. 2 AIR FLOW PATTERNS IN TWO BUILDING UNITS LOCATED ON END-ON POSITION

The former is through air changes and latter through wind motion. these are carried out by natural or mechanical means.

6.2 Natural Ventilation

6.2.1 Requirements of air motion in the early summer and late post-monsoon periods are usually small. These can be easily met by providing adequate cross ventilation through rooms and thus the energy used for inducing air motion can be saved. In many office buildings, rooms are located on both sides of a central corridor. In such cases, cross ventilation may be facilitated by openings at ceiling level of the corridor. Since the speed and direction of outdoor wind vary continuously, it is difficult to assess the actual energy saving by this system.

6.2.2 It is also recommended that minimum 80 percent of the recommended glazing area should be left as ventilation openings.

6.3 Mechanical Ventilation

6.3.1 Mostly ceiling fans are used for inducing air motion for comfort. Exhaust fans are also made use of in a few typical places like stores, bath rooms, etc, for the replacement of vitiated air by fresh outdoor air. A ventilation survey conducted has shown that judicious selection of fan sizes could result in a considerable saving in the fan energy consumption. When the actual ventilated zone does not cover the entire room area then smaller sizes of fans can be employed with advantage and further saving in energy could be achieved. Thus there is a need for the formulation of norms for the selection and use of ceiling fans so that undesired wastage of energy due to oversizing of fans and their improper location could be avoided.

6.3.2 *Ceiling Fans—Coverage and Power Consumption* — Ceiling fan induces air motion over a zone underneath around its axis of rotation. The diameter of this zone is termed as the sweep of the zone. Power consumed by larger fans is obviously higher, but their power consumption per square metre of floor area is less and service value higher; evidently improper use of fans irrespective of the room dimensions is likely to result in higher power consumption. For example, in a single seated room where the sweep of the working zone is around 3 m, a 1050 mm fan will be sufficient and use of larger fans will obviously result in wastage of energy.

6.3.3 *Number and Sizes of Fans for Rooms of Different Floor Area* — From the point of view of energy conservation, the number of fans and the optimum sizes for rooms of different dimensions are given in Table 3.

6.3.4 *Location of the Fans* — To utilise the maximum output of a fan and thus making maximum possible use of the energy spent for its operation, it is essential that their layout is most judiciously worked out. Number of fans to be installed is found as above. Next, for determining their best layout, the room is equitably divided in zones equal in number to the fans to be installed. At the centre of each zone is fitted a fan of the chosen size. The height of the fan is an equally important consideration for its efficient functioning. Ceiling fans are found to perform best when their height above the floor is $(3H + W)/4$, H being the room height and W the height of the workplane above the floor. A fan hanging too high or too low does not produce the rated output and results in an indirect wastage of energy. In normal rooms with ceiling height around 3 m and average workplane height of 0.9 m, the optimum height of fan blades from the floor is about 2.5 m. it is worth mentioning that the clearance distance between the fan blades and ceiling should never be less than 0.3 m, otherwise the fan performance will be adversely affected and power input will not be fully utilized.

TABLE 3 OPTIMUM SIZE/NUMBER OF FANS FOR ROOMS OF DIFFERENT SIZES

(*Clause* 6.3.3.1)

LENGTH, m / WIDTH, m	4	5	6	7	8	9	10	11	12	14	16
3	1 200/1	1 400/1	1 500/1	1 050/2	1 200/2	1 400/2	1 400/2	1 400/2	1 200/3	1 400/3	1 400/3
4	1 200/1	1 400/1	1 200/2	1 200/2	1 200/2	1 400/2	1 400/2	1 500/2	1 200/3	1 400/3	1 500/3
5	1 400/1	1 400/1	1 400/2	1 400/2	1 400/2	1 400/2	1 400/2	1 500/2	1 400/3	1 400/3	1 500/3
6	1 200/2	1 400/2	900/4	1 050/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
7	1 200/2	1 400/2	1 050/4	1 050/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
8	1 200/2	1 400/2	1 200/4	1 200/4	1 200/4	1 400/4	1 400/4	1 500/4	1 200/6	1 400/6	1 500/6
9	1 400/2	1 400/2	1 400/4	1 400/4	1 400/4	1 400/4	1 400/4	1 500/4	1 400/6	1 400/6	1 500/6
10	1 400/2	1 400/2	1 400/4	1 400/4	1 400/4	1 400/4	1 400/4	1 500/4	1 400/6	1 400/6	1 500/6
11	1 500/2	1 500/2	1 500/4	1 500/4	1 500/4	1 500/4	1 500/4	1 500/4	1 500/6	1 500/6	1 500/6
12	1 200/3	1 400/3	1 200/6	1 200/6	1 200/6	1 400/6	1 400/6	1 500/6	1 200/7	1 400/9	1 400/9
13	1 400/3	1 400/3	1 200/6	1 200/6	1 200/6	1 400/6	1 400/6	1 500/6	1 400/9	1 400/9	1 500/9
14	1 400/3	1 400/3	1 400/6	1 400/6	1 400/6	1 400/6	1 400/6	1 500/6	1 400/9	1 400/9	1 500/9

APPENDIX A

(Clause 5.2)

DETAILS OF DESIGN FOR NATURAL VENTILATION

A-1. MECHANISM OF NATURAL VENTILATION

A-1.1 Natural ventilation in buildings is due to two forces, namely, thermal or temperature forces or stack effect and aeromotive or wind forces. When both wind and stack presure are acting, each pressure may be calculated as acting independently under conditions ideal to it and then a percentage be applied. However, ventilation in residential buildings due to stack pressure, both in hot arid region and hot humid region, appears to be insignificant and may be neglected, as when both wind pressure and stack pressure are acting, wind pressure effect may be assumed to be predominant.

A-2. VENTILATION DUE TO THERMAL FORCE

A-2.1 When a temperature difference exists between the outside and inside air of a building, a pressure gradient is developed along the vertical direction over the walls of the building. If the temperature inside is higher than that outside, the upper parts of the building will have higher pressure while the lower parts will have lower pressure. When openings are provided in these regions, air enters through the lower openings and escapes through the upper. In case the indoor air temperature is lower than outside, the air flow will be reversed. The rate of flow induced by thermal force is given by the equation:

$$Q = 7.0\ A\ \sqrt{h\,(t_r - t_0)}$$

where

Q = volume of air in m^3/min,

A = free area of inlet opening in m^2,

h = vertical distance between inlets and outlets in m,

t_r = average temperature of indoor air at the height h in °C, and

t_0 = temperature of outdoor air in °C.

Example 1

With an average indoor temperature of 30°C, outdoor temperature of 25°C and a vertical distance of 3.0 m between the centres of the openings, the quantity of air flow is given by,

$$Q = 7\sqrt{3 \times 5}\ (m^3/min/m^2)$$

or

$$Q = 27.118\ (m^3/min/m^2)$$

A-3. VENTILATION DUE TO WIND FORCES

A-3.1 When wind strikes a building, a region of higher pressure is created on windward wall, while the sides, leeward wall and roof are all subjected to reduced pressure. A pressure gradient is thereby created across the building in the direction of the incident wind. This pressure gradient causes the air to flow through the building from openings in the region of higher pressure to openings located in lower pressure.

In the simple case of an isolated enclosure in which openings are provided in each of two opposite walls, the rate of air flow can be calculated by the equation:

$$Q = KAV$$

where

Q = rate of air flow in m^3/h,

A = area of smaller opening in m^2,

V = outdoor wind speed in m/h, and

K = coefficient of effectiveness.

The coefficient of effectiveness, K depends upon the direction of the wind relative to the opening, and on the ratio between the areas of the two openings. It is maximum when the wind blows directly on to the opening and it increases with the relative size of the larger opening. Figure 3 gives the values of K for various ratios of the two openings, for winds perpendicular to the opening and at 45° to it.

Changes in wind directions up to 30° on either side of the normal to the window wall have little effect on the value of K. For wind directions outside these limits, the value of K may be considered to change linearly with wind direction.

Example 2

With an outdoor wind speed of 5 km/h and wind incident normally on the window wall, the wind incident normally on the window wall, the quantity of air flow is

$$Q = 0.6(1)(5\,000)\ (m^3/h/m^2)$$

$$Q = 3\,000\ (m^3/h/m^2)$$

A-4. VENTILATION DUE TO COMBINED EFFECT OF WIND AND THERMAL FORCES

A-4.1 The actual flow in a building results from the combined effect of thermal and wind forces. The two forces may either oppose or reinforce each other, depending on the direction of the wind and on whether the internal or the external temperature is higher. When acting simultaneously, the rate of air flow through the building may be computed by the equation

$$Q^2 = Q_w^2 + Q_T^2$$

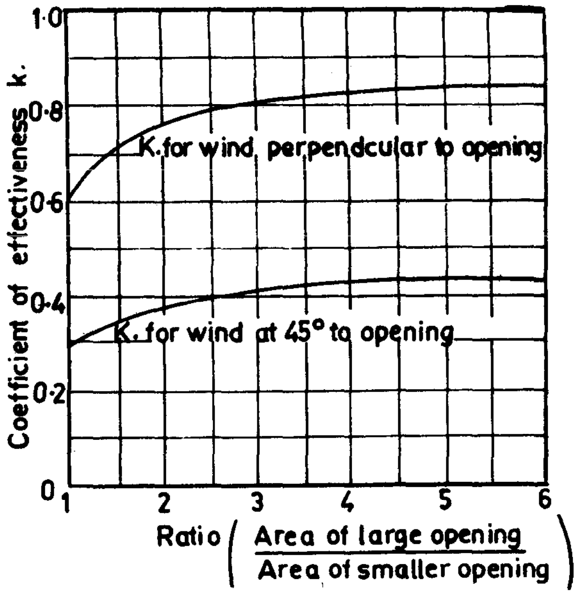


Fig. 3 VALUES OF COEFFICIENT OF EFFECTIVENESS k FOR FLOW THROUGH TWO OPENINGS

where

Q = resultant volume of air flow in m^2/min,

Q_w = volume of air flow due to wind force in m^3/min, and

Q_T = volume of air flow due to thermal force in m^3/min.

It is thus seen that even when the two forces are nearly equal in magnitude, and operate in the same direction, the resulting air flow is about 40 percent greater than that produced by either force acting independently. This percentage decreases rapidly as one force increases over the other.

A-5. PROBABLE INDOOR WIND SPEED

A-5.1 Room with Windows on One Wall Only

A-5.1.1 The available wind velocity in a room with single window on the windward side is about 10 percent of outdoor velocity at points up to a distance one-sixth of room width from the window. Beyond this, the velocity decreases rapidly and hardly any air movement is produced in the leeward half portion of the room.

A-5.1.2 The average indoor wind velocity is generally less than 10 percent of outdoor velocity. The value, however, is increased up to 15 percent when two windows are provided instead of one and wind impinges obliquely on them.

A-5.2 Room with Windows on Two Sides

A-5.2.1 When identical windows are provided on opposite walls and one of the windows faces normally incident wind, the average indoor velocity at a plane passing through the sill of the windows 0.9 m above the floor, is determined from Fig. 4. For example, for windows with 20 percent of floor area, the average indoor wind velocity is about 25 percent of outdoor velocity.

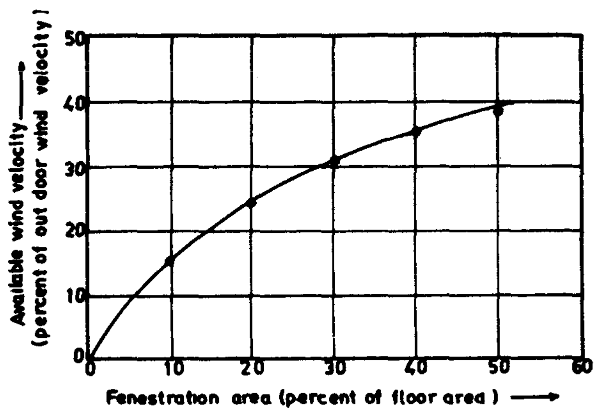


FIG. 4 EFFECT OF AREA OF OPENINGS ON AVERAGE INDOOR WIND VELOCITY

A-5.2.2 For a different sill height, the available average velocity (V_s) at the sill level may be computed using the equation:

$$V_s = V_{0.9} + 0.072\ (1 - S)V_0$$

where

$V_{0.9}$ = average indoor wind velocity in km/h as determined from **A-5.2.1**

S = relative sill height with reference to normal sill height of 0.9 m, and

V_0 = outdoor wind velocity in km/h.

Example 3

For a sill height of 0.75 m.

$$S = \frac{0.75}{0.9} = 0.83$$

and

$$V_s = V_{0.9} + 0.072\ (1 - 0.83)V_0$$
$$= V_{0.9} + 0.012\,3V_0$$

A-5.2.3 When the sizes of inlet and outlet are not equal, the area of inlet is first expressed as percent of the total area of fenestration and the corresponding value of performance efficiency (E) is determined from Fig. 5. The average indoor wind velocity V is then obtained by multiplying the value of E with that of V_s calculated in **A-5.2.2**. The value of local velocity at different point shows a deviation from that of the average taken over the whole room area. For a given value of ratio of inlet size and total area of fenestration, the root mean square deviation (RMSD) of local velocity from the average value may be obtained from the curve in Fig. 6.

A-5.2.4 For obliquely incident wind, the value of V determined in **A-5.2.3** is multiplied by a factor given in Table 4.

TABLE 4 EFFECT OF ORIENTATION ON INDOOR AIR MOTION

[*Clause* A-5.2.3]

Relative Size of Openings	Multiplying Factor for 45° Incidence
(1)	(2)
Inlet > outlet	1
Inlet = Outlet	Varying from 0.8 for fenestration area 25 percent of floor area to 0.85 for fenestration of larger sizes.
Inlet < Outlet	0.7

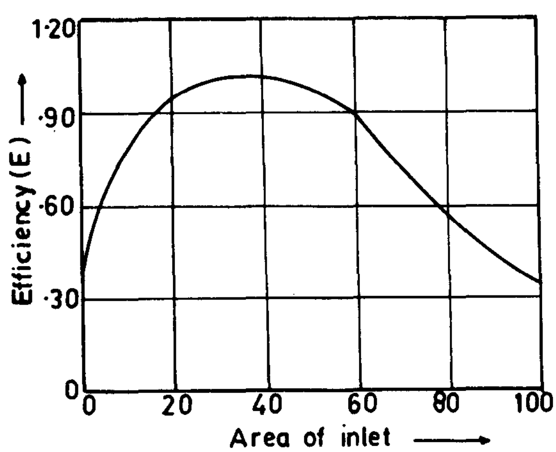


FIG. 5 EFFECT OF SIZE OF INLET ON THE PERFORMANCE EFFICIENCY

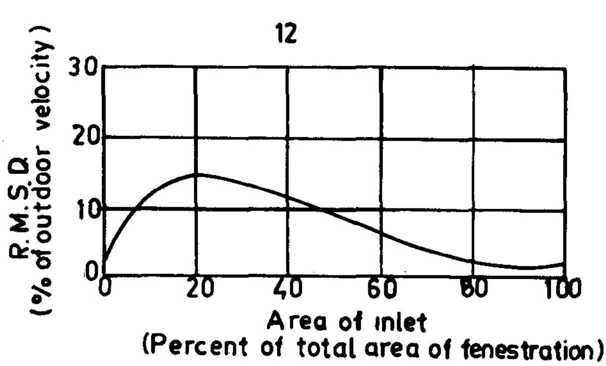


FIG. 6 EFFECT OF SIZE OF INLET ON ROOT MEAN SQUARE DEVIATIONS

A-5.2.5 The value of V obtained above is considerably influenced by change in the location of openings with respect to the outdoor wind. The factors representing the changes in V, for some of the typical cases, are given in Table 5. For a given window location and orientation, the average indoor wind velocity may be obtained by adding the corresponding factor to the value of V obtained in the foregoing steps.

A-5.2.6 Louvers, which are provided for protection against rain and for prevention of direct entry of sun through the windows, have a bearing on indoor air flow pattern. The influence of some simple types of louvers on room air motion is summarized in Table 6. Thus the average indoor wind velocity in a room with louvered window is obtained by adding the corresponding correction factors to the value of V obtained in **A-5.2.5**.

A-5.2.7 The presence of a verandah on windward or leeward side of a room influences the room air motion. Table 7 shows the effect on average indoor wind velocity of some of the common types of verandah.

To get the value of average indoor wind velocity for the given type, location and orientation of a verandah in front of window, the correction factor may be taken from Table 7 and applied to the value of V obtained in **A-5.2.5**. The value remains almost unaffected in case the verandah height is lower than that of the room.

A-5.2.8 The type of interconnection between the different rooms and the location of the intermediate door play an important role in the establishment of indoor wind pattern. The value of average indoor wind velocity in a room of a multi-room house is determined by subtracting from V an appropriate value given (as percentage of V) in Table 8.

Example 4

To find out the probable average indoor wind velocity in the living room of a two-roomed house (*see* Fig. 7) when wind is incident normally on the exposed side of the room. The living room has a floor area of 11.3 m^2. Area of the window opening on the exposed side is 1.6 m^2 and area of the window opening on the leeward side is 1.9 m^2.

Solution

i) Referring to Fig. 7:

Size of inlet	=	1.6 m^2
Size of outlet	=	1.9 m^2
Floor area	=	11.3 m^2

TABLE 5 EFFECT OF WINDOW LOCATION ON INDOOR AIR MOTION

(Clause A-5.2.5)

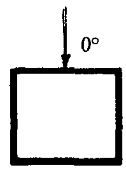
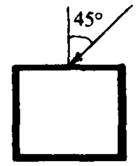
Window Location ↓ / Orientation →	Change in v (% of v)	
		
	0	0
	−10	+40
	−10	−15
	−15	0
	−15	0
	0	0
	−10	+40
	−10	−15
	0	−60
	−20	−10
	−20	−60

TABLE 6 INFLUENCE OF LOUVERS ON INDOOR AIR MOTION

(*Clause* A-5.2.6)

TYPE OF LOUVER (Fig. 1A)	CHANGE IN V (AS PERCENT OF V)	
	0°	45°
Horizontal (sunshade) (*chajja*)	−20	−20
L-type (horizontal and vertical)	+5	+10
Box type:		
Contraction ratio 1 : 1	0	−25
Contraction ratio 2 : 1	0	0
Multiple horizontal	−10	−13
Multiple vertical	−15	−25

TABLE 7 EFFECT OF VERANDAH ON INDOOR AIR MOTION

(*Clause* A-5.2.7)

SL No.	TYPE OF VERANDAH	LOCATION	CHANGE IN V (AS PERCENT OF V)	
			0°	45°
(1)	(2)	(3)	(4)	(5)
i)	Open on three sides	Windward	+15	+10
		Leeward	+15	+10
ii)	Open on two sides	Windward	0	0
		Leeward	0	0
iii)	Open side parallel to the room wall	Windward	−10	−10
		Leeward	0	0
iv)	Open side perpendicular to the room wall	Windward	−50	−30
		Leeward	0	+15

∴ Total area of fenestration

= 3.5 m²
= 31 percent of floor area.

∴ Indoor wind velocity ($V_{0.9}$) from Fig. 4 = 32 percent of outdoor velocity (V_0)

ii) $\dfrac{\text{Size of inlet} \times 100}{\text{Total area of fenestration}} = 45$ percent

∴ Performance efficiency, from Fig. 5 = 100

∴ $V_{0.9} = 0.32\ V_0$

iii) Sill height in the present case = 0.76 m

∴ Average indoor wind velocity (V_1) at a plane passing through the sill of window is given by:

$$V_1 = \left[0.32 + \frac{7.2}{100}\left(1 - \frac{0.76}{0.9}\right)\right] V_0$$

$$= 0.331\ V_0$$

iv) Since the wind is incident normally and inlet is located almost in the centre of the wall, no correction is needed (Table 5).

v) Since the window is provided with a horizontal louver, the reduction in V_1, as determined from Table 6, is 20 percent.

$$\therefore\ V_1 = 0.331\left(1 - \frac{20}{100}\right) V_0$$

$$= 0.265\ V_0$$

vi) In the present case, the reduction in room air velocity due to series connection (as determined from Table 8) is −20 percent.

∴ Final value of average indoor wind velocity

$$= 0.265\left(1 - \frac{20}{100}\right) V_0$$

= 21.2 percent of outdoor wind velocity.

NOTE — The correction factors given in different tables are applicable for the window sizes mostly used in practice. In case the building design details are not directly covered by this information, an appropriate value of the correction factor may be obtained by the intrapolation of the relevant data.

Example 5

To find out the probable average indoor wind speed in a room (4.2 × 3.6 m²) having inlet of 2.1 × 1.2 m² and outlet of 2.2 × 1.1 m². It may be assumed that wind is incident within 30° to the normal to the inlet, and height of sill is 0.70 m.

Solution :

i) Size of inlet = 2.52 m²

Size of outlet = 2.42 m²

Floor area = 15.12 m²

Total area of fenestration = 4.94 m²
= 32.7 percent of floor area.

∴ Indoor wind speed, V_1 from Fig. 4 is equal to 32.2 percent of outdoor wind.

ii) $\dfrac{\text{Size of inlet}}{\text{Total area of fenestration}} = 0.51$ or 51 percent

∴ Performance efficiency, from Fig. 5 = 0.97

∴ $V_1 = 32.7 \times 0.97$
= 31.7 percent of outdoor wind speed.

iii) sill height in the present case = 0.70 m

∴ Average wind speed at a plane passing through the sill of window is given by:

$$V_1 = \left[0.317 + 0.072\left(1 - \frac{0.70}{0.9}\right)\right] V_0$$

$$= 0.333\ V_0$$

= 33.3 percent of outdoor wind velocity.

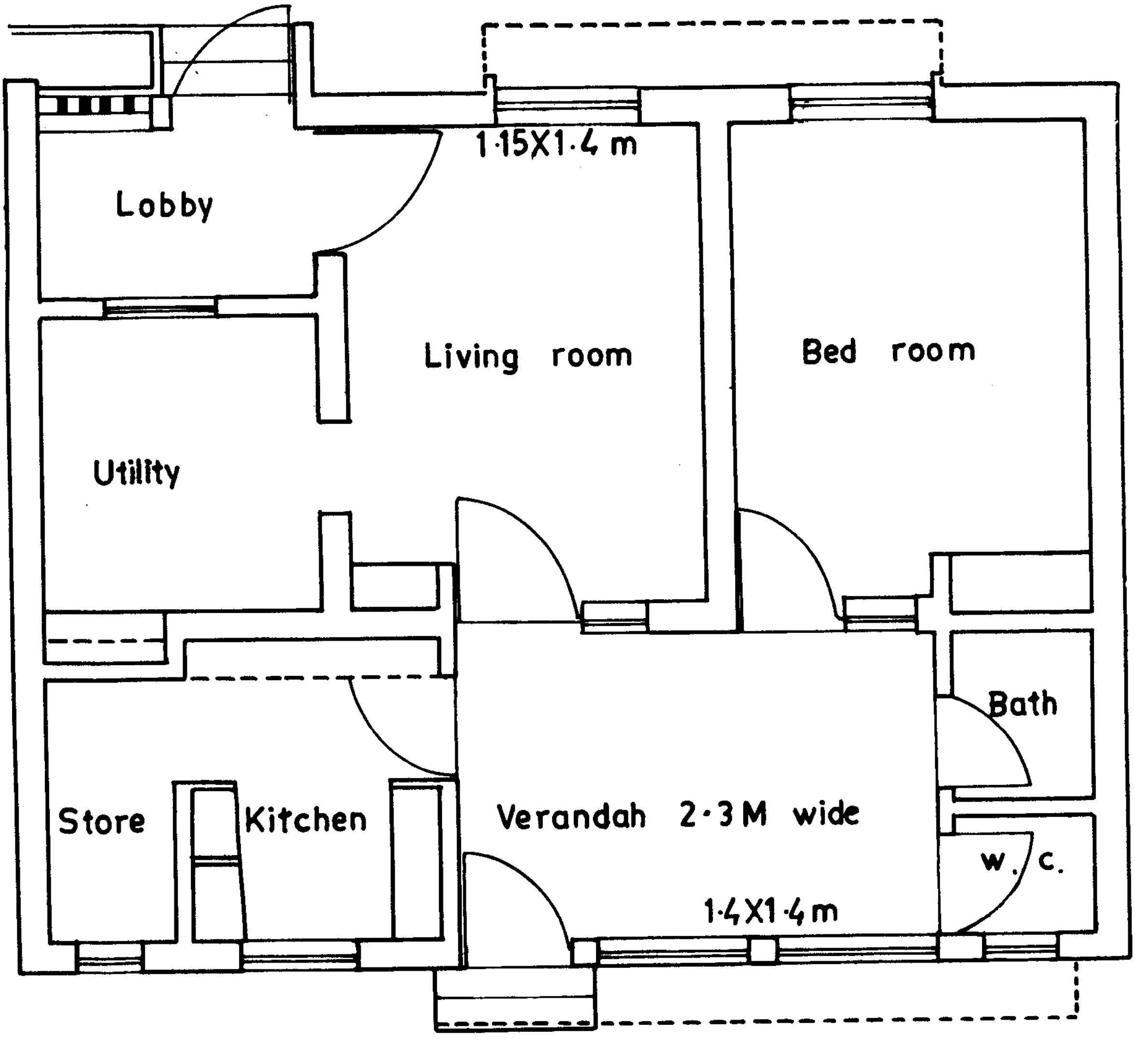
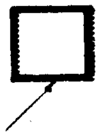
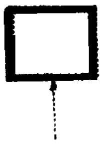
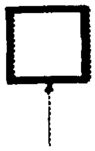
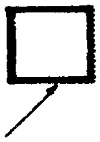


FIG. 7 PLAN OF A TYPICAL TWO ROOM HOUSE

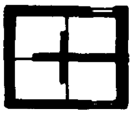
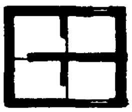
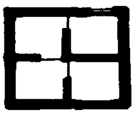
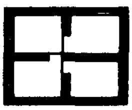
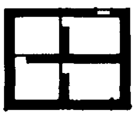
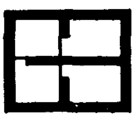
TABLE 8 EFFECT OF LOCATION OF INTER-CONNECTING DOORS ON AIR MOTION IN ROOMS

(*Clause* A-5.2.8)

		← ORIENTATION → Location of Inter-connecting doors ↓		
			7.5 7.5	15 15
— —	— —		10 20	45 15
80 80	75 75		15 25	45 15
35 15	15 20		15 20	50 15
45 30	20 20		20 20	55 30
— 20	— 45		10 25	45 35
50 35	45 25		— 25	— 15
50 —	45 —		25 25	50 15
55 35	40 25		40 20	55 20
25 15	15 15		15 30	40 15

(*Continued*)

TABLE 8 EFFECT OF LOCATION OF INTER-CONNECTING DOOR ON AIR MOTION IN ROOM—*Contd.*

Reduction in V(% of V)	Location of Intermediate Door	Reduction in V(% of V)
50 25		20 20
40 30		45 20
40 30		25 25
30 55		50 20
55 55		35 15
30 45		45 20
30 35		35 20

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PART 4 LIGHTING

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PART 4 LIGHTING

GENERAL

1.1 Introduction — Lighting design requires adequate provision of daylighting, artificial lighting and supplementary artificial lighting depending upon the type of building and the visual task to be executed by the occupants. Design methods described here conform to the National Building Code of India 1983 and are based on IS : 2440-1975 'Guide for daylighting of buildings (*second revision*)', IS : 7942-1976 'Code of practice for daylighting of educational buildings', IS : 6060-1971 'Code of practice for daylighting of factory buildings' and IS : 3646 (Part 1)-1966 'Code of practice for interior illumination: Part 1 Principles of good lighting and aspects of design'.

The basis of daylighting design adopted in the Indian Standards is the clear design sky which is representative of the prevalent sky condition in India and ensures adequate daylight for most of the working hours. Daylight indoors depend upon the size and location of windows, room size, interior finish and external obstruction, such as building, tree and mountain. The computations of expected daylight indoors involve the determination of sky components, inter-reflected component and the external reflected component. From the tables of sky components and the methods of calculation of internal and external reflected components as given in IS : 2440-1975, the design curves have been obtained which have also been included in IS : 7942-1976. These design curves provide relationship between daylight factors at fixed locations in a room and the window size expressed as percentage of the floor area. Depending upon the requirement of daylight factor, the area of window openings can be easily read from these curves.

The design curves enable the determination of the area of window openings required for a given daylight factor. The exact analyses of daylight availability indoors for specific details of length, height, distribution and location of window openings, room size, interior finish and external obstruction is possible through the methods described in IS : 2440-1975. To simplify these calculations, the sky component protractors based on the tables of sky components and nomogram for internal reflected component have been provided in this part of the Handbook. Lux grid included in IS : 7942-1976 can also be used for detailed design and analysis. The use of these design aids is illustrated with various examples.

Artificial lighting design has been covered through lumen method and point-by-point method. These methods enable the design for general lighting as well as local lighting in the work areas. Supplementary lighting can also be treated as general and local supplementary lighting. While provision of local supplimentary lighting can be estimated by point-by-point method, design curves for determining general supplementary lighting required during period of poor daylight availability have been included. The design curves for general supplementary lighting for periods of poor daylight availability are based on exhaustive studies on subjective assessment of occupants. These curves give the requirement of general supplementary lighting for normal interior finish depending upon the floor area and the size of windows expressed as percentage of floor area. To satisfy the task illumination requirement, local lighting may have to be provided, in addition to the general supplementary lighting.

1.2 Light and Vision — The primary purpose of light and lighting is to provide illumination for the performance of visual task with a maximum of speed, accuracy, ease and comfort, and a minimum of strain and fatigue.

1.3 Light and the Energy Spectrum — Light is radiant energy evaluated in terms of its capacity of producing the sensation of sight. Visible energy is a very small portion of the wide range of the electromagnetic radiation spectrum. All these radiations travel through space in the form of electromagnetic waves at a speed of 3×10^8 metres per second (in vacuum). They are characterized by the wavelength and frequency. The distance between successive crests of a wave is termed as wavelength and is denoted by λ (*see* Fig. 1). The frequency is denoted by ν. It is proportional to the ratio of velocity and wavelength in a medium through which the radiant energy passes, but it is fixed independently of the medium.

The visible spectrum (*see* Fig. 2), to which the human eye responds, is a narrow band of wavelengths between 400 and 800 nm.

1.4 Eye and its Ability to See — The structure and working of human eye (*see* Fig. 3) resembles that of a camera. Light enters through an opening (pupil) in the centre of the iris and image is formed on the retina which is a light sensitive surface at the back of the eyeball containing nerve fibres branching out from optic nerve and ending in cone and rod-shaped structures.

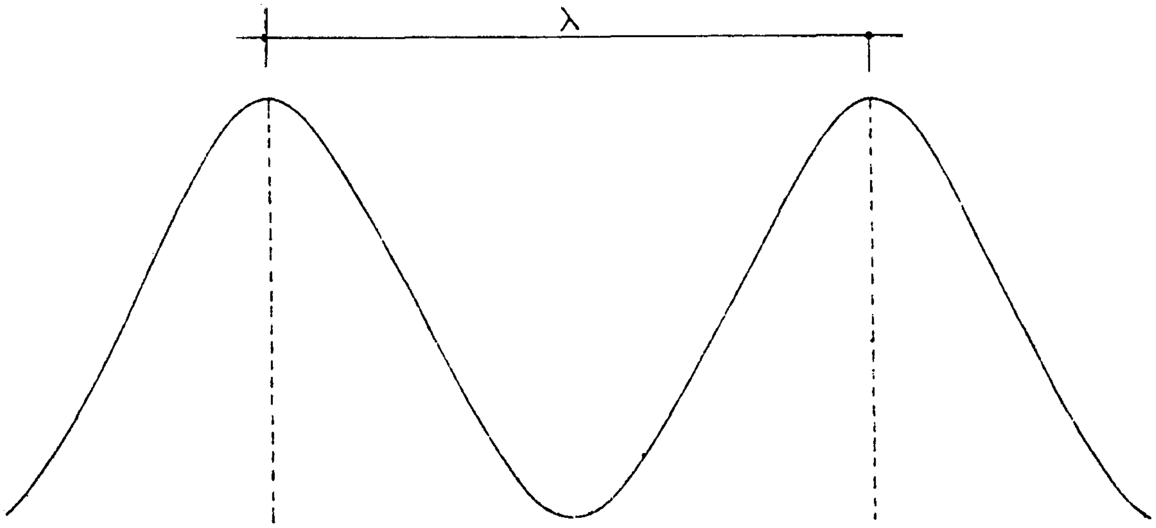

FIG. 1 CONCEPT OF WAVELENGTH IN WAVE PROPAGATION

The rods and cones are photo receptors sensitive (*see* Fig. 4) to low (scotopic vision) and high (photopic vision) level of illumination respectively. The cones are responsible for discrimination of fine details and perception of colour, and are found principally in the centre of retina with the greatest concentration at the fovea, an area about 0.3 mm in diameter. The rods have no colour response and are found only outside the foveal region, increasing in number with distance from the fovea. There are no rods and cones at the point where the optic nerve enters the eye. This point is insensitive to light stimulus and is called blind spot.

1.4.1 *Visual Field* — The angular range within which the eye can see the objects is called the visual field. The visual field of each eye is partly blocked by the nose, eyebrow and the cheek. The common visual field of both the eyes is called 'Binocular visual field' (*see* Fig. 5). The total visual field of both the eyes extends approximately 160° in the horizontal plane and 120° in the vertical plane. The central field alongwith the surroundings is limited to a circle approximately 30° from the optical axis. Beyond this angle, the vision is indistinct and only the changes in brightness or movement can be detected. The limits of the central field comprising visual task and its background vary with the task.

1.4.2 *Visual Acuity* — The size of the object in terms of visual angle (the angle subtended by the object at the eye) is one of the most important factors in seeing. The visual angle (*see* Fig. 6) depends upon the size of the object and its distance from the eye. The larger the angular size of the object, the more readily it can be seen. The ability of the eye to distinguish fine details is called visual acuity. It is expressed as the reciprocal of the visual angle in minutes subtended at the eye by the smallest detail that can be seen. Visual acuity is markedly increased with increase in illumination.

1.4.3 *Contrast Sensitivity* — Brightness of the object and the brightness contrast between the object and its immediate background are important factors for the seeing process. The brightness of an object depends upon the amount of light incident and the proportion of that light reflected or transmitted in the direction of the eye. The difference in the brightness of the background and the object expressed as a fraction of the background brightness is known as contrast. The variation of contrast sensitivity with background brightness is shown in Fig. 7.

1.4.4 *Time Response* — The time factor is of particular importance in seeeing the moving objects. High levels of lighting considerably increase the visibility of moving objects by increasing the spped of vision (*see* Fig. 8).

1.5 Lighting Terms and Units

1.5.1 *Absorbance* — It is the ratio of the flux absorbed by the medium to the incident flux. The sum of the total reflectance, total transmittance and the absorbance is one.

1.5.2 *Candle Power (CP)* — It is the luminous intensity of a source in a given direction expressed in candelas.

1.5.3 *Candle Power Distribution Curve* — It is a curve showing the variation of luminous intensity of a lamp or luminaire with angle of emission. A vertical candle power distribution represents the variation of luminous intensity with angle of elevation in a vertical plane through the light centre. A horizontal candle power

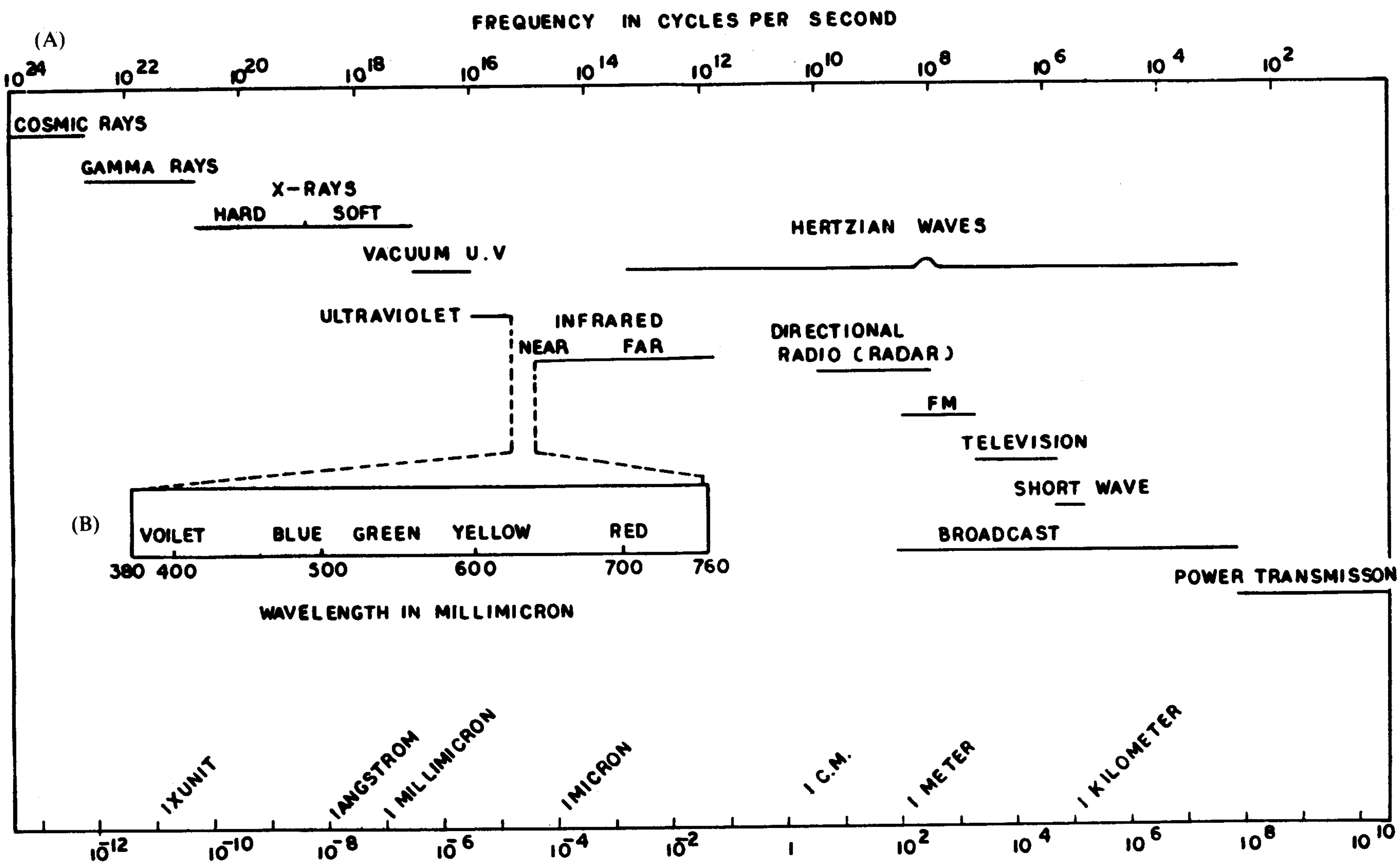

FIG. 2 LIGHT SPECTRUMS: (A) ELECTROMAGNETIC SPECTRUM AND (B) VISIBLE SPECTRUM

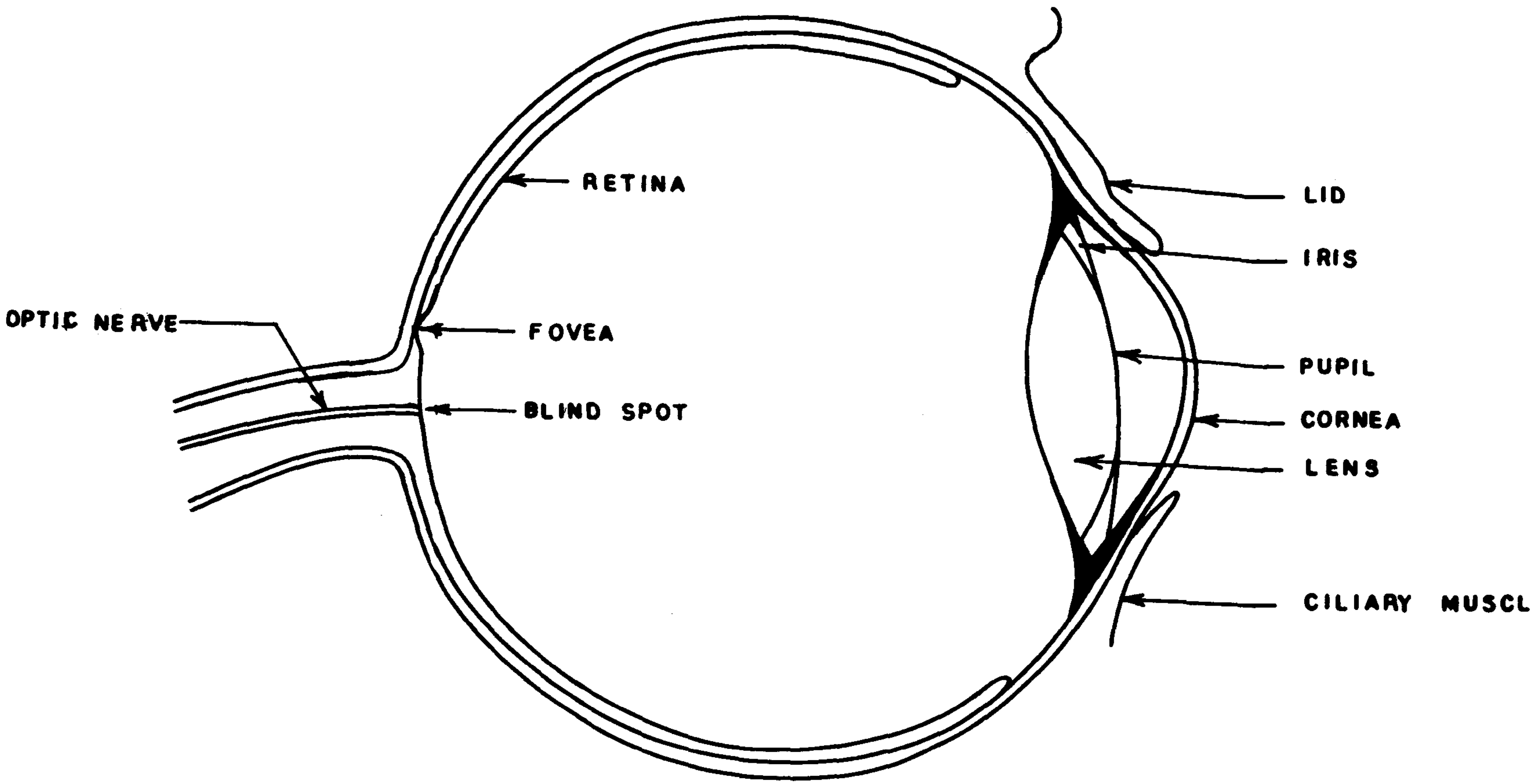

FIG. 3 VERTICAL CROSS-SECTION OF THE HUMAN EYE

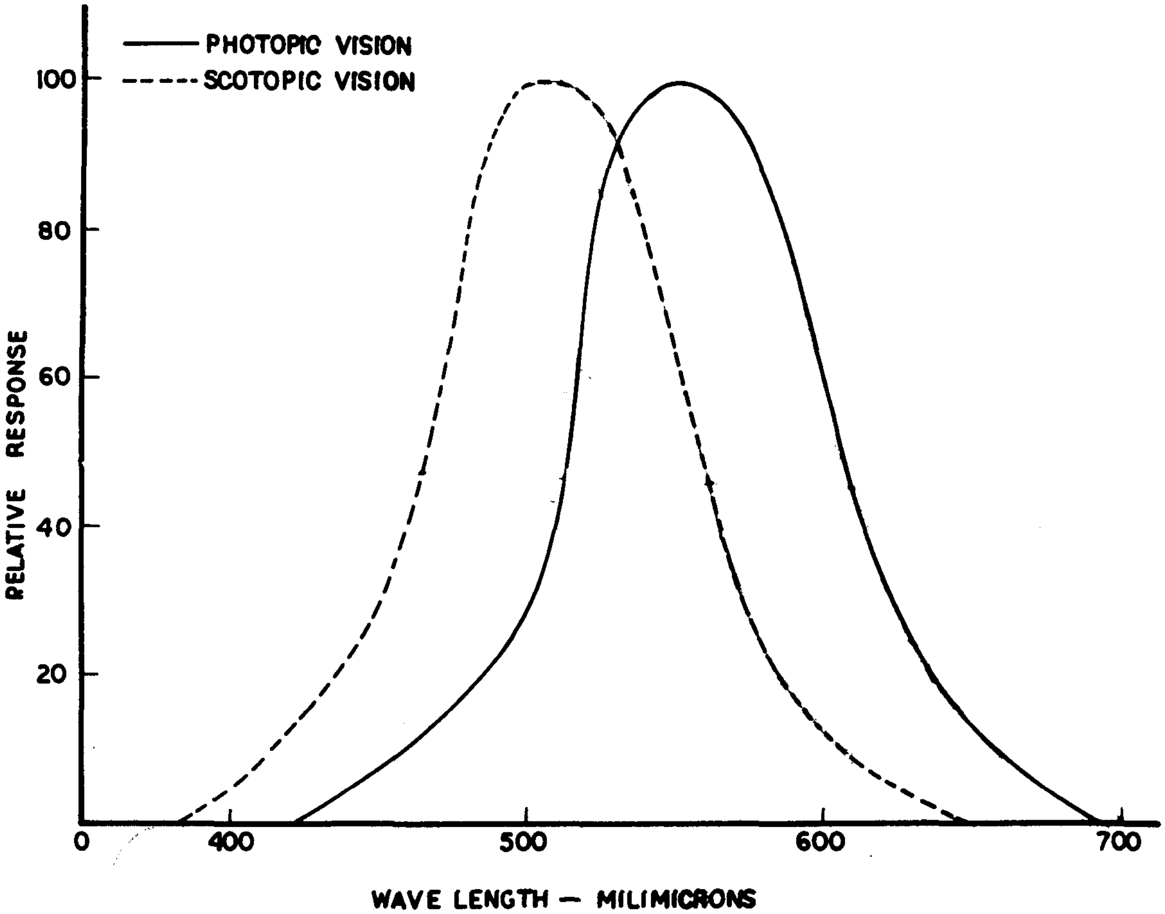

FIG. 4 RELATIVE SPECTRAL SENSITIVITY OF HUMAN EYE FOR PHOTOPIC AND SCOTOPIC VISION

distribution represents the variation of luminous intensity with angle of azimuth in a horizontal plane through the light centre.

1.5.4 *Clear Design Sky* — It is half of the sky vault opposite the sun for a solar altitude of 15° (above the horizon); the whole sky vault providing 8 000 lux diffuse illumination and 16 000 lux total illumination on a horizontal plane, and having a luminance distribution varying as cosecant of the angle of view (cosec θ) between 15° and 90° above horizon and remaining constant between 0° and 15° above horizon.

1.5.5 *Chroma* — It is the attribute of the perceived object colour used to describe its departure from grey of the same lightness.

1.5.6 *Chromaticity Coordinates of a Light* — These are the ratios of each of the tristimulus values of the light to the sum of the three tristimulus values and are denoted by x, y, z;

where

$$x = \frac{X}{X+Y+Z},$$

$$y = \frac{Y}{X+Y+Z}, \text{ and}$$

$$z = \frac{Z}{X+Y+Z}$$

1.5.7 *Coefficient of Utilization* — It is the ratio of the lumens received on the workplane to the lumens emitted by the lamps.

1.5.8 *Colour of a Light Source* — It is the characteristics of the source determined by its spectral composition and the spectral properties of the average normal human eye.

1.5.9 *Colour of an Object* — It is the colour of the light reflected or transmitted by an object when illuminated by a standard light source such as illuminant A, B or C.

1.5.10 *Colour Temperature of a Light Source* — It is the temperature at which a black body radiator must be operated to have a chromaticity equal to that of the light source.

1.5.11 *Compound or Mixed Reflection* — It is the phenomenon of reflection in which regular

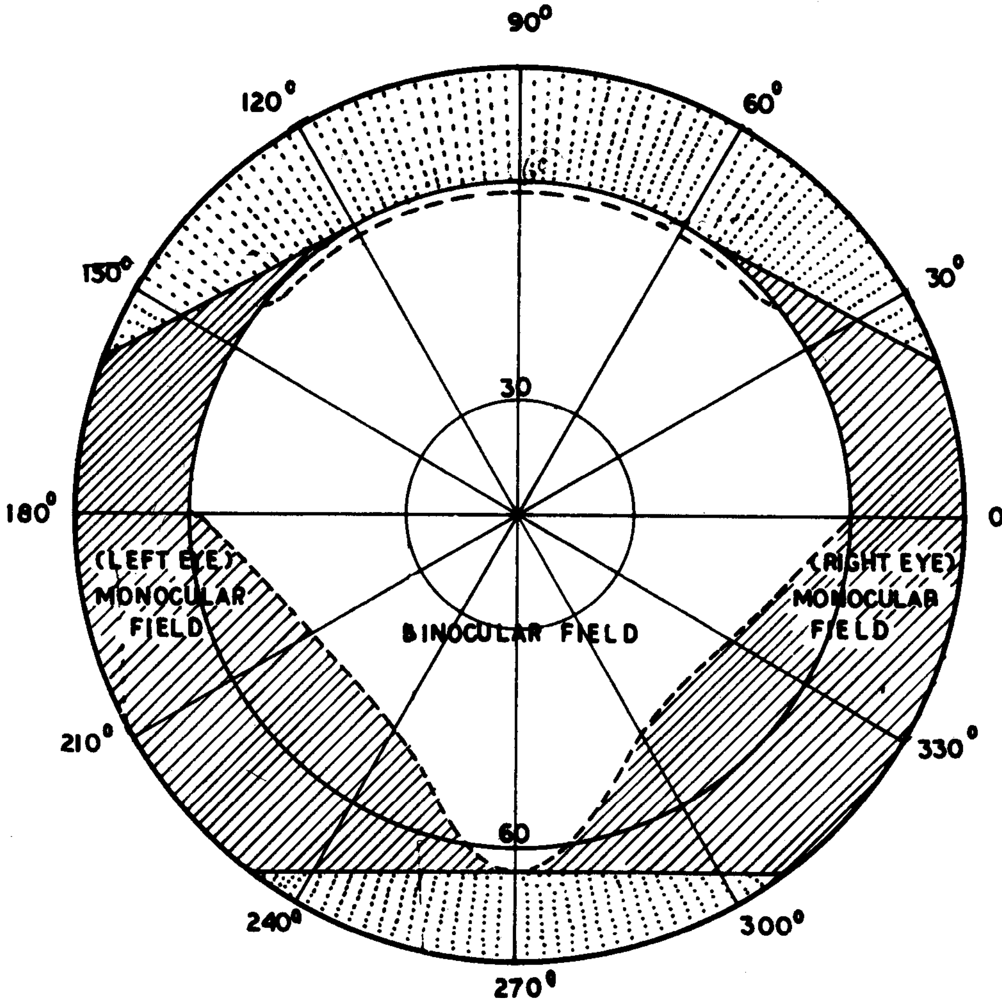

FIG. 5 BINOCULAR VISUAL FIELD OF HUMAN EYE

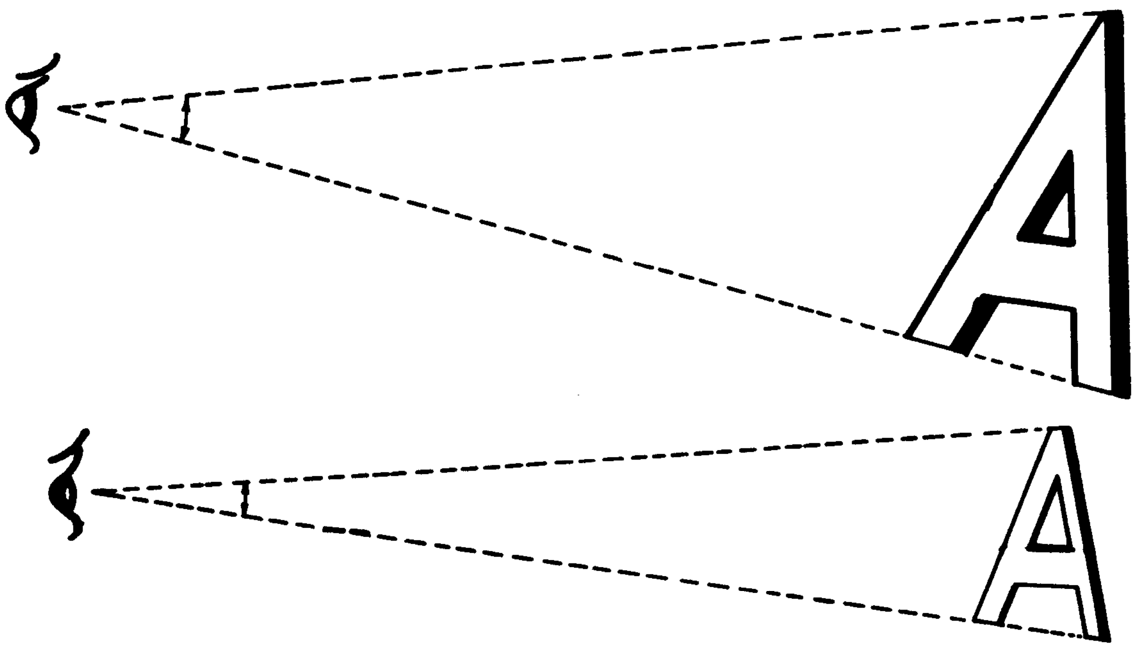

FIG. 6 VISUAL ANGLE SUBTENDED AT THE EYE

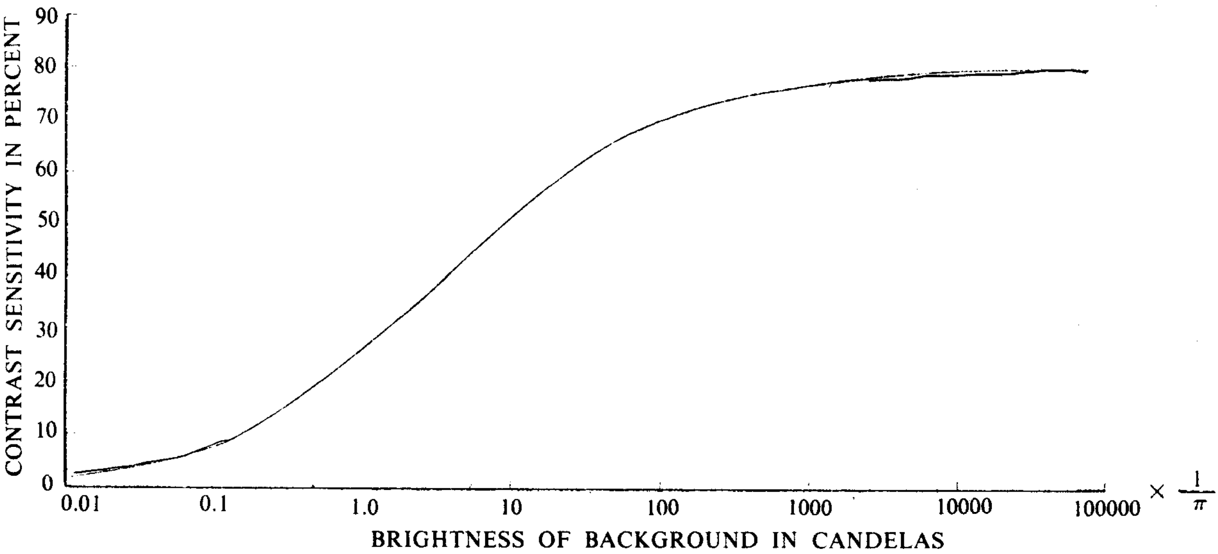

FIG. 7 VARIATION OF CONTRAST SENSITIVITY WITH BACKGROUND BRIGHTNESS

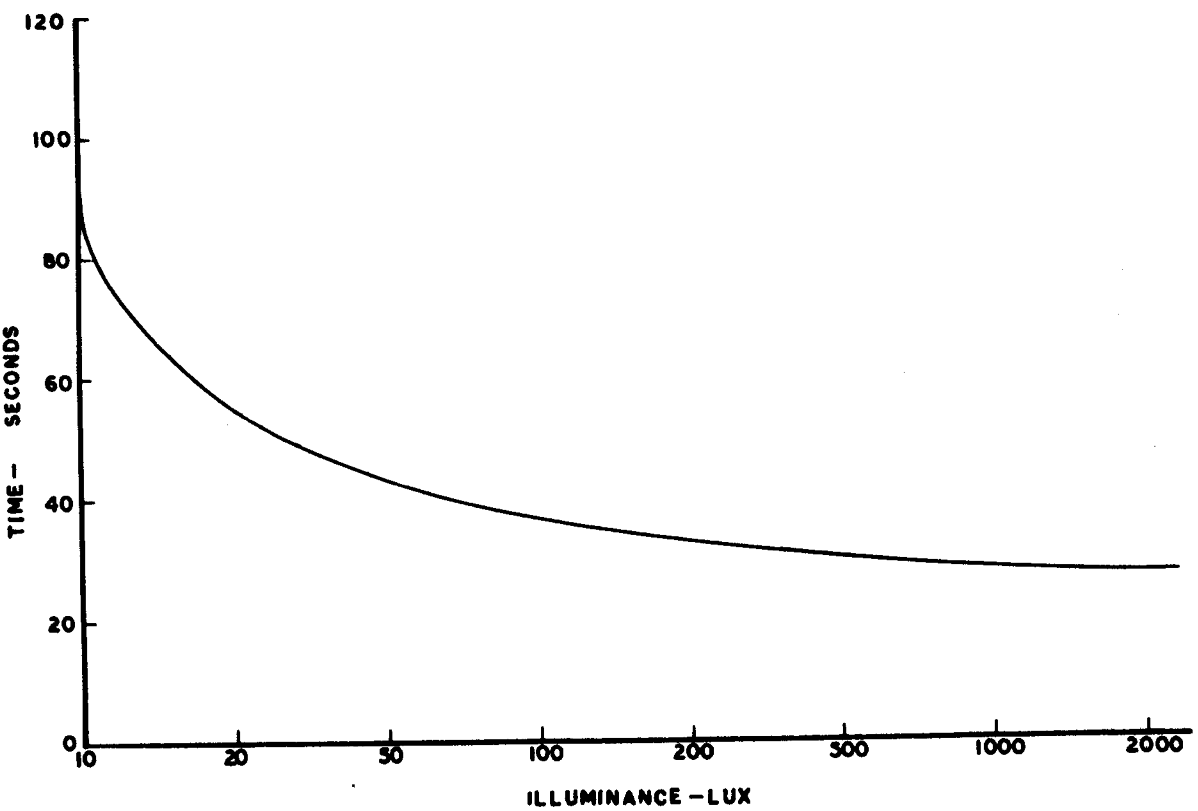

FIG. 8 VARIATION OF SPEED OF VISION WITH ILLUMINANCE

and diffuse reflection occur simultaneously (*see* Fig. 9).

1.5.12 *Daylight Factor (DF)* — It is the percentage ratio of the daylight illumination at an indoor point on a given plane to the simultaneous outdoor illumination on a horizontal plane due to whole (unobstructed) of the sky vault, excluding the direct sunlight. For the clear design sky, the daylight factor is a percentage fraction of 8 000 lux. Daylight factor is the sum of sky component (SC), the external reflected component (ERC) and the internal reflected component (IRC).

1.5.13. *Diffuse Reflection* — It is the phenomenon of reflection in which the reflected light is diffused such that it is in non-image forming state (*see* Fig. 9).

1.5.14 *Diffuse Transmission* — It is the phenomenon of transmission of light through a medium in which the transmitted light is diffused such that it is in a non-image forming state.

1.5.15. *Diffuser* — A material which can redirect the luminous flux from a source, primarily by the process of diffuse transmission.

1.5.16 *Direct Glare* — Glare resulting from high brightness or insufficiently shielded light sources in the field of view.

1.5.17 *External Reflected Component (ERC)* — It is the percentage ratio of the illumination reaching directly at a given point after reflection from external surfaces to the design sky illumination.

1.5.18 *Fenestration* — Any opening or arrangement of openings (normally filled with media for control) for the admission of daylight.

1.5.19 *Filter* — It is a device which changes by transmission the magnitude and/or the spectral composition of the flux incident on it. Filters are called selective (coloured) or neutral according to whether or not they alter the spectral distribution of the incident flux.

1.5.20 *Glare* — It is the effect of brightness or brightness differences within the visual field which causes annoyance, discomfort or loss of visual performance.

1.5.21 *Hue* — It is the attribute of a perceived object colour which determines whether it is red, yellow, green, blue or the like.

1.5.22 *Illuminance (E)* — It is the quotient of the flux incident on a surface divided by the area of the surface (that is, density of luminous flux incident on a surface) when the flux is uniformly distributed. The unit of illumination is lux (lx), the term used for lumen/m^2. Lux is also sometimes referred to as metre candle which is the illumination on the surface of an imaginary sphere of radius 1 m due to a uniform point source of intensity 1 Cd at its centre. The solid angle subtended by 1 m^2 of this unit sphere at the centre is 1 steradian (*see* Fig. 10). Therefore, the flux intercepted by 1 m^2 is 1 lumen and hence the illumination is 1 lux.

1.5.23 *Illuminant A* — It is one of the three standard illuminants (A, B, C) specified as practical laboratory sources for colorimetry. Illuminant A is a tungsten lamp operated at 2854 K colour temperature.

1.5.24 *Illuminant B* — It consists of illuminant A plus a filter such that it approximates a black body source operating at 4 800 K. It approximately corresponds to the colour temperatures of daylight.

1.5.25 *Illuminant C* — It consists of illuminant A and a filter to approximate a black body source operating at 6 500 K which corresponds to the colour temperatures of the combination of direct sun and clear sky light.

1.5.26 *Internal Reflected Component (IRC)* — It is the percentage ratio of the illumination reaching a given point after reflections from internal surfaces of the room to the design sky illumination.

1.5.27 *Isocandle Line* — It is a curve showing all the directions in space about a source of light in which the candle power is the same. A series of such curves for different candle power values is called isocandle diagram.

1.5.28 *Isolux Line* — It is a curve showing all the points on a surface where the illumination is the same. A series of such curves for various illumination values is called an isolux diagram.

1.5.29 *Luminaire* — It is a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, protect the lamps and connect the lamps to the power supply.

1.5.30 *Luminous Efficacy of a Light Source* — It is the ratio of the total luminous flux emitted by the source to the total power input to the source. Luminous efficacy is expressed in lumens/watt.

1.5.31 *Luminous Emittance (L)* — It is the luminous flux per unit area (density of luminous flux) emitted from a surface. The unit of luminous emittance is lumen/m^2 (lm/m^2).

1.5.32 *Luminous Flux (F)* — It is the time rate of flow of light (luminous energy) and is the quantity characteristic of radiant flux which expresses its capacity to produce visual sensation evaluated according to the values of relative luminous efficiency for the light adopted eye. The unit of luminous flux is lumen (lm).

1.5.33 *Luminous Intensity (I)* — It is the quotient of the luminous flux on an element of surface normal to the direction of the view divided by the solid angle (in steradians) subtended by the element at the source. The unit

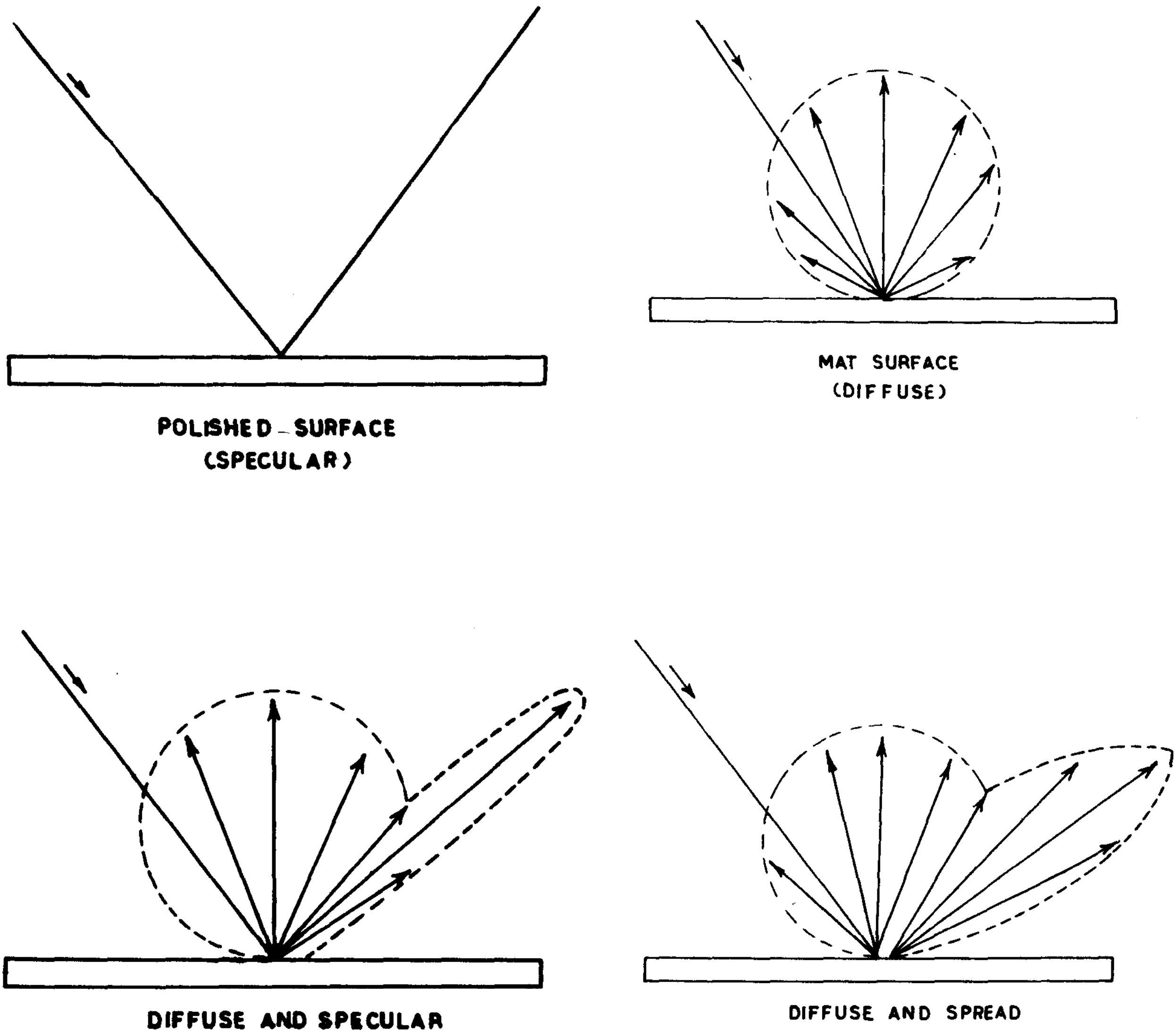

FIG. 9 SPECULAR, DIFFUSE AND COMPOUND REFLECTION FROM SURFACES

of luminous intensity is candela (Cd) which is defined as one sixtieth of the luminous intensity of one square centimetre of a black body radiator operating at the temperature of solidification of platinum.

1.5.34 *Maintenance Factor* — It is the ratio of the illumination on a given area after a period of time to the initial illumination on the same area. The period of time is such that the illumination depreciates to a minimum value corresponding to the cleaning, servicing and relamping schedule.

1.5.35 *Matt Surface* — A surface from which the reflection is predominantly diffuse without or with a negligible specular component.

1.5.36 *Mean Spherical Candle Power (MSCP)* — It is the average candle power of a source in all directions in space and is equal to the total luminous flux (lumens) divided by 4π.

1.5.37 *Mixed Transmission* — It is the phenomenon of transmission of light through a medium in which regular and diffuse transmission occur simultaneously.

1.5.38. *Mounting Height* — It is the vertical distance of the light centre of the luminaire above the horizontal workplane.

1.5.39 *Photometric Brightness (Luminance) (L)* — It is the luminous flux per unit of projected area per unit solid angle leaving a surface at a given point in a given direction. In other words, it is the luminous intensity of a surface in a given direction per unit projected area of the surface as viewed from that direction. The unit of

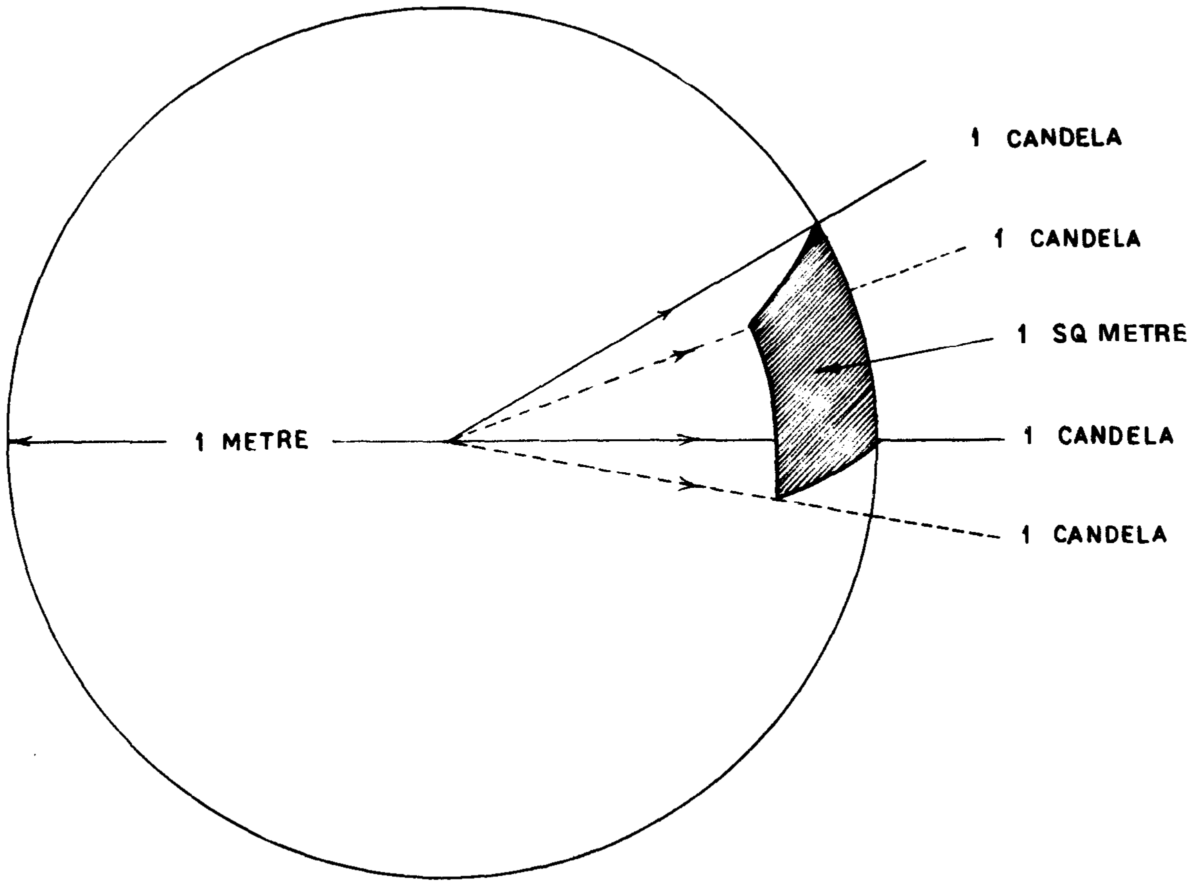

FIG. 10 UNIT SPHERE DEPICTING INCIDENCE OF LUMINOUS FLUX ON UNIT AREA FROM 1 CANDELA SOURCE AT ITS CENTRE

photometric brightness is Nit, the term used for candela/m^2.

For uniformly diffusing surface emitting or reflecting at the rate of one lumen/m^2, the photometric brightness would be $\frac{1}{\pi}$ candela/m^2.

1.5.40 *Reflectance* — It is the ratio of the flux reflected by a surface to the incident flux. The quantity reported may be total reflectance, specular (regular) reflectance, diffuse reflectance or spectral reflectance depending on the component measured.

1.5.41 *Reflected Glare* — Glare resulting from specular reflections of high brightness sources on polished surfaces in the field of view.

1.4.42 *Reflector* — It is a device used to redirect the luminous flux primarily by the process of reflection.

1.5.43 *Room Index* — It is a number indicating room proportions, calculated from length, width and ceiling height.

1.5.44 *Sky Component (SC)* — It is the percentage ratio of the illumination at a given point from the visible sky to the design sky illumination.

1.5.45 *Specular Angle* — It is the angle between the perpendicular to the surface and the reflected ray that is numerically equal to the angle of incidence and lies in the same plane as the incident ray and the perpendicular (*see* Fig. 9).

1.5.46 *Transmittance* — It is the ratio of the flux transmitted through a medium to the incident flux. The quantity reported may be total transmittance, regular transmittance, diffuse transmittance or spectral transmittance depending on the component measured.

1.5.47 *Tristimulus Values of a Light* — These are the amounts of three primaries, red, blue and green light, required to match the colour of the given light and are denoted by *X, Y, Z*.

1.5.48 *Value* — It is the attribute of the perceived object colour by which the object seems to transmit or reflect greater or lower fraction of the incident light.

1.5.49 *Work Plane* — It is the plane at which work is done and at which illumination is specified and measured. Unless otherwise indicated, this is assumed to be a horizontal plane 85 cm above the floor. In certain situations, it may vary from 60 to 90 cm depending upon the task to be carried out.

1.5.50 *Zonal Constant* — It is a factor by which the mean candle power emitted in a given angular zone is multiplied to obtain the number of lumens in the zone. It is the phenomenon of reflection of light at specular angle without scattering (*see* Fig. 9).

1.6 Laws of Illumination

1.6.1 *Cosine Law* — The cosine law states that the illumination E of any surface varies as the cosine (*see* Fig. 11) of the angle θ of incidence. The angle of incidence is the angle between the normal to the surface and the direction of the incident light. The cosine law, when combined with the inverse square law, gives:

$$E = \frac{I}{r^2} \cos\theta$$

where I is the intensity in the given direction.

The distance r of source from the given point can be expressed in terms of normal distance h of the source from the surface. Substituing $h/\cos\theta$ for r and combining inverse square law with cosine law, a cosine cubed equation is obtained:

$$E = \frac{I}{h^2} \cos^3 \theta$$

1.6.2 *Lambert's Law* — The Lambert's law states that the luminous intensity in any direction due to a uniformly diffusing plane surface varies as the cosine of the angle between that direction and the perpendicular to that surface (*see* Fig. 11). If I_o is the normal intensity, the intensity I in any direction θ from the normal to the surface is given by:

$$I = I_o \cos\theta$$

The photometric brightness of such a surface is uniform at all angles of view. A surface obeying Lambert's law is said to be uniformly diffusing surface.

1.6.3 *Principle of Integrating Sphere* — If the flux input in the integrating sphere due to a source is F and the reflectance of the surface of integrating sphere is R, the inter-reflected flux F_r is obtained by adding up the flux due to first and subsequent reflections.

$$F_r = F.R + F.R^2 + F.R^3 + ... = \frac{F.R}{1 - R}$$

The quotient of the inter-reflected flux divided by the surface area A of the sphere gives inter-reflected illumination E_r on any part of the sphere wall

$$E_r = \frac{F.R}{A(1-R)}$$

The integrating sphere formula can be used within reasonable accuracy for estimating the inter-reflected illumination in rooms lit by daylight or artificial light. The split flux method recommended in IS : 2440-1975 is a slight modification of the integrating sphere formula.

1.7 Principles of Good Lighting — Good lighting aims at providing adequate illuminance for the execution of task, a good distribution of

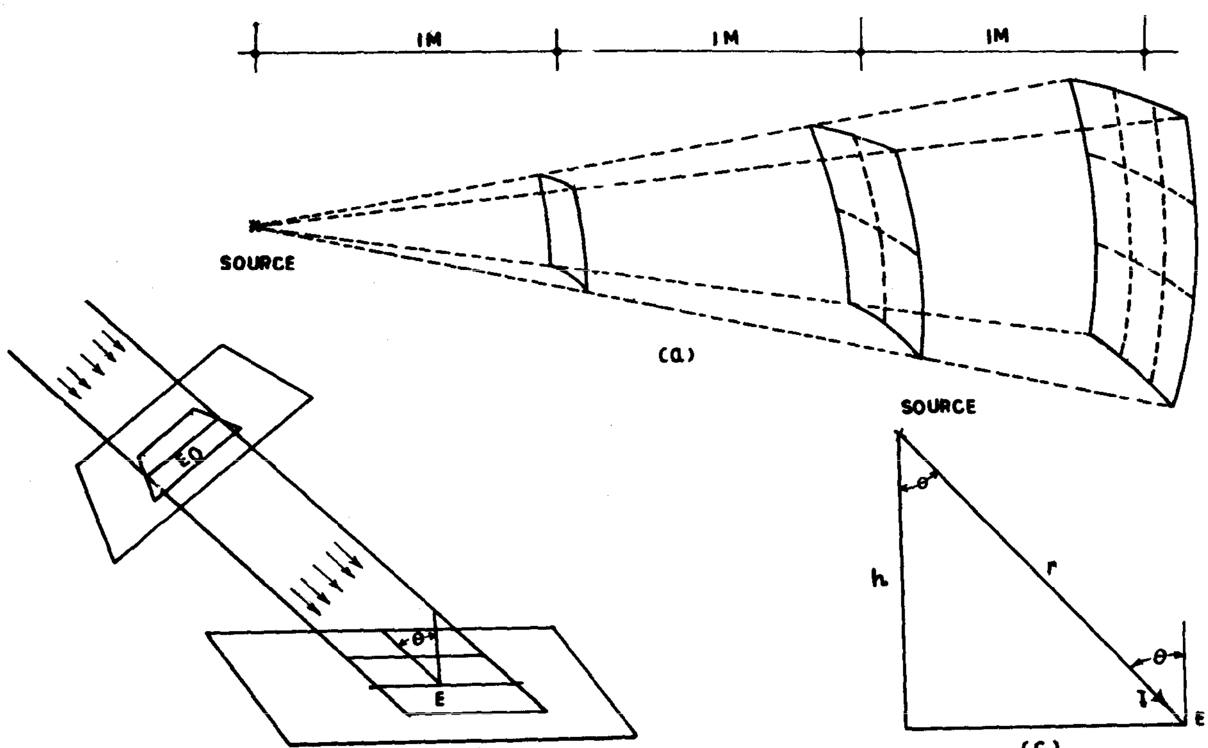

FIG. 11 DEPENDENCE OF ILLUMINANCE ON DISTANCE, ANGLE OF INCIDENCE AND MOUNTING HEIGHT
(a) THE INVERSE SQUARE LAW (b) THE LAMBERT COSINE LAW (c) THE COSINE CUBED LAW

the work plane illuminance, flicker and glare free lighting, suitable brightness ratios, a good diffusion of light with appropriate modelling effect and acceptable colour environment.

1.7.1 *Quantity of Lighting* — One of the most obvious measures of the adequacy of light is the task illuminance. If the size of the critical detail of any visual task and its reflection characteristics are known, it is possible to state the appropriate value of illuminance which will enable the visual task to be performed satisfactorily. Good lighting, however, requires the consideration of safety and welfare alongwith that of visual efficiency. The recommended values of task illuminance as given in IS : 3646 (Part 2)-1966 'Code of practice for interior illumination : Part 2 Schedule for values of illumination and glare index', are based on the criteria of visual performance and amenity. Since higher standards of amenity are desirable, IS : 3646 (Part 1)-1966 recommends that the illuminance of all working areas within a building should generally by 150 lux, even if the visual demands are satisfied by lower values.

1.7.2 *Distribution of Work Plane Illuminance* — It is usually desirable to provide reasonably uniform general illumination over the entire utilizable area of a room. IS : 3646 (Part 1)-1966 recommends that the diversity ratio of minimum to maximum work plane illuminance should not be less than 0.7. Maximum spacing to mounting height or ceiling height ratios are generally specified for different types of luminaires for attaining reasonable uniformity. In daylighting design also, the uniformity of illuminance should be improved by suitable positioning of windows and by increasing the internal reflected component of daylight. However, the uniformity of workplane illuminance is not so critical in daylighting design as in the artificial lighting. Where variation in illuminance helps to create an attractive atmosphere, it is advantageous to concentrate light on specific work areas.

1.7.3 *Flicker* — The combination of light from lamps on two electrical circuits, one lagging and the other leading in phase, reduces the stroboscopic effects arising out of cyclic variation of light output. Similarly, operation of lamps from 3-phase power system also reduces such effects in an installation. The flicker in fluorescent lamps is most noticeable at the ends and these should be shielded from the direct view.

1.7.4 *Glare Free Lighting* — Glare is caused by bright sources seen either directly or by reflection in polished surfaces. The higher the brightness of a source in the field of view, the greater is the visual discomfort caused by it. The size and position of the source and the brightness contrast between the source and its surroundings are also important factors in determining the extent of glare. Larger the area of a glare source, the greater is the glare caused by it. This is true even for low brightness sources. A large area of low brightness source in the field of view may be as uncomfortable as a single small source of higher brightness. Glare is, however, reduced by shifting the source away from the line of vision and by decreasing the contrast between the source and its surroundings.

1.7.4.1 Precautions against excessive glare are the shielding of light sources within the field of view, the use of light colours on ceiling and walls to reduce contrast, placing the light sources away from the line of vision wherever possible and restricting the source brightness to reasonable limits. Disability (reduction in visibility) and discomfort caused by reflection of bright sources in polished or glossy surfaces may be mitigated by arranging the relative positions of the light sources and the task so that the reflected images of the sources are outside the field of view. Use of matt surfaces instead of polished surfaces should be preferred to avoid this type of glare.

1.7.5 *Brightness Ratios* — Proper brightness ratio or brightness contrast between adjacent surfaces is an important requirement of good lighting. Excessive brightness ratios, even though not severe enough to cause glare, may be seriously deterimental to lighting quality. Brightnesses in the peripheral field, if higher than the brightness of the task, tend to distract the eye from the task. High brightness of the task with relatively low brightness of the surrounding is also undersirable. Brightness ratio between task and immediate surroundings such as book and the table top should not exceed three to one. Also, the brightness ratio anywhere in the visual field should not be greater than ten to one.

1.7.6 *Diffusion and Modelling* — The flow of light from numerous rondom directions is known as diffusion. It is measured in terms of the absence of sharp shadows. The degree of diffusion desirable for a task depends upon the type of work to be performed. Diffuse light is desirable for such critical seeing task as reading and writing where sharp shadows are detrimental to satisfactory performance of the task. For preventing specular reflections such as in viewing polished metal surfaces in a machine shop, a highly diffuse light is essential.

Diffusion of light is achieved by using multiple sources preferably with large area low brightness luminaires of indirect and semi-indirect type, and by providing light coloured matt finishes on ceiling, walls, furniture and the floor.

The appearance of a three dimensional object on the other hand is affected by the directional component of light. Directional light can emphasize the form and texture of an object and make its appearance more pleasing. This effect is known as modelling and can be utilized for improving the visibility of some task details such as surface irregularities which are almost invisible under diffuse light, and also for improving the appearance of objects. A good modelling effect is achieved when light appears to flow predominantly from one direction at an angle of 30° or more from the vertical and when the ratio of maximum to minimum illuminance on vertical surfaces through a given vertical axis is 4 : 1; higher ratios over 5 : 1 result in harsh shadows and ratios below 2 : 1 result in softer shadows.

1.7.7 *Colour and Colour Rendering* — The apparent colour of a reflecting surface is determined by the spectral reflectance characteristics of the surface and the spectral composition of light by which it is illuminated. The appearance of a coloured surface is different for light sources of different spectral composition. This property of light sources is known as colour rendering. For such specialized applications like colour matching, colour discrimination processes and certain inspection tasks, it is desirable to select lamps on the basis of their colour rendering properties rather than luminous efficacy. In some applications, the advantage can also be taken of the colour distortion producted by a light source for enhancing the contrast between different parts of the task. That is why mercury vapour lamps are generally used in coal picking belts in collieries.

2. ILLUMINATION REQUIREMENT

2.1 Task illuminance depends upon the fineness or angular size of critical details of the task to be executed. The recommended values of task illuminance as given in IS : 3646 (Part 2)-1966 are based on the standards of visual performance, welfare, safety and amenity as appropriate to different types of tasks. These are applicable for both daylighting and artificial lighting. Task illuminance for daylighting design is expressed in terms of percentage of the outdoor design illumination which is 8 000 lux for the clear design sky in India. Hence 1 percent daylight factor corresponds to 80 lux. The recommended values of task illuminance are given in Table 1. For daylighting design purposes, the recommended daylight factors can be obtained on dividing the recommended task illuminance by 80.

2.2 Task Illuminance — For a visual performance *not less than 90 percent of the maximum* performance and a poor contrast between the details of the task, the required task illuminance E is given by the formula :

$$E = \frac{19.34}{R.S \times 1.5} \times 10^4 \quad \text{lux}$$

where R is the highest percentage reflection factor in the relevant detail of the task and S is the apparent size of the critical detail in minutes of arc. The angular size S of the critical detail can be calculated from the formula:

$$S = 3435 \times \frac{\text{Actual size of critical detail}}{\text{Viewing distance}}$$

The computed values of task illuminance may be increased by a factor of 1.5 where the consequences of oversights are serious such as in surgery or handling dangerous and costly materials or apparatus, and where the average age of personnels involved exceeds 40 years. The recommended values of task illuminance given in IS : 3646 (Part 2)-1966 are based on the standards of visual performance, welfare, safety and amenity as judged appropriate to the occupation. These are applicable for both artificial lighting and daylighting. Task illuminance for daylighting design are expressed in terms of daylight factors.

2.3 Recommended Values of Illumination and Glare Index — Recommended values of task illuminance and limiting values of glare index are given in Table 1.

3. DAYLIGHTING

3.1 Daylight is a natural source of light which meets all the requirements of good lighting. For ages human eye has been adapted to environment produced by daylight. The daylight provides a desirable dynamic environment varying in perfect consonance with the nature outdoors. Further contact with the nature through direct view outside can also be provided by windows admitting daylight. Adequate provision of daylight in buildings through proper planning of fenestration in respect of position, area and shape is, therefore, an important aspect of building design. Under clear sky conditions in India, plentiful daylight is available outdoors which can be used for satisfactory illumination in buildings for most of the daylight hours. By proper design of windows, one can eliminate the use of artificial lights in most of the buildings which are meant for work during hours of good daylight availability. Where working hours are expected to extend over the entire daylight hours, supplementary artificial lighting can be provided for the period of poor daylight availability.

The parameters that are important in daylighting design are outdoor design conditions, room size and finish, angular size and finish of external obstructions, size, position and distribution of windows and overall transmittance of windows. The requirements of good lighting, namely, adequate illuminance, proper distribution of illuminance and freedom from high brightness ratios, are same for both artificial lighting and daylighting.

3.2 Brightness Distribution of Clear Design Sky — The brightness at an angle θ above the horizon is given by the expression:

$$B_\theta = B_z \operatorname{cosec}\theta \text{ for } \theta \text{ between } 15° \text{ and } 90°$$

$$\text{and } B_\theta = \text{constant for } \theta \text{ between } 0° \text{ and } 15°$$

where B_z is the brightness at the zenith.

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION AND LIMITING VALUES OF GLARE INDEX

Buildings and Processes	Recommended Illumination lux	Limiting Glare Index
A. Offices, Schools and Public Buildings		
Airport buildings		
Reception area (desks)	300	22
Customs and immigration halls	300	22
Circulation areas, lounges	150	—
Assembly and concert		
Foyers, auditoria	100 to 150	
Platforms	450	
Corridors	70	
Stairs	100	
Banks		
Counters, typing, accounting book area	300	19
Public areas	150	19
Cinemas		
Foyers	150	
Auditoria	50	
Corridors	70	
Stairs	100	
Libraries		
Shelves (stacks)	70 to 150*	—
Reading rooms (newspapers and magazines)	150 to 300	19
Reading tables	300 to 700†	22
Binding and bookrepair	300 to 700†	22
Cataloguing, sorting, stock-rooms	150 to 300	19
Museums and art galleries		
Museums:		
General	150	16
Displays	Special lighting	16
Art galleries:		
General	100‡	10
Paintings	200§	10
Offices		
Entrance halls and reception areas	150	—
Conference rooms, executive offices	300	19
General offices	300	19
Business machine operation	450	19

*On vertical surface.

†Higher values are for local lighting of tasks involving very fine details.

‡For galleries with separate picture lighting. In small galleries without wall lighting, the illumination should be increased to 200 lux.

§On vertical surface, special attention should be paid to colour quality of light.

(Continued)

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION AND LIMITING VALUES OF GLARE INDEX — (*Continued*)

BUILDINGS AND PROCESSES	RECOMMENDED ILLUMINATION lux	LIMITING GLARE INDEX
Drawing offices:		
General	300	16
Boards and tracing	450	16
Corridors and lift cars	70	
Stairs	100	
Lift lobbies	150	
Telephone exchanges:		
Mannual exchange rooms (on desks)	200*	16
Main distribution frame room	150	25
Schools and colleges		
Assembly halls:		
General	150	16
When used for examinations	300	16
Platforms	300	16
Class and lecture rooms:		
Desks	300	16
Blackboards	200 to 300 †	
Embroidery and sewing rooms:	700	10
Art rooms	450 ‡	16
Laboratories	300	16
Libraries:		
Shelves, stacks	70 to 100 †	
Reading tables	300	16
Manual training:	*See* appropriate trade	
Offices	300	19
Staff rooms, common rooms	150	16
Corridors	70	
Stairs	100	
Theatres		
Foyers	150	
Auditoria	70	
Corridors	70	
Stairs	100	
Dental surgeries		
Waiting rooms	150	
Surgeries:		
General	300	
Chairs	Special lighting	
Laboratories	300	

*Special lighting will be required for switchboard.
† On vertical surfaces.
‡ Special attention should be paid to the direction and quality of the light.

(*Continued*)

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION AND LIMITING VALUES OF GLARE INDEX — (*Continued*)

BUILDINGS AND PROCESSES	RECOMMENDED ILLUMINATION lux	LIMITING GLARE INDEX
Doctors' Surgeries		
Waiting rooms, consulting rooms	150	
Corridors	70	
Stairs	100	
Sight testing (acuity) wall charts and near vision types	450*	
Hospitals		
Reception and waiting rooms	150	16
Wards:		
General	100	13†
Beds	150	
Operating theatres:		
General	300	10
Tables	Special lighting	
Laboratories	300	19
Radiology departments	100	
Casualty and outpatients departments	150	16
Stairs, corridors	100	
Dispensaries	300	19
B. Hotels, Restaurants, shops and Homes		

NOTE — The lighting of some of these locations will be determined primarily by aesthetic considerations and the illumination recommendations should be taken as a guide only. For the same reason, glare indices are given for working areas only.

BUILDINGS AND PROCESSES	RECOMMENDED ILLUMINATION lux	LIMITING GLARE INDEX
Hotels		
Entrance halls	150	
Reception and accounts	300	
Dining rooms (tables)	100	
Lounges	150	
Bedrooms:		
General	100	
Dressing tables, bed heads, etc.	200	
Writing rooms (tables)	300	
Corridors	70	
Stairs	100	
Laundries	200	25
Kitchens	200†	25
Goods and passenger lifts	70	
Cloakrooms and toilets	100†	
Bathrooms	100†	
Restaurants		
Dining rooms:		
Tables	100	
Cash desks	300	
Self-carrying counters	300	
Kitchens	200*	25
Cloakrooms and toilets	100*	

*Supplementary local lighting should be provided over kitchen equipment and at mirrors.
†Supplementary local lighting should be used as required for counters and display areas.

(*Continued*)

TABLE 1 RECOMMENDED VALUES OF ILLUMINATION AND LIMITING VALUES OF GLARE INDEX — (*Continued*)

Buildings and Processes	Recommended Illumination lux	Limiting Glare Index
Homes		
Kitchens	200	
Bathrooms	100*	
Stairs	100	
Workshops	200	
Garages	70	
Sewing and darning	700	
Reading (casual)	150	
Homework and sustained reading	300	

*Supplementary local lighting should be provided at mirrors.

The illumination on a horizontal plane outdoors due to the entire sky at the design time is 8 000 lux and that due to the sky and the sun is 16 000 lux. The clear design sky basis holds good for any orientation of the building and ensures adequate daylight indoors for about 90 percent of the daytime working hours. In between the morning and evening solar altitudes of 15°, the indoor illumination increases as the sun goes up in the sky and also as it approaches the windows.

3.3 Components of Daylight Factor — Daylight reaching an indoor point comprises: (a) light received directly from the visible part of the sky, (b) light received directly due to reflections from external surfaces which are visible from the given point and (c) light received after inter-reflection between room surfaces. These components are also expressed as percentage ratio of the design sky illuminance on a horizontal plane outdoors. These are termed as sky component (SC), external reflected component (ERC) and internal reflected component (IRC) respectively. Daylight factor is obtained by addiing up these three components.

$$DF = SC + ERC + IRC$$

The value of sky component is zero at any point on the horizontal ceiling of a room; it receives only ERC and IRC. For a single sidelit room, the window wall receives only IRC, since the sky and external surfaces are not visible from any point on the window wall in case of windows on the same wall. The sky component is also zero beyond the 'no sky line' on a horizontal workplane. The values of ERC and IRC increase with the increase of reflectance of relevant external surfaces and internal surfaces of a room.

3.3.1 Direct sunlight is excluded from the definition of daylight factor, as it is not desirable from the viewpoint of lighting quality. It creates problems of harsh shadows and severe brightness imbalances resulting in glare. Direct sunlight also brings in undesirable heat in summer. Therefore adequate shading devices are recommended not only for thermal comfort but also for visual comfort.

3.4 Recommended Daylight Factors — Recommended daylight factors for typical building interiors are given in Table 2. In this table, 1 percent DF is taken as equivalent to 80 lux. Thus 2.5 percent DF will be equal to 200 lux.

The recommended daylight factors should be ensured, generally, on a horizontal workplane at the room centre and other specific locations, such as school desks, blackboards, office tables, etc.

TABLE 2 RECOMMENDED DAYLIGHT FACTORS FOR INTERIORS

(*Clause* 3.4)

(1 percent DF = 80 lux)

Sl No.	Location	Daylight Factor, Percent
i)	*Dwellings*	
	Kitchen	2.5
	Living room	0.625
	Study room	1.9
	Circulation	0.313
ii)	*Schools*	
	Class room desk top, black board	1.9-3.8
	Laboratory	2.5-3.8
iii)	*Offices*	
	General	1.9
	Drawing, typing	3.75
	Enquiry	0.625-1.9
iv)	*Hospitals*	
	General wards	1.25
	Pathological laboratory	2.5-3.75
v)	*Libraries*	
	Stack room	0.9-1.9
	Reading room	1.9-3.75
	Counter area	2.5-3.75
	Catalogue room	1.9-2.5

3.5 Design Parameters

3.5.1 *Penetration and Spread of Sky Component* — Penetration is the maximum distance of a sky component (SC) contour along the normal to the window wall. The breadth of a SC contour at half the penetration depth is the measure of the area covered by that sky component and is termed here as 'lateral spread'. Table 3 and 4 give penetration and lateral spread of 1.5, 1.0 and 0.5 percent SC for several window dimensions. Figure 12 depicts the penetration and lateral spread of 1.0 percent SC on the horizontal plane at sill level due to a window of size 2.1 × 0.9 m. The effect of sill height on penetration and spread is given in Fig. 13.

3.5.1.1 Generally, penetration is greater with taller windows and spread is better with broader windows. However, a proper distribution of taller windows can provide a good penetration as well as a good spread of sky component on the workplane. Similarly, a suitable sill height above the workplane will enable broader windows to provide a good distribution of light. More windows on the same wall or adjacent and opposite walls give better distribution of light than a single large window.

3.5.1.2 External obstructions reduce the sky component to zero beyond a certain distance from the window. The workplane area, over which sky component is zero, receives illumination only through ERC and IRC. Such areas beyond 'no sky line' (tangent to the zero sky component contour beyond which sky is not visible) should be carefully designed so as to have satisfactory illuminance. The principal work areas involving critical tasks should be located in such regions where the sky component is significant. It is preferable that some area of the sky at an angle of 20 to 25° above horizon should illuminate the principal work areas.

3.5.2 *Sill Height* — For carrying out a task while standing or squatting on floor, suitable workplane levels are 1.0 and 0.3 m high respectively. Since the part of a window below the workplane does not contribute significantly to the workplane illuminance, a sill height slightly greater than or equal to the height of the workplane above the floor level is desirable. The optimum sill for good illumination as well as good ventilation should be between the illumination workplane and the head level of a person.

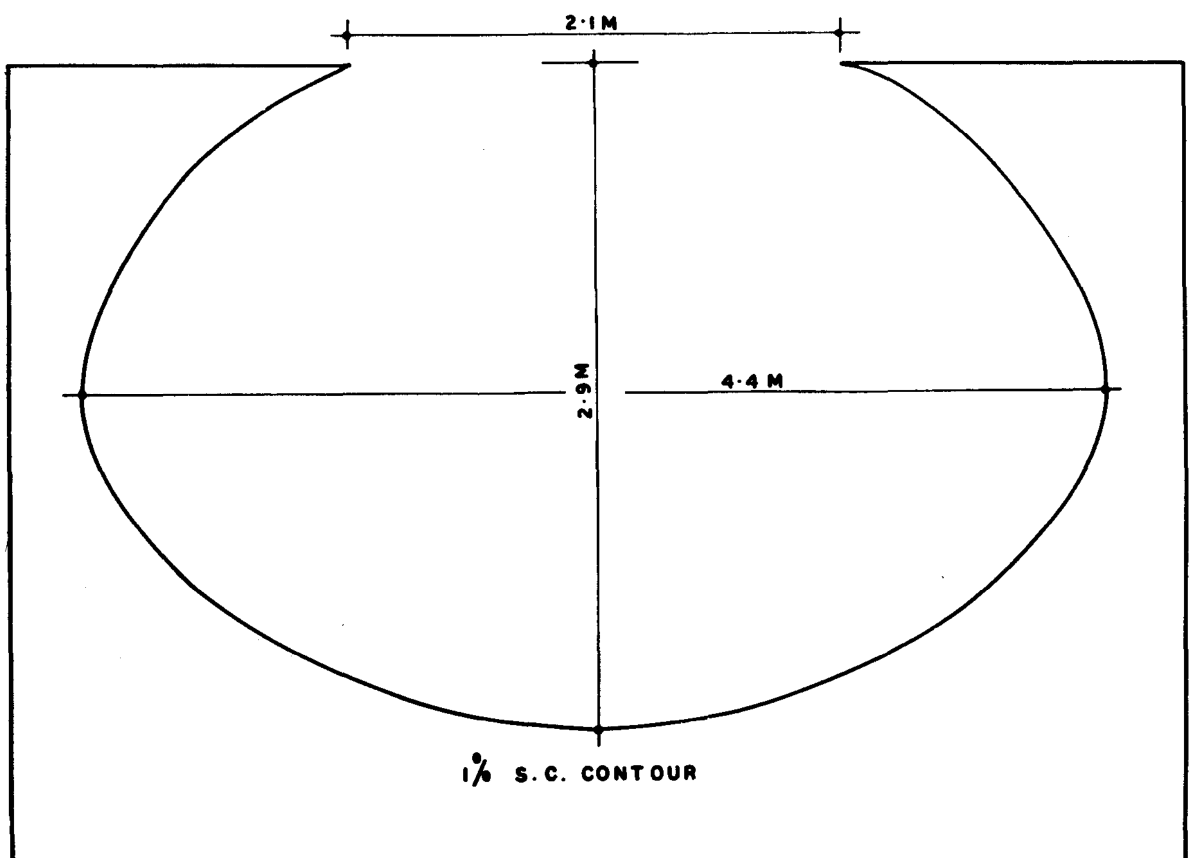

FIG. 12 TYPICAL SKY COMPONENT CONTOUR DEPICTING ITS PENETRATION AND SPREAD ON A HORIZONTAL PLANE

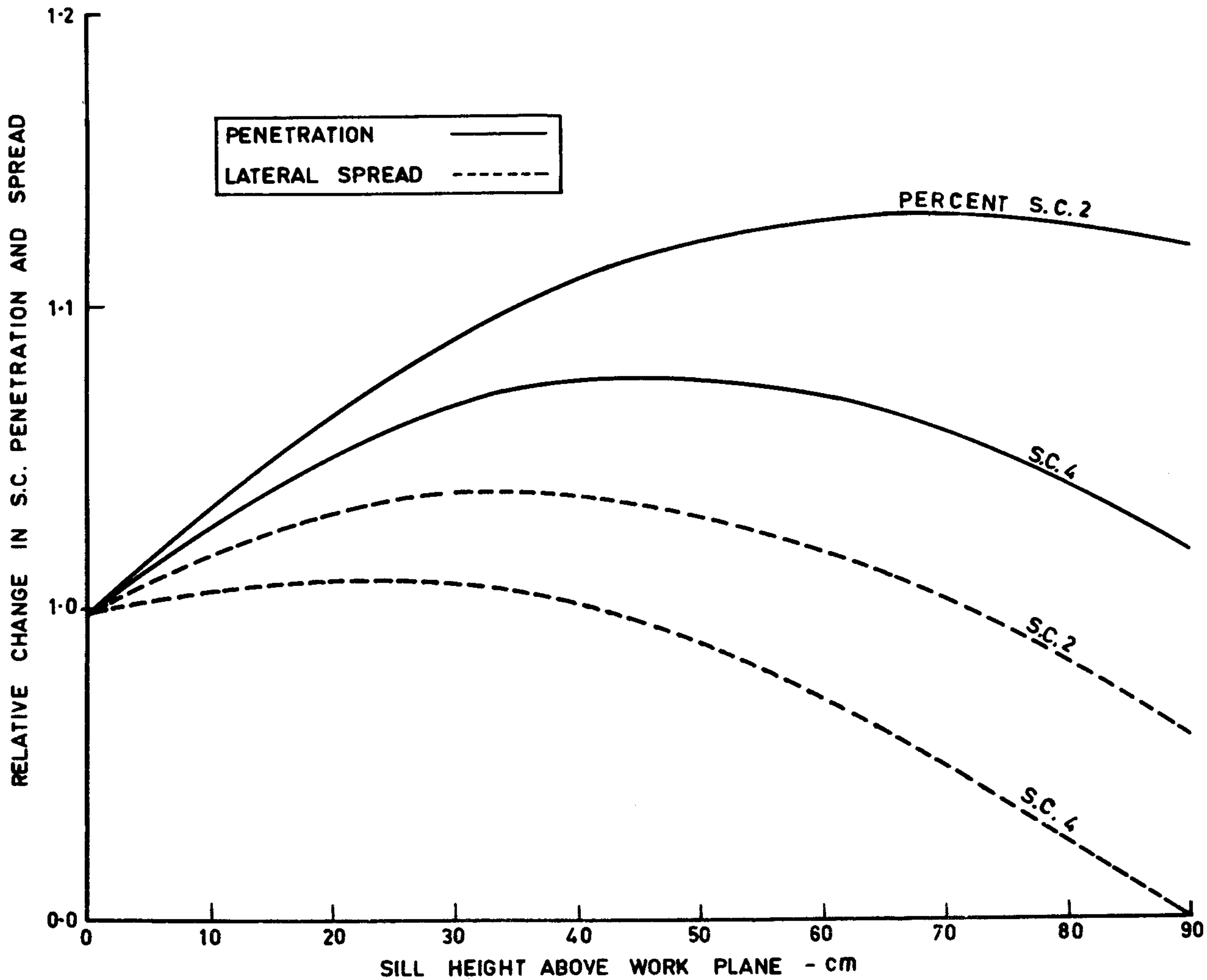

FIG. 13 VARIATION PENETRATION AND SPREAD OF SKY COMPONENT WITH SILL HEIGHT

TABLE 3 PENETRATION FOR THREE VALUES OF SKY COMPONENT

WINDOW LENGTH (m),	0.9			1.5			2.1			2.7		
SKY COMPONENT, PERCENT	1.5	1.0	0.5	1.5	1.0	0.5	1.5	1.0	0.5	1.5	1.0	0.5
WINDOW HEIGHT, m	VENTILATION, m											
0.9	1.8	2.0	2.5	2.2	2.7	3.4	2.5	2.9	3.9	3.0	3.3	4.4
1.5	2.1	2.5	3.5	2.6	3.3	4.6	3.1	3.9	5.3	3.6	4.4	5.9
2.1	2.6	3.4	4.7	3.6	4.4	5.6	4.2	5.0	6.5	4.2	5.7	7.2

TABLE 4 LATERAL SPREAD FOR THREE VALUES OF SKY COMPONENT

WINDOW LENGTH (m),	0.9			1.5			2.1			2.7		
SKY COMPONENT, PERCENT	1.5	1.0	0.5	1.5	1.0	0.5	1.5	1.0	0.5	1.5	1.0	0.5
WINDOW HEIGHT, m	LATERAL SPREAD, m											
0.9	2.0	2.6	3.3	2.8	3.5	4.5	3.7	4.4	5.4	4.4	5.0	6.2
1.5	3.0	3.7	6.0	3.9	5.1	6.4	5.0	6.2	7.5	5.0	7.0	8.4
2.1	4.4	5.3	8.3	5.8	6.7	8.0	6.9	7.6	9.0	7.0	8.3	9.6

3.5.3 *Room Dimension* — The dimension of a room (for a ceiling height 3.0 m) perpendicular to the window wall should be less than 7.0 m for unilateral lighting from side windows. For a room depth of 7.0 m or more, windows on opposite walls are recommended. As a general rule, unilateral lighting from side windows will be unsatisfactory if the room depth is more than two and a half times the height of the window top above the floor level. The maximum height of the window top and consequently the penetration of sky component is limited by the ceiling height. In general, lighting of smaller rooms from sky and inter-reflection is better than larger rooms.

3.5.4 *Surface Reflectances* — The amount of internal and external reflected components is governed respectively by the reflectance of internal surfaces of a room and external surfaces reflecting light into the room. For any choice of colour scheme, the reflectances of different surfaces can be suitably fixed.

3.5.4.1 The reflectance of common finishes and surfaces are given in Table 5. Leaving exceptions under special conditions, the desirable reflectances of room surfaces for general applications are listed in Table 6.

3.5.5 *External Obstructions* — External obstruction like opposite buildings, trees, etc, reduce the sky component but add to the external reflected component. The external reflected component varies directly as the reflectance and illuminance of obstruction and also as the solid angle subtended by the obstruction at the given point. The obstructions at a distance of three times their height or more from window facade are not significant and may be ignored. As the separation between a window facade and opposite building is reduced, there is a progressive reduction of daylight indoors due to a reduction of sky components.

TABLE 5 REFLECTANCE OF COMMON FINISHES AND SURFACES

(*Clause* 3.5.4.1)

TYPICAL FINISH OF SURFACE	REFLECTANCE
White wash	0.7-0.8
Cream colour	0.6-0.7
Light green	0.5-0.6
Light blue	0.4-0.5
Light pink	0.6-0.7
Dark red	0.3-0.4
Medium grey	0.3
Cement terrazo	0.25-0.35
Brick	0.4-0.5
Vegetation (mean)	0.25

TABLE 6 DESIRABLE REFLECTANCES OF ROOM SURFACES

(*Clause* 3.5.4.1)

SURFACE	REFLECTANCE
Ceiling	0.7-0.8
Wall	0.5-0.6
Table top	0.35-0.50
Floor	0.15-0.30

3.5.5.1 Layout of buildings is significant in determining the daylight availability inside. While continuous rows of parallel buildings result in maximum reduction of daylight, perpendicular staggered blocks cause minimum reduction of daylight for the same spacing to height ratio. The relative availability of daylight in multistoreyed blocks of different relative orientations are given in Table 7.

3.5.6 *Transmittance of Window Elements* — Overall transmission of daylight through windows depends upon dirt collection on window panes, glazing material and shading devices. The decrease in daylight illumination due to accumulation of dirt on window surfaces varies with the location, the angle at which the glass is mounted and the cleaning schedule. Average maintenance factors as a fraction of clean glass transmittance are given in Table 8.

3.5.6.1 A round value of 0.8 for the maintenance factor for vertical glazings in clean areas and for periodic cleaning of window panes once in three to six months is quite reasonable for design purposes.

3.5.6.2 The transmittance of a 3 mm plain glass is 0.85 for diffuse and 0.9 for normal incidence. If any other type of glass or plastics is used as glazing material, its actual transmittance should be taken into account. In case of plastics, the transmittance decreases with weathering and it should also be accounted for. Transmittance of several glazing material for diffuse incidence is listed in Table 9.

3.5.6.3 The transmittance of simple box type louvers of 60 cm width is about 0.85 for a medium finish. The transmittance of a complex louvre system is slighty less than the box type of louvers. Sashes, window bars and other window elements occupying a certain area of the window reduce the daylight indoors in proportion of the area so obstructed.

3.6 Daylighting Design — Design graphs provided in Fig. 14 and 15 are those included in IS : 7942-1976 and have been extended up to 30 percent fenestration based on computations of daylight factors as described in IS : 2440-1975. These are ready reckoners for arriving at window dimensions to provide a given daylight factor on the working plane in rooms of different floor areas and depth (dimension normal to the window) up to 12 m. These curves give expected daylight factor at the centre and the rear (near the rear wall) of the room for different location of windows on the shorter or longer wall of the room. The window areas is expressed as percentage of floor area that will provide the daylight for four possible situations, namely: (a) the aperture is just an opening in the wall, (b) the opening is glazed with 3 mm thick glass, (c) the glazed opening is a wooden window and (d) the glazed opening is a metal window.

It may be noted that the wooden window cuts off more daylight than the metallic window frame for the given gross window area.

3.6.1 The following assumptions have been made in arriving at the results given in Fig. 14 and 15.

a) The finish of ceiling, walls and floor is white (70-75 percent reflectance). Light finish (40-

TABLE 7 DAYLIGHT AVAILABILITY AT THE GROUND FLOOR IN FOUR STOREYED BUILDINGS AS PERCENTAGE OF ILLUMINANCE OF UNOBSTRUCTED BUILDINGS

(*Clause* 3.5.5.1)

Layout	Ratio of Distance Between Blocks to Their Height			
	0.5	1.0	1.5	2.0
Infinite parallel rows	24	42	55	60
Parallel blocks (Length = 2x height)	26	45	61	72
Perpendicular blocks (length = 2x height)	28	53	72	76

TABLE 8 AVERAGE WINDOW MAINTENANCE FACTORS

(*Clause* 3.5.6)

Building	Office in Clean Location	Factory in Dirty Location			
Window Position	Vertical	Vertical	30° from vertical	60° from vertical	Horizontal
1	2	3	4	5	6
	Maintenance Factor				
Average over 6 months	0.83	0.71	0.65	0.58	0.54
Value at the end of 3 months	0.82	0.69	0.62	0.54	0.50
Value at the end	0.73	0.55	0.45	0.39	0.34

TABLE 9 DIFFUSE TRANSMITTANCE OF GLAZING MATERIALS

(*Clause* 3.5.6.2)

MATERIAL (1)	THICKNESS (2) mm	TRANSMITTANCE (3)
Clear glass	3.0	0.85
Wire-cast glass	6.0	0.67
Heat absorbing glass	3.2-3.5	0.62
Prismatic glass	3.6	0.76
Glass fibre reinforced polyster sheet	2.0-3.0	0.60-0.40
Double glazing	3 mm each	0.72
Pattern glass (colourless)	3.2 mm	0.78

50 percent reflectance) and medium grey (25-30 percent reflectance);

b) Ceiling height is 2.75 m (design graphs are, however, valid up to ceiling height of 3.05 m);

c) Windows are provided with louvers to cut the incursion of direct sunlight;

d) Combined thickness of wall and width of louver is taken to be 60 cm;

e) Outside ground reflection factor is taken as 0.25;

f) No external obstructions. In case of presence of external obstruction in the vicinity of window facade, window sizes need be proportionately increased as given in Table 7.

g) Sill height is taken to be 75 to 105 cm above the floor level. Sill height should be higher than the working plane for maximum advantage of illumination on the working plane; and

h) The length to width ratio for the room should not be greater than 3 : 2.

3.6.2 The fenestration percentage of floor area arrived at by using Fig. 14 and 15 is expected to provide the required amount of daylight at the point in question. However, the presence of dirt on glass reduces the quantity of light entering the room and the glazing has to be cleaned periodically.

3.6.3 The design curves can be used to determine the size of central or corner located windows on either longer or shorter wall of a room. For uniformly distributing daylight on the working plane, the splitting of window area is preferable as compared to a single centrally located window. Such a splitting may not be possible for a window on shorter wall but it is generally possible in case of longer wall of a room. For splitting purposes, the percent fenestration should be determined for corner located windows and the area arrived at may be split into two or more windows. Also the percent fenestration should be determined for the rear point for all such occupancies where all the locations for work are equally probable and required to be lit adequately. However, since in residential buildings the location of critical tasks can be adjusted to be near the window, area may be determined for the centre point of a room. Also for windows on opposite walls, the centre of a room on the working plane forms a suitable reference point for determining the window area.

3.7 Worked Examples

3.7.1 *Residential Buildings*

Example 1

Determine the percent fenestration for providing 1.9 percent daylight factor in a study room of a dwelling for locating a window on : (a) longer wall and (b) shorter wall.

Solution A

i) Use graph for corner located window (*see* Fig. 15) so that the window area may be distributed, if possible.

ii) Read on curve W_L (longer wall) for daylight factor at the centre (solid curve) marked *A* representing floor area less than 30 m^2 within which the normal room sizes in a dwelling are provided.

iii) Reading for 1.9 percent daylight factor along the ordinate representing wooden frame which is commonly used in dwellings, the required window area on the abscissa is obtained as 9.5 percent of the floor area.

Solution B

i) Assuming that the window on shorter wall will be centrally located, use graph for centrally located window (*see* Fig. 14).

ii) Read on curve W_s (shorter wall) for daylight factor at the centre (solid curve) marked *A* representing floor area less than 30 m^2.

iii) Reading for 1.9 percent daylight factor along the ordinate representing wooden frame, the required window area on the abscissa is 10.7 percent of the floor area.

Example 2

Determine the percent fenestration for providing 2.5 percent daylight factor in a kitchen of a dwelling for locating a window on : (a) longer wall and (b) shorter wall.

Solution A

i) Use graph for corner located window (*see* Fig. 15) so that the window may be provided in any suitable location on the wall.

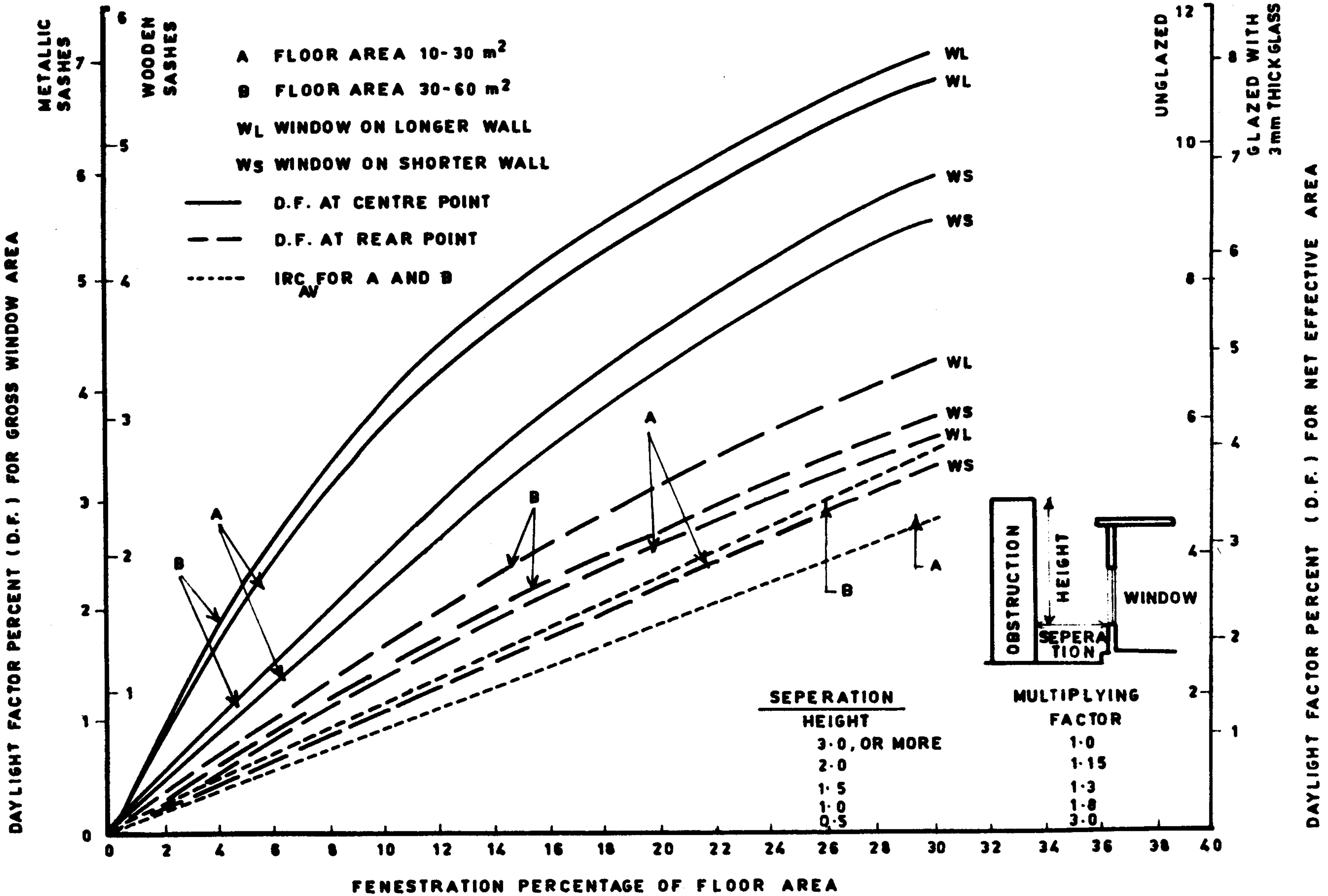

FIG. 14 DAYLIGHT FACTORS ON THE WORKING PLANE FOR A CENTRALLY LOCATED WINDOW

ii) Read on curve W_L (longer wall) for daylight factor at the centre (solid curve) marked *A* representing floor area less than 30 m^2.

iii) Reading for 2.5 percent daylight factor along the ordinate representing wooden frame, the required window area on the abscissa is obtained as 12.4 percent of the floor area.

Solution B

i) Assuming that the window on shorter wall will be centrally located, use graph for centrally located window (*see* Fig. 14).

ii) Read on curve W_s (shorter wall) for daylight factor at the centre (solid curve) marked *A* representing floor area less than 30 m^2.

iii) Reading for 2.5 percent daylight factor along the ordinate representing wooden frame, the required window area on the abscissa is obtained as 14.3 percent of the floor area.

3.7.2 *Educational Buildings*

Example 3

Determine the percent fenestration for providing 1.9 percent daylight factor up to the rear point in a class room of a school for locating window on longer wall.

Solution

i) Use graph for corner located window (*see* Fig. 15) so that the window area may be split and windows may be evenly distributed on the wall.

ii) Read on the curve W_L (longer wall) for daylight factor at the rear point (broken curve) marked *B* representing floor area more than 30 m^2.

iii) Reading for 1.9 percent daylight factor along the ordinate representing metallic frame, the required window area on the abscissa is obtained as 12.2 percent of the floor area.

NOTE — The window area obtained in Example 3 will also hold good for a large office room and a stack room in a library which have the same requirement of 1.9 percent daylight factor.

3.7.3 *Institutional Buildings*

Example 4

Determine the percent fenestration for providing 3.75 percent daylight factor in a large laboratory in a hospital building.

Solution

i) Use graph for corner located windows (*see* Fig. 15) so that the window area arrived at may be split and windows may be evenly distributed on the longer wall.

ii) Read on the curve W_L (longer wall) for daylight factor at the rear point (broken curve) marked *B* representing floor area greater than 30 m^2.

iii) Reading for 3.75 percent daylight factor along the ordinate representing metallic frame, the required window area on the abscissa is obtained as 25.2 percent of the floor area.

NOTE — The window area obtained in Example 4 will also hold good for drawing office, library reading room and pathological laboratory which have the same requirement of 3.75 percent daylight factor.

3.7.4 *Assembly Buildings*

Example 5

Determine the percent fenestration for providing 1.25 percent daylight factor for general illumination in an exhibition hall.

Solution

i) Use graph for corner located window (*see* Fig. 15) so that the window area arrived at may be evenly distributed on the longer wall.

ii) Read on the curve W_L (longer wall) for daylight factor at the rear point (broken curve) marked *B* representing floor area greater than 30 m^2.

iii) Reading for 1.25 percent daylight factor along the ordinate representing metallic frame, the required window area on the abscissa is obtained as 8 percent of the floor area.

3.7.5 *Business Buildings*

Example 6

Determine the percent fenestration for providing 2.5 percent daylight factor up to the rear point in a catalogue room of moderate size in a library for locating: (a) window on shorter wall and (b) window (s) on longer wall.

Solution A

i) Use graph for centrally located window (*see* Fig. 14).

ii) Read on curve W_s (shorter wall) for daylight factor at the rear (broken curve) marked *A* representing floor area less than 30 m^2.

iii) Reading for 2.5 percent daylight factor along the ordinate representing metallic window frame, the required window area on the abscissa is obtained as 22.5 percent of the floor area.

Solution B

i) Use graph for corner located window (*see* Fig. 15) so that the window area arrived at may be evenly distributed on the wall.

ii) Read on the curve W_L (longer wall) for daylight factor at the rear point (broken curve) marked *A* representing floor area less than 30 m^2.

iii) Reading for 2.5 percent daylight factor along the ordinate corresponding to metallic frame, the required window area on the abscissa is obtained as 16.1 percent of the floor area.

The window areas arrived at in the above examples hold good when there is no substantial external obstruction in the vicinity of the window facade. In case of external obstruction, the required window areas should be enhanced by a factor as given in Fig. 14 and 15 depending upon the separations to height ratio of the obstruction. From the fenestration percent of the floor area, the actual window area is obtained as follows:

Required window area =

$$\frac{\text{Fenestration percent} \times \text{Floor area}}{100}$$

Choosing a suitable height of the window (s), the window length can be determined for the required window area.

4. DAYLIGHTING ANALYSIS

4.1 Methods of lighting calculation described in **4.2** and **4.3** can be employed for precise prediction of illuminance at any point due to natural light, artificial lights or the combination of natural light and artificial lights. Several design aids for detailed analysis have been developed to facilitate the estimation of light for design purposes. These are protractors for direct component of daylight factor, nomogram for indirect component of daylight factor and lux grids for design of side windows.

4.2 Computation of Daylight Factors — The calculation of daylight factor requires estimation of sky component, external reflected component and internal reflected component for clear design sky condition which is accepted as standard outdoor condition.

4.2.1 *Sky Component (SC)*

4.2.1.1 The sky component values can be read from Table 10 to 12 for any point located along perpendicular line through one of the bottom corners of a rectangular element of a window (Fig. 16A). The angular dimension of any such window element of length *l* and height *h* are expressed as l/d and h/d for any point at a normal distance *d* from the external surface of the window aperture.

4.2.1.2 From the projection of the given point on the window, plane rectangles are drawn so as to cover the entire window area. The contribution to SC from different rectangular areas with projected point as the corner can be determined from the tables against their l/d and h/d values. By suitable addition or substraction of contribution from these rectangular areas, the sky component from the given window can be determined. In Fig. 16 B to 16 H, the sky components $(SC)_{ABCD}$ and $(SC)_{effective}$ due to the window ABCD at the given point *P* are obtained from equations (1) to (7) respectively as follows:

$$(SC)_{ABCD} = (SC)_{NMDA} + (SC)_{NMCB} \quad \ldots (1)$$

$$(SC)_{effective} = (SC)_{EDCF} = (SC)_{NMDE} + (SC)_{NMCF} \quad (2)$$

$$(SC)_{ABCD} = (SC)_{NMDE} + (SC)_{NMCF} - (SC)_{NLAE} - (SC)_{NLBF} \quad \ldots (3)$$

$$(SC)_{ABCD} = (SC)_{NMCF} - (SC)_{NMDE} - (SC)_{NLBF} + (SC)_{NLAE} \quad \ldots (4)$$

$$(SC)_{effective} = (SC)_{ABCD} - (SC)_{AEFB} \quad \ldots (5)$$

$$(SC)_{effective} = (SC)_{ABCD} - (SC)_{AEFG} \quad \ldots (6)$$

$$(SC)_{effective} = (SC)_{ABCD} \quad \ldots (7)$$

4.1.1.3 Table 10, 11 and 12 are to be used for a horizontal workplane, a vertical workplane (for example, blackboard) perpendicular to the window and a vertical workplane parallel to the window respectively. If the workplane is inclined at an angle θ to either of the vertical planes (perpendicular or parallel to the window), the sky components $(SC)_v$ and $(SC)_h$ on the relevant vertical plane and the horizontal plane respectively through the point in question should be determined. The sky component on the inclined plane is obtained from the following relation:

$$(SC)_\theta = (SC)_h \cos\theta + (SC)_v \sin\theta \quad \ldots (8)$$

4.2.1.4 The values obtainable from the Table 10 to 12 are for rectangular open unglazed windows, with no external obstructions. These values shall be corrected for the presence of window bars, glazing and external obstructions, if any.

4.2.1.5 *Calculation of sky component*

Example 7

Determine the sky component on the horizontal workplane at a point 3.0 m away from the window of size 1.8 m × 1.5 m when the sill above the workplane is 0.6 m and the horizontal displacement of the point from the nearest edge of the window in 0.9 m.

Solution

Referring to Fig. 16E, the length *l* and height *h* of the rectangles *NMCF*, *NMDE*, *NLBF* and *NLAE* are (2.7 × 2.1), (0.9 × 2.1), (2.7 × 0.6) and (0.9 × 0.6) metres respectively. The normal distance *d* of the given point from the external surface of the window aperture is 3.0 m. Therefore, l/d and h/d values for above rectangles are (0.9 × 0.7), (0.3 × 0.7), (0.9 × 0.2) and (0.3×0.2) respectively. From Table 10, for horizontal workplane, the values of sky components for these pairs of l/d and h/d are 5.709, 2.441, 0.878 and 0.403 respectively. From equation (4), the required sky component is thus:

$$(SC)_{ABCD} = (SC)_{NMCF} - (SC)_{NMDE} - (SC)_{NLBF} + (SC)_{NLAE}$$
$$= 5.709 - 2.441 - 0.878 + 0.403$$
$$= 2.793$$
$$= 2.79 \text{ percent}$$

Example 8

For the window and distance of the point same as given in Example 7, determine the sky component for a workplane 0.6 m above the sill when the point is located along the central line.

Solution

Referring to Fig. 16C, the length l and height h of each of the rectangles $NMDE$ and $NMCF$ are 0.9 m and $(l/d,\ h/d)$ will be (0.3, 0.3). Now from Table 10, the sky components due to each rectangle of l/d and h/d as 0.3 and 0.3 is 0.859. Since the part of the window below the level of the point in question does not contribute to the sky component, the effective SC according to equation (3) is given by:

$$(SC)_{\text{effective}} = (SC)_{EDCF} = (SC)_{NMDE} + (SC)_{NMCF}$$
$$= 0.859 + 0.859$$
$$= 1.718$$
$$= 1.72 \text{ percent}$$

Example 9

For the window and the distance of the point same as in Example 7, determine the sky component if the workplane coincides with the sill level and the given point is along the perpendicular through one of the bottom corners of the window; assume that there is an obstruction due to parallel building blocks (of height 2.60 m and 10 m away from the window) up to an angle of 12° above horizon as seen from the point in question.

Solution

Referring to Fig. 16F, the obstruction shades off 0.6 m of the window above the sill (tan 12°

$$= 0.2 = \frac{h_{\text{shaded}}}{d} = \frac{h_{\text{shaded}}}{3}; \text{ hence } h_{\text{shaded}}$$
$$= 0.6 \text{ m}).$$

The length and height (l,h) of the rectangles $ABCD$ and $AWFB$ are 1.6 m and 1.5 m, and 1.8 m and 0.6 m respectively. Therefore l/d and h/d values will be 0.6 and 0.5, and 0.6 and 0.2 respectively. From Table 10, the sky components for these l/d, h/d values are 3.099 and 0.699 respectively. The required sky component, according to equation (5), is :

$$(SC)_{\text{effective}} = (SC)_{ABCD} - (SC)_{AEFB}$$
$$= 3.099 - 0.699$$
$$= 2.4 \text{ percent}$$

4.2.2 *External Reflected Component*

4.2.2.1 External reflected component due to any surface of uniform luminance can be calculated precisely with the help of sky factor Tables 13 and 14 for planes perpendicular and parallel to the window plane respectively. For a perpendicular plane, the window dimension parallel to the line of intersection of the given plane with the window plane is to be taken as l and the other dimension as h. Thus Table 13 can be used for calculating ERC on a vertical plane perpendicular to a vertical window provided the height of the window is taken for l and its length for h.

4.2.2.2 The contribution of daylight reflected by external obstruction is determined with the help of perspective projection of the obstruction on the window plane with respect to the given indoor point. Noting l/d and h/d values of the projected areas and using Table 13 or 14, depending upon the orientation of the workplane with respect to the window plane, sky factors are determined in the same way as for the sky components. Since sky factor (SF) is the illuminance at a point expressed as percentage fraction of the luminance of the reflecting surface in apostilbs (or foot Lamberts), ERC is obtained on multiplying sky factor (SF) by the ratio of luminances of the reflecting surface and the design sky illuminance.

$$\text{ERC} = \text{SF} \times \frac{L_{\text{obs}}}{D} = \text{SF} \times \frac{E_{\text{obs}} \times R_{\text{obs}}}{D}$$

where L_{obs}, E_{obs}, R_{obs} and C_{obs} refer to luminance, illuminance, reflectance and window factor of the external obstruction respectively, and D is the design sky illuminance. Alternatively, the sky component corresponding to the obstructed part of a window can be approximately converted to sky factor (SF) by multiplication of SC value with the ratio of the design sky illuminance and the sky luminance at the mean angle of elevation of the obstruction; the reciprocal of the ratio is called brightness factor (BF)

$$\text{SF} = \text{SC} \times \frac{1}{\text{BF}} \qquad \ldots(10)$$

The inverse brightness factors, 1/BF are given in Table 15.

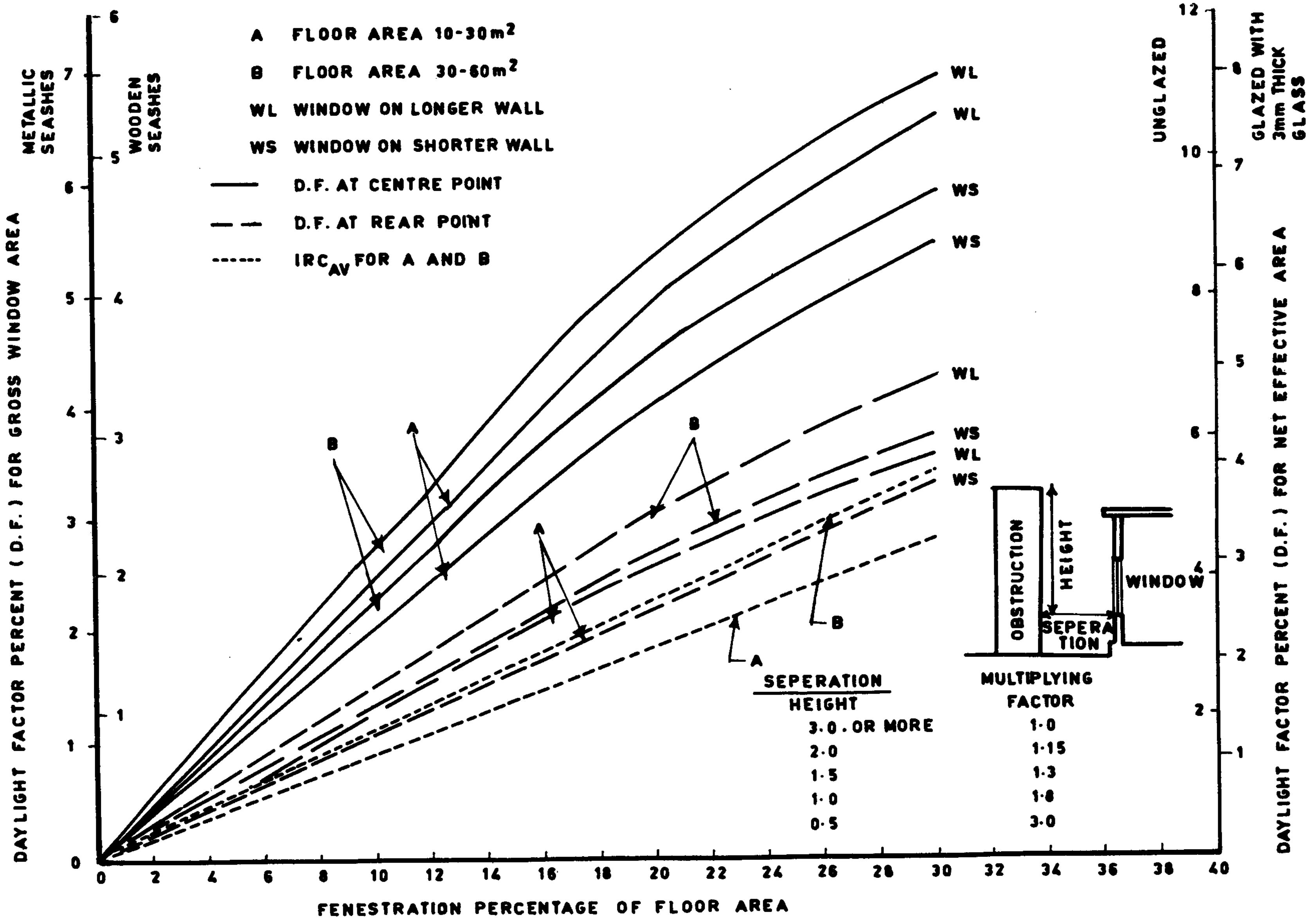

FIG. 15 DAYLIGHT FACTORS ON THE WORKING PLANE FOR A CORNER LOCATED WINDOW

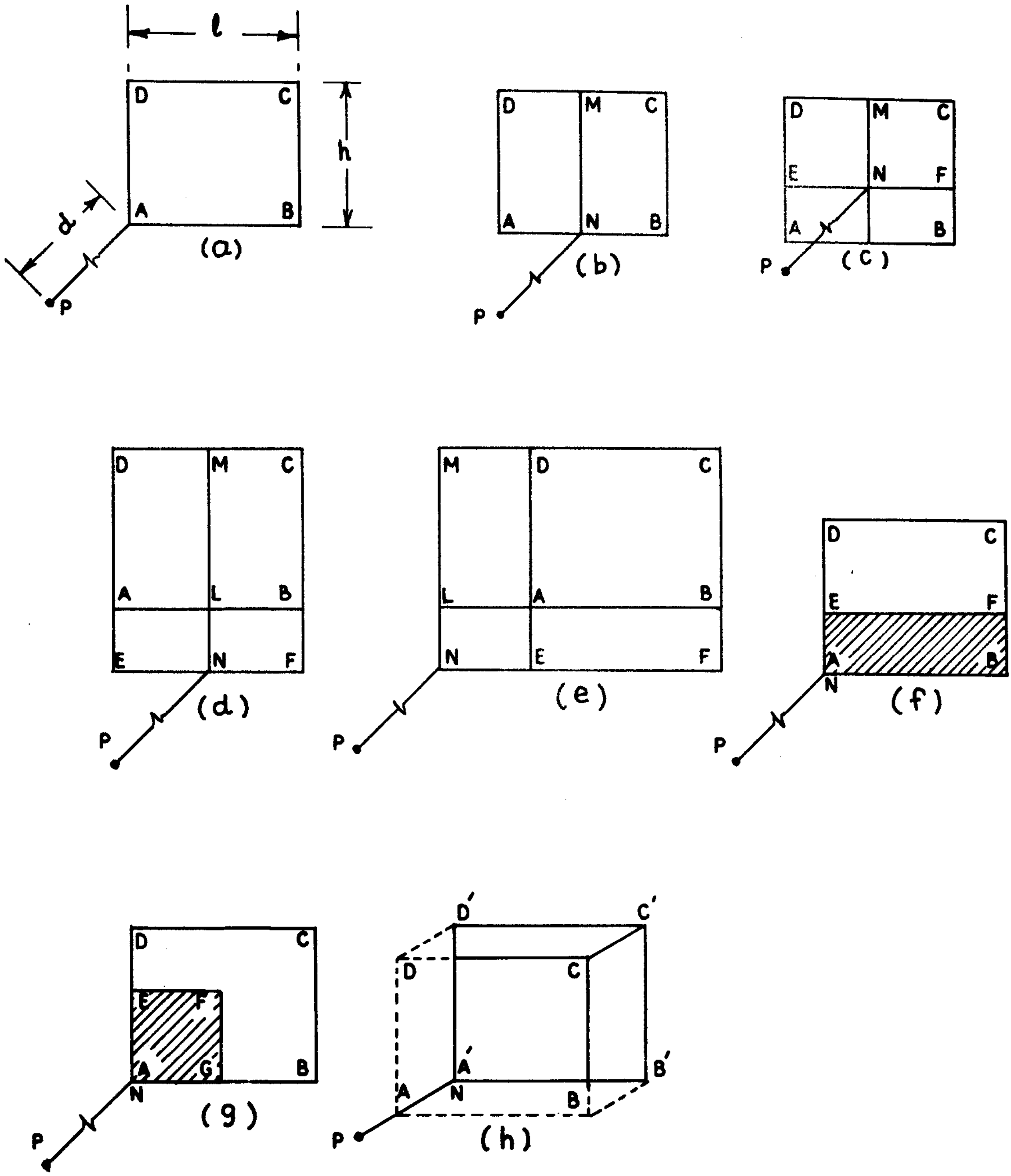

FIG. 16 DETERMINATION OF SKY COMPONENT AT A GIVEN POINT BY DELINEATION OF RECTANGLES ON WINDOW WALL THROUGH THE PROJECTION OF THE POINT

TABLE 10 PERCENTAGE SKY COMPONENTS ON THE HORIZONTAL PLANE DUE TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY

(*Clause* 4.2.1.1)

h/d \ l/D	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0.1	0.036	0.071	0.104	0.133	0.158	0.179	0.198	0.213	0.225	0.235	0.243	0.250	0.256
0.2	0.141	0.277	0.403	0.516	0.614	0.699	0.770	0.829	0.878	0.918	0.950	0.977	0.999
0.3	0.300	0.589	0.859	1.102	1.315	1.499	1.653	1.782	1.888	1.976	2.048	2.108	2.157
0.4	0.460	0.905	1.322	1.702	2.041	2.337	2.590	2.804	2.984	3.134	3.258	3.361	3.446
0.5	0.604	1.169	1.741	2.247	2.700	3.099	3.444	3.740	3.992	4.204	4.383	4.533	4.659
0.6	0.732	1.443	2.114	2.732	3.289	3.781	4.211	4.582	4.900	5.171	5.401	5.596	5.761
0.7	0.844	1.665	2.441	3.159	3.808	4.385	4.891	5.330	5.709	6.034	6.311	6.548	6.751
0.8	0.942	1.858	2.727	3.532	4.262	4.914	5.488	5.989	6.423	6.798	7.119	7.395	7.632
0.9	1.026	2.025	2.974	3.855	4.657	5.375	6.011	6.567	7.051	7.470	7.832	8.144	8.413
1.0	1.099	2.169	3.188	4.135	5.000	5.776	6.465	7.071	7.600	8.060	8.458	8.803	9.102
1.1	1.161	2.294	3.372	4.377	5.296	6.124	6.861	7.510	8.079	8.576	9.008	9.383	9.709
1.2	1.215	2.401	3.531	4.586	5.553	6.425	7.204	7.893	8.498	9.027	9.489	9.892	10.243
1.3	1.262	2.493	3.668	4.767	5.775	6.687	7.503	8.226	8.861	9.422	9.912	10.339	10.713
1.4	1.302	2.573	3.787	4.924	5.968	6.915	7.764	8.517	9.188	9.769	10.283	10.733	11.127
1.5	1.337	2.643	3.891	5.060	6.136	7.114	7.991	8.772	9.464	10.073	10.609	11.080	11.493
1.6	1.367	2.703	3.981	5.179	6.283	7.287	8.190	8.996	9.710	10.341	10.897	11.386	11.817
1.7	1.394	2.756	4.060	5.283	6.412	7.440	8.366	9.192	9.927	10.577	11.151	11.657	12.104
1.8	1.417	2.803	4.129	5.375	6.526	7.574	8.520	9.366	10.119	10.786	11.376	11.898	12.359
1.9	1.438	2.884	4.190	5.456	6.626	7.693	8.656	9.520	10.289	10.972	11.577	12.112	12.586
2.0	1.456	2.880	4.244	5.527	6.714	7.798	8.778	9.656	10.440	11.137	11.755	12.303	12.789
3.0	1.559	3.087	4.553	5.937	7.223	8.403	9.478	10.448	11.321	12.103	12.804	13.431	13.993
4.0	1.600	3.168	4.676	6.100	7.426	8.646	9.759	10.768	11.678	12.498	13.235	13.897	14.493
5.0	1.620	3.208	4.735	6.179	7.525	8.765	9.897	10.925	11.854	12.693	13.448	14.128	14.742
10.0	1.648	3.263	4.818	6.289	7.662	8.930	10.089	11.144	12.100	12.965	13.747	14.454	15.094
INF	1.657	3.282	4.846	6.327	7.710	8.986	10.155	11.220	12.186	13.060	13.851	14.567	15.217

(*Continued*)

TABLE 10 PERCENTAGE SKY COMPONENTS ON THE HORIZONTAL PLANE DUE TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY —*Contd.*

h/d \ *l/D*	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
0.1	0.261	0.264	0.263	0.270	0.272	0.274	0.276	0.284	0.286	0.287	0.288	0.288
0.2	1.018	1.033	1.046.	1.056	1.065	1.072	1.079	1.110	1.118	1.122	1.125	1.125
0.3	2.197	2.231	2.259	2.282	2.302	2.318	2.333	2.401	2.241	2.429	2.436	2.437
0.4	3.516	3.574	3.623	3.664	3.699	3.728	3.753	3.873	3.909	3.922	3.935	3.937
0.5	4.765	4.853	4.928	4.990	5.043	5.088	5.126	5.312	5.366	5.387	5.408	5.410
0.6	5.901	6.020	6.121	6.208	6.281	6.344	6.397	6.661	6.739	6.769	6.798	6.802
0.7	6.924	7.071	7.198	7.307	7.400	7.481	7.551	7.902	8.006	8.047	8.087	8.092
0.8	7.836	8.011	8.162	8.292	8.405	8.502	8.587	9.029	9.164	9.217	9.268	9.276
0.9	8.645	8.846	9.019	9.170	9.301	9.415	9.515	10.045	10.214	10.280	10.345	10.355
1.0	9.361	9.585	10.780	9.950	10.093	10.228	10.343	10.957	11.162	11.243	11.323	11.335
1.1	9.992	10.239	10.454	10.642	10.806	10.951	11.078	11.776	12.017	12.114	12.209	12.224
1.2	10.549	10.816	11.050	11.254	11.434	11.593	11.732	12.509	12.786	12.900	13.013	13.030
1.3	11.040	11.326	11.577	11.797	11.992	12.163	12.314	13.167	13.478	13.609	13.742	13.762
1.4	11.473	11.777	12.044	12.279	12.487	12.670	12.833	13.758	14.102	14.251	14.404	14.427
1.5	11.857	12.176	12.458	12.707	12.927	13.122	13.295	14.298	14.666	14.832	15.006	15.033
1.6	12.196	12.531	12.826	13.088	13.319	13.525	13.708	14.768	15.176	15.359	15.555	15.585
1.7	12.498	12.846	13.154	13.427	13.669	13.885	14.078	15.199	15.638	15.838	16.056	16.091
1.8	12.766	13.127	13.446	13.730	13.983	14.208	14.409	15.590	16.058	16.274	16.516	16.554
1.9	13.006	13.378	13.708	14.002	14.264	14.498	14.707	15.944	16.441	16.673	16.937	16.980
2.0	13.220	13.603	13.943	14.246	14.516	14.758	14.975	16.265	16.790	17.037	17.325	17.372
3.0	14.496	14.947	15.353	15.718	16.048	16.346	16.676	18.301	19.051	19.432	19.943	20.046
4.0	15.030	15.514	15.951	16.347	16.706	17.033	17.330	19.241	20.142	20.623	21.322	21.495
5.0	15.296	15.798	16.252	16.664	17.040	17.382	17.695	19.740	20.740	21.293	22.148	22.393
10.0	15.674	16.201	16.681	17.118	17.518	17.885	18.222	20.491	21.681	22.390	23.676	24.238
INF	15.806	16.342	16.831	17.278	17.688	18.064	18.410	20.770	22.046	22.838	24.463	26.111

TABLE 11 PERCENTAGE SKY COMPONENTS ON THE VERTICAL PLAN PERPENDICULAR TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY

(*Clause* 4.2.1.1)

h/d \ l/D	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0.1	0.036	0.141	0.303	0.506	0.734	0.971	1.207	1.432	1.643	1.836	2.011	2.168	2.308
0.2	0.071	0.277	0.594	0.993	1.442	1.190	2.374	2.820	3.236	3.618	3.964	4.276	4.554
0.3	0.103	0.401	0.863	1.445	2.100	2.793	3.475	4.130	4.743	5.306	5.818	6.278	6.690
0.4	0.126	0.491	1.059	1.779	2.597	3.460	4.326	3.166	5.958	6.691	7.359	7.967	8.507
0.5	0.142	0.554	1.197	2.015	2.947	3.937	4.938	5.914	6.842	7.707	8.503	9.228	9.883
0.6	0.154	0.600	1.298	2.187	3.204	4.288	5.389	6.468	7.498	8.464	9.358	10.177	10.922
0.7	0.162	0.634	1.372	2.316	3.397	4.552	5.729	6.887	7.997	9.042	10.013	10.097	11.723
0.8	0.169	0.660	1.429	2.413	3.543	4.754	5.990	7.209	8.382	9.490	10.523	11.476	12.350
0.9	0.174	0.680	1.472	2.487	3.655	4.909	6.192	7.460	8.683	9.841	10.924	11.926	12.847
1.0	0.178	0.695	1.505	2.545	3.743	5.030	6.350	7.657	8.921	10.120	11.243	12.284	13.245
1.1	0.181	0.707	1.532	2,591	3.812	5.126	6.475	7.814	9.110	10.342	11.498	12.573	13.566
1.2	0.183	0.716	1.552	2.626	3.866	5.202	6.575	7.939	9.261	10.521	11.705	12.807	13.827
1.3	0.185	0.723	1.568	2.655	3.910	5.263	6.655	8.040	9.384	10.666	11.873	12.998	14.041
1.4	0.186	0.729	1.582	2.678	3.945	5.312	6.720	8.122	9.484	10.785	12.011	13.155	14.217
1.5	0.188	0.734	1.592	2.697	3.973	5.352	6.773	8.189	9.566	10.883	12.124	13.285	14.364
1.6	0.189	0.738	1.601	2.712	3.996	5.385	6.816	8.244	9.634	10.963	12.219	13.394	14.486
1.7	0.189	0.741	1.608	2.724	4.016	5.412	6.852	8.290	9.690	11.031	12.298	13.484	14.589
1.8	0.190	0.744	1.614	2.735	4.032	5.434	6.882	8.328	9.737	11.087	12.364	13.561	14.675
1.9	0.191	0.746	1.619	2.743	4.045	5.453	6.908	8.360	9.777	11.135	12.402	13.625	14.749
2.0	0.191	0.748	1.623	2.751	4.056	5.469	6.929	8.387	9.811	11.175	12.468	13.680	14.811
3.0	0.193	0.756	1.642	2.785	4.109	5.544	7.030	8.517	9.972	11.371	12.699	13.950	15.120
4.0	0.194	0.759	1.648	2.794	4.124	5.566	7.058	8.554	10.018	11.427	12.767	14.029	15.212
5.0	0.194	0.760	1.650	2.798	4.129	5.574	7.069	8.568	10.036	11.449	12.793	14.060	15.248
10.0	0.194	0.761	1.652	2.801	4.135	5.581	7.080	8.582	10.053	11.470	12.818	14.090	15.283
INF	0.194	0.761	1.652	2.802	4.136	5.582	7.081	8.584	10.056	11.473	12.822	14.095	15.288

(*Continued*)

TABLE 11 PERCENTAGE SKY COMPONENTS ON THE VERTICAL PLAN PERPENDICULAR TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY —*Contd.*

h/d \ l/D	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
0.1	2.433	2.544	2.642	2.730	2.808	2.878	2.940	3.309	3.461	3.536	3.641	3.678
0.2	4.802	5.022	5.219	5.393	5.549	5.683	5.812	6.547	6.850	7.000	7.211	7.284
0.3	7.058	7.385	7.677	7.936	8.168	8.375	8.560	9.657	10.110	10.335	10.651	10.760
0.4	8.990	9.420	9.804	10.146	10.451	10.724	10.968	12.421	13.024	13.323	13.743	13.889
0.5	10.472	10.999	11.476	11.897	12.273	12.610	12.912	14.712	15.462	15.835	16.360	16.542
0.6	11.596	12.204	12.752	13.244	13.686	14.084	14.441	16.583	17.478	17.924	18.552	18.771
0.7	12.465	13.138	13.745	14.296	14.793	15.241	15.646	18.111	19.148	19.665	20.397	20.653
0.8	13.147	13.873	14.531	15.129	15.670	16.161	16.606	19.361	20.538	21.127	21.961	22.253
0.9	13.690	14.459	15.159	15.790	16.375	16.902	17.381	20.386	21.701	22.360	23.297	23.625
1.0	14.120	14.931	15.600	16.387	16.948	17.504	18.012	21.237	22.680	23.408	24.446	24.810
1.1	14.478	15.314	16.079	16.778	17.416	17.999	18.531	21.946	23.508	24.303	24.441	25.841
1.2	14.776	15.628	16.418	17.141	17.802	18.407	18.961	22.543	24.208	25.072	26.309	26.745
1.3	15.003	15.887	16.698	17.442	18.123	18.747	19.320	23.049	24.809	25.735	27.070	27.542
1.4	15.198	16.101	16.931	17.692	18.391	19.032	19.621	23.480	25.326	26.308	27.741	28.249
1.5	15.361	16.280	17.125	17.902	18.616	19.272	19.875	23.850	25.772	26.808	28.336	28.880
1.6	15.497	16.430	17.289	18.079	18.806	19.475	20.090	24.169	26.161	27.245	28.866	29.445
1.7	15.611	16.556	17.427	18.229	18.968	19.648	20.274	24.444	26.501	27.629	29.340	29.955
1.8	15.708	16.663	17.545	18.357	19.105	19.795	20.431	24.684	26.799	27.969	29.765	30.416
1.9	15.791	16.755	17.645	18.466	19.224	19.922	20.567	24.893	27.062	28.270	30.149	30.835
2.0	15.861	16.833	17.731	18.560	19.325	20.031	20.684	25.077	27.294	28.537	30.496	31.217
3.0	16.211	17.224	18.164	19.036	19.844	20.594	21.289	26.082	28.619	30.108	32.676	33.742
4.0	16.316	17.343	18.298	19.185	20.008	20.772	21.483	26.439	29.128	30.745	33.687	35.064
5.0	16.357	17.390	18.351	19.243	20.073	20.844	21.562	26.592	29.359	31.049	34.232	35.972
10.0	16.398	17.436	18.403	19.302	20.138	20.917	21.641	26.758	29.624	31.419	35.049	37.531
INF	16.404	17.443	18.411	19.311	20.148	20.928	21.654	26.785	29.672	31.490	35.274	39.172

TABLE 12 PERCENTAGE SKY COMPONENTS ON THE VERTICAL PLAN PARALLEL TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY

(*Clause* 4.2.1.1)

h/d \ *l/d*	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0.1	0.728	1.429	2.078	2.660	3.167	3.600	3.964	4.265	4.513	4.717	4.883	5.020	5.132
0.2	1.429	2.803	4.077	5.221	6.220	7.073	7.790	8.385	8.876	9.278	9.609	9.880	10.103
0.3	2.068	4.061	5.913	7.580	9.040	10.285	11.337	12.212	12.934	13.528	14.016	14.417	14.747
0.4	2.529	4.970	7.249	9.312	11.133	12.707	14.042	15.164	16.097	16.870	17.507	18.025	18.458
0.5	2.852	5.608	8.186	10.529	12.606	14.410	15.952	17.256	18.350	19.262	20.021	20.652	21.177
0.6	3.086	6.070	8.867	11.415	13.681	15.656	17.353	18.793	20.008	21.027	21.879	22.592	23.189
0.7	3.259	6.413	9.373	12.074	14.482	16.588	18.402	19.949	21.257	22.359	23.285	24.063	24.716
0.8	3.389	6.672	9.755	12.573	15.090	17.296	19.201	20.830	22.212	23.380	24.365	25.195	25.895
0.9	3.489	6.869	10.046	12.955	15.556	17.840	19.817	21.511	22.952	24.173	25.206	26.078	26.816
1.0	3.565	7.021	10.272	13.250	15.917	18.263	20.297	22.043	23.531	24.795	25.866	26.773	27.542
1.1	3.625	7.139	10.447	13.481	16.200	18.594	20.674	22.462	23.989	25.288	26.391	27.326	28.121
1.2	3.672	7.233	10,586	13.663	16.423	18.857	20.973	22.795	24.353	25.681	26.810	27.770	28.587
1.3	3.709	7.307	10.696	13.807	16.602	19.067	21.213	23.062	24.646	25.998	27.148	28.128	28.963
1.4	3.739	7.366	10.784	13.924	16.745	19.236	21.406	23.278	24.884	26.255	27.424	28.420	29.271
1.5	3.763	7.414	10.856	14.018	16.861	19.373	21.563	23.454	25.077	26.465	27.649	28.660	29.523
1.6	3.783	7.453	10.914	14.095	16.956	19.485	21.692	23.599	25.236	26.632	27.835	28.857	29.732
1.7	3.799	7.485	10.962	14.158	17.034	19.578	21.798	23.718	25.368	26.781	27.989	29.022	29.906
1.8	3.812	7.512	11.002	14.211	17.099	19.655	21.886	23.817	25.478	26.800	28.118	29.160	30.052
1.9	3.824	7.534	11.035	14.254	17.153	19.719	21.960	23.900	25.570	27.001	28.226	29.276	30.175
2.0	3.833	7.553	11.062	14.291	17.199	19.773	22.022	23.970	25.647	27.086	28.318	29.374	30.279
3.0	3.876	7.639	11.192	14.463	17.412	20.027	22.316	24.302	26.016	27.491	28.757	29.846	30.783
4.0	3.888	7.663	11.228	14.511	17.471	20.098	22.398	24.396	26.121	27.606	28.884	29.983	30.930
5.0	3.893	7.672	11.241	14.529	17.494	20.125	22.430	24.432	26.161	27.650	28.932	30.035	30.986
10.0	3.897	7.681	11.254	14.546	17.515	20.150	22.459	24.466	26.199	27.693	28.978	30.085	31.041
INF	3.898	7.682	11.256	14.548	17.518	20.154	22.464	24.471	26.205	27.699	28.985	30.093	31.049

(*Continued*)

TABLE 12 PERCENTAGE SKY COMPONENTS ON THE VERTICAL PLAN PARALLEL TO A VERTICAL WINDOW FOR THE TROPICAL DESIGN SKY —*Contd.*

h/d \ l/d	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
0.1	5.225	5.301	5.365	5.418	5.463	5.501	5.533	5.687	5.733	5.749	5.765	5.766
0.2	10.286	10.439	10.565	10.671	10.760	10.835	10.899	11.207	11.296	11.330	11.362	11.365
0.3	15.020	15.246	15.434	15.591	15.724	15.836	15.931	16.390	16.523	16.574	16.623	16.627
0.4	18.816	19.113	19.360	19.568	19.742	19.890	20.015	20.624	20.801	20.868	20.933	20.939
0.5	21.613	21.978	22.275	22.530	22.746	22.923	23.082	23.836	24.056	24.140	24.222	24.229
0.6	23.689	24.109	24.462	24.761	25.014	25.229	25.412	26.299	26.561	26.662	26.759	26.768
0.7	25.267	25.731	26.124	26.438	26.742	26.984	27.192	28.214	28.517	28.634	28.748	28.758
0.8	26.486	26.987	27.412	27.775	28.084	28.350	28.578	29.720	30.065	30.198	30.327	30.399
0.9	27.441	27.972	28.424	28.810	29.141	29.426	29.672	30.927	31.303	31.451	31.590	31.610
1.0	28.196	28.752	29.226	29.633	29.982	30.283	30.544	31.889	32.302	32.467	32.627	32.643
1.1	28.798	29.375	29.869	30.293	30.658	30.973	31.246	32.670	33.117	33.297	33.473	33.491
1.2	29.283	29.878	30.388	30.826	31.204	31.532	31.816	33.309	33.796	33.891	34.173	34.193
1.3	29.676	30.286	30.810	31.261	31.631	31.989	32.283	33.836	34.350	34.550	34.756	34.779
1.4	29.998	30.621	31.157	31.618	32.018	32.365	32.667	34.274	34.813	35.035	35.247	35.271
1.5	30.262	30.897	31.443	31.914	32.322	32.677	32.986	34.641	35.202	35.436	35.663	35.689
1.6	30.482	31.125	31.680	32.160	32.575	32.937	33.253	34.950	35.532	35.776	36.017	36.046
1.7	30.665	31.317	31.879	32.366	32.788	33.156	33.477	35.211	35.812	36.067	36.321	36.352
1.8	30.818	31.477	32.046	32.539	32.967	33.340	33.666	35.435	36.052	36.316	36.584	36.671
1.9	30.948	31.613	32.186	32.686	33.119	33.497	33.828	35.626	36.259	36.532	36.812	36.847
2.0	31.058	31.728	32.308	32.811	33.249	33.631	33.965	35.791	36.438	36.719	37.011	37.048
3.0	31.592	32.291	32.898	33.427	33.889	34.294	34.654	36.640	37.680	37.715	38.107	38.157
4.0	31.748	32.457	33.074	33.611	34.082	34.497	34.860	36.915	37.699	38.063	38.510	38.579
5.0	31.808	32.521	33.142	33.683	34.157	34.574	34.943	37.028	37.834	38.214	38.696	38.781
10.0	38.867	32.584	33.208	33.753	34.231	34.652	35.024	37.144	37.978	38.382	38.927	39.057
INF	31.876	32.593	33.218	33.764	34.243	34.664	35.037	37.162	38.003	38.411	38.978	39.172

TABLE 13 PERCENTAGE SKY FACTORS ON A PLANE PERPENDICULAR TO THE WINDOW

(*Clause* 4.2.2.1)

h/d \ *l/d*	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0.1	0.016	0.031	0.045	0.057	0.068	0.077	0.085	0.092	0.097	0.102	0.105	0.108	0.110
0.2	0.061	0.119	0.174	0.222	0.265	0.301	0.332	0.357	0.378	0.396	0.410	0.422	0.431
0.3	0.131	0.256	0.373	0.478	0.571	0.650	0.716	0.772	0.818	0.855	0.885	0.912	0.933
0.4	0.218	0.429	0.624	0.801	0.957	1.090	1.203	1.298	1.377	1.442	1.495	1.540	1.577
0.5	0.316	0.622	0.907	1.165	1.393	1.590	1.757	1.898	2.015	2.112	2.193	2.259	2.315
0.6	0.419	0.824	1.202	1.546	1.851	2.116	2.342	2.533	2.693	2.826	2.937	3.029	3.106
0.7	0.521	1.024	1.496	1.927	2.310	2.644	2.931	3.175	3.379	3.551	3.695	3.814	3.914
0.8	0.618	1.216	1.779	2.294	2.759	3.156	3.503	3.799	4.050	4.261	4.438	4.586	4.710
0.9	0.709	1.396	2.043	2.637	3.170	3.638	4.044	4.392	4.688	4.938	5.149	5.327	5.476
1.0	0.792	1.561	2.286	2.954	3.555	4.085	4.547	4.945	5.285	5.573	5.818	6.024	6.199
1.1	0.867	1.710	2.507	3.242	3.906	4.493	5.008	5.453	5.834	6.160	6.437	6.672	6.872
1.2	0.935	1.844	2.705	3.502	4.223	4.864	5.427	5.916	6.337	6.698	7.006	7.268	7.492
1.3	0.995	1.964	2.883	3.735	4.508	5.198	5.805	6.335	6.793	7.187	7.324	7.813	8.060
1.4	1.049	2.071	3.042	3.943	4.743	5.497	6.145	6.712	7.204	7.630	7.995	8.309	8.578
1.5	1.097	2.166	3.183	4.128	4.991	5.765	6.450	7.052	7.573	8.029	8.421	8.759	9.049
1.6	1.140	2.251	3.309	4.294	5.194	6.004	6.723	7.356	7.909	8.389	8.805	9.165	9.475
1.7	1.178	2.327	3.421	4.441	5.376	6.218	6.967	7.629	8.209	8.714	9.152	9.532	9.862
1.8	1.211	2.393	3.520	4.575	5.538	6.409	7.187	7.875	8.478	9.006	9.465	9.864	10.212
1.9	1.241	2.453	3.609	4.691	5.683	6.581	7.383	8.095	8.721	9.269	9.748	10.165	10.529
2.0	1.268	2.507	3.689	4.796	5.813	6.735	7.560	8.293	8.940	9.507	10.003	10.437	10.816
3.0	1.427	2.824	4.163	5.423	6.590	7.657	8.624	9.492	10.268	10.959	11.573	12.118	12.601
4.0	1.493	2.955	4.338	5.683	6.913	8.043	9.071	9.999	10.834	11.582	12.251	12.850	13.385
5.0	1.525	3.019	4.455	5.812	7.074	8.235	9.294	10.253	11.118	11.896	12.594	13.221	13.785
10.0	1.554	3.078	4.543	5.929	7.220	8.410	9.497	10.485	11.378	12.184	12.910	13.565	14.155
INF	1.586	3.142	4.639	6.056	7.379	8.601	9.720	10.739	11.663	12.500	13.257	13.943	14.564

(*Continued*)

TABLE 13 PERCENTAGE SKY FACTORS ON A PLANE PERPENDICULAR TO THE WINDOW —*Contd.*

h/d \ l/d	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
0.1	0.112	0.114	0.116	0.117	0.118	0.119	0.120	0.122	0.123	0.124	0.124	0.124
0.2	0.439	0.445	0.451	0.456	0.460	0.462	0.465	0.478	0.482	0.484	0.485	0.485
0.3	0.951	0.965	0.977	0.988	0.996	1.002	1.009	1.390	1.047	1.051	1.053	1.054
0.4	1.607	1.632	1.653	1.671	1.685	1.696	1.708	1.761	1.776	1.782	1.786	1.788
0.5	2.361	2.399	2.431	2.458	2.481	2.498	2.516	2.597	2.620	2.629	2.635	2.639
0.6	3.170	3.223	3.268	3.306	3.338	3.363	3.388	3.502	3.535	3.548	3.557	3.563
0.7	3.997	4.067	4.126	4.176	4.218	4.251	4.285	4.437	4.482	4.500	4.512	4.519
0.8	4.814	4.902	4.976	5.040	5.093	5.135	5.177	5.371	5.430	5.453	5.469	5.478
0.9	5.602	5.708	5.798	5.875	5.940	5.992	6.044	6.284	6.357	6.386	6.406	6.418
1.0	6.346	6.472	6.578	6.669	6.746	6.808	6.870	7.158	7.248	7.283	7.307	7.322
1.1	7.041	7.183	7.306	7.413	7.503	7.575	7.647	7.988	8.094	8.136	8.165	8.183
1.2	7.683	7.846	7.985	8.104	8.209	8.290	8.372	8.766	8.890	8.939	8.974	8.995
1.3	8.272	8.453	8.608	8.742	8.857	8.950	9.043	9.491	9.634	9.691	9.732	9.737
1.4	8.810	9.008	9.179	9.327	9.455	9.558	9.662	10.165	10.328	10.393	10.440	10.469
1.5	9.299	9.513	9.701	9.863	10.003	10.116	10.230	10.789	10.972	11.046	11.100	11.133
1.6	9.744	9.976	10.177	10.351	10.503	10.626	10.750	11.365	11.569	11.652	11.712	11.750
1.7	10.147	10.395	10.610	10.797	10.960	11.093	11.227	11.897	12.122	12.215	12.282	12.325
1.8	10.513	10.775	11.004	11.203	11.377	11.520	11.663	12.388	12.634	12.737	12.812	12.859
1.9	10.845	11.121	11.362	11.573	11.757	11.909	12.062	12.840	13.109	13.221	13.304	13.356
2.0	11.147	11.436	11.689	11.911	12.105	12.266	12.427	13.258	13.549	13.671	13.762	13.820
3.0	13.031	13.413	13.752	14.055	14.325	14.504	14.783	16.059	16.561	16.791	16.971	17.093
4.0	13.865	14.295	14.681	15.028	15.340	15.608	15.877	17.451	18.128	18.457	18.733	18.957
5.0	14.292	14.794	15.161	15.533	15.870	16.162	16.454	18.219	19.025	19.437	19.804	20.097
10.0	14.688	15.171	15.609	15.005	16.369	16.684	17.000	18.976	19.942	20.473	20.985	21.464
INF	15.128	15.642	16.110	16.537	16.629	17.125	17.621	19.879	21.101	21.858	22.742	25.000

TABLE 14 PERCENTAGE SKY FACTORS ON A PLANE PARALLEL TO THE WINDOW

(*Clause* 4.2.2.2)

h/d \ l/d	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
0.1	0.314	0.616	0.896	1.147	1.336	1.553	1.709	1.839	1.946	2.034	2.106	2.165	2.213
0.2	0.616	1.209	1.759	2.252	2.683	3.051	3.360	3.617	3.828	4.002	4.144	4.261	4.357
0.3	0.896	1.759	2.559	3.279	3.909	4.447	4.901	5.278	5.590	5.846	6.057	6.228	6.372
0.4	1.147	2.252	3.279	4.204	5.015	5.710	6.297	6.786	7.191	7.525	7.800	8.026	8.212
0.5	1.366	2.683	3.909	5.015	5.986	6.822	7.530	8.122	8.613	9.019	9.353	9.629	9.858
0.6	1.553	3.051	4.447	5.710	6.822	7.782	8.596	9.280	9.848	10.320	10.710	11.032	11.299
0.7	1.709	3.360	4.901	6.297	7.530	8.596	9.504	10.279	10.907	11.437	11.876	12.241	12.544
0.8	1.839	3.617	5.278	6.786	8.122	9.280	10.269	11.103	11.802	12.385	12.870	13.273	13.608
0.9	1.946	3.828	5.590	7.191	8.613	9.848	10.907	11.802	12.553	13.184	13.708	14.146	14.511
1.0	2.034	4.002	5.846	7.525	9.019	10.320	11.437	12.385	13.184	13.853	14.413	14.881	15.273
1.1	2.106	4.144	6.057	7.800	9.353	10.710	11.876	12.870	13.708	14.413	15.004	15.499	15.915
1.2	2.165	4.261	6.228	8.026	9.629	11.032	12.241	13.273	14.146	14.881	15.499	16.018	16.453
1.3	2.213	4.357	6.372	8.212	9.858	11.299	12.544	13.608	14.511	15.273	15.915	16.455	16.910
1.4	2.233	4.437	6.489	8.367	10.047	11.521	12.796	13.888	14.816	15.601	16.263	16.822	17.294
1.5	2.286	4.502	6.586	8.495	10.204	11.706	13.207	14.122	15.072	15.877	16.557	17.133	17.618
1.6	2.314	4.557	6.668	8.602	10.335	11.860	13.183	14.319	15.287	16.109	16.805	17.395	17.894
1.7	2.337	4.603	6.736	8.692	10.446	11.991	13.332	14.485	15.469	16.306	17.016	17.618	18.128
1.8	2.356	4.641	6.793	8.768	10.538	12.100	13.457	14.625	15.623	16.473	17.195	17.808	18.328
1.9	2.371	4.671	6.837	8.825	10.611	12.186	13.555	14.735	15.745	16.605	17.337	17.956	18.487
2.0	2.386	4.701	6.882	8.885	10.684	12.272	13.654	14.846	15.867	16.738	17.479	18.110	18.646
3.0	2.453	4.834	7.080	9.147	11.009	12.658	14.099	15.347	16.422	17.345	18.135	18.812	19.393
4.0	2.472	4.872	7.137	9.223	11.104	12.771	14.230	15.496	16.588	17.528	18.334	19.027	19.623
5.0	2.475	4.877	7.145	9.233	11.116	12.785	14.247	15.515	16.609	17.551	18.359	19.055	19.653
10.0	2.487	4.901	7.181	9.281	11.175	12.856	14.329	15.609	16.715	17.668	18.487	19.193	19.802
INF	2.488	4.903	7.184	9.285	11.180	12.862	14.337	15.617	16.724	17.678	18.498	19.206	16.816

(*Continued*)

TABLE 14 PERCENTAGE SKY FACTORS ON A PLANE PARALLEL TO THE WINDOW —*Contd.*

h/d \ l/d	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
0.1	2.253	2.886	3.314	2.337	2.356	2.371	2.386	2.453	2.472	2.481	2.487	2.488
0.2	4.437	4.502	4.557	4.603	4.641	4.671	4.701	4.834	4.872	4.877	4.901	4.903
0.3	6.489	6.586	6.668	6.736	6.793	6.840	6.882	7.080	7.137	7.145	7.181	7.184
0.4	8.367	8.495	8.602	8.692	8.767	8.826	8.885	9.147	9.223	9.233	9.281	9.285
0.5	10.047	10.204	10.335	10.446	10.538	10.611	10.684	11.009	11.104	11.116	11.175	11.180
0.6	11.521	11.706	11.860	11.991	12.100	12.186	12.272	12.658	12.771	12.785	12.856	12.862
0.7	12.796	13.307	13.183	13.332	13.457	13.555	13.654	14.099	14.230	14.246	14.329	14.337
0.8	13.888	14.122	14.319	14.485	14.625	14.735	14.846	15.347	15.496	15.515	15.609	15.617
0.9	14.816	15.072	15.287	15.469	15.623	14.747	15.868	16.422	16.588	16.609	16.715	16.724
1.0	15.601	15.877	16.109	16.306	16.473	16.605	16.738	17.345	17.528	17.551	17.688	17.678
1.1	16.263	16.557	16.905	17.016	17.195	17.337	17.479	18.135	18.334	18.359	18.487	18.498
1.2	16.822	17.132	17.395	17.618	17.808	17.860	18.110	18.812	18.027	19.055	19.193	19.206
1.3	17.294	17.618	17.894	18.128	18.328	18.487	18.647	19.393	19.623	19.653	19.802	19.816
1.4	17.692	18.030	18.317	18.562	18.771	18.838	19.106	19.893	20.137	20.169	20.329	20.343
1.5	18.030	18.370	18.677	18.931	19.148	19.323	19.498	20.323	20.581	20.602	20.786	20.801
1.6	18.317	18.677	18.985	19.248	19.473	19.654	19.935	20.695	20.967	21.003	21.184	21.200
1.7	18.562	18.931	19.248	19.518	19.750	19.936	20.123	21.018	21.303	21.341	21.531	21.548
1.8	18.771	19.148	19.473	19.750	19.988	20.180	20.372	21.298	21.596	21.636	21.835	21.854
1.9	18.938	19.323	19.654	19.936	20.180	20.377	20.575	20.527	21.837	21.877	22.087	22.108
2.0	19.106	19.458	19.835	20.123	20.372	20.575	20.778	21.757	22.078	22.122	22.340	22.361
3.0	19.893	20.323	20.695	21.018	21.258	21.527	21.757	22.922	23.331	23.391	23.687	23.717
4.0	20.137	20.581	20.967	21.303	21.596	21.837	22.078	23.331	23.785	23.875	24.214	24.254
5.0	20.169	20.615	21.001	21.341	21.636	21.879	22.122	23.391	23.857	23.933	24.311	24.274
10.0	20.329	20.786	21.184	21.531	21.835	22.087	22.340	23.687	24.214	24.311	24.797	24.376
INF	20.343	20.801	21.200	22.548	21.854	22.108	22.361	23.717	24.254	24.358	24.876	25.000

TABLE 15 INVERSE BRIGHTNESS FACTORS (1/BF) FOR THE CLEAR DESIGN SKY

(*Clause* 4.2.2.2)

Mean Angle of Elevation degree	Inverse Brightness Factor
5	0.43
10	0.43
15	0.43
20	0.57
25	0.71
30	0.84
35	0.96
40	1.08
45	1.18
50	1.28
55	1.37
60	1.45
65	1.52
70	1.58
75	1.62
80	1.64
85	1.67

4.2.2.3 The average window factors for a sunlit surface, a non-sunlit surface without opposite obstructions and non-sunlit surface with opposite obstructions may be taken as 5, 1 and 0.5 respectively. These values multiplied by the surface reflectance gives the ratio of surface luminance to design sky illuminance. Table 16 provides the ratio of surface luminance to design sky illuminance for dull, medium and light finished surfaces (reflectances 0.2, 0.4 and 0.6 respectively).

TABLE 16 RATIO OF SURFACE LUMINANCE AND DESIGN SKY ILLUMINANCE

(*Clause* 4.2.2.4)

Surface Reflec-tance	Sunlit Surface	Unobstructed Non-Sunlit Surface	Non-Sunlit Surface with Opposite Obstructions
(1)	(2)	(3)	(4)
0.2	1.0	0.2	0.1
0.4	2.0	0.4	0.2
0.6	3.0	0.6	0.3

4.2.2.4 The ratio of surface luminance of sunlit ground to the design sky illuminance for the clear design sky condition is twice its reflectance. The external reflected component due to any surface is the product of sky factor and the above ratio for the surface in question.

Example 10

In Example 9, for the sky component calculation, determine ERC due to given building blocks parallel to the window facade for surface reflectance of 0.2 when the blocks are: (a) non-sunlit and unobstructed and (b) sunlit.

Solution

The values of l/d and h/d for the projected obstruction on the window are 0.6 and 0.2 respectively. From Table 13 (for the horizontal plane), sky factor is 0.301 for the above values of l/d and h/d. From Table 16, the ratios of surface luminance to design sky illuminance for a non-sunlit and unobstructed surface, and for a sunlit surface are 0.2 and 1.0 respectively. Therefore

ERC = SF × Ratio of surface luminance and design sky illuminance

= 0.301 × 0.2 = 0.06 percent for non-sunlit and unobstructed surface

and ERC = 0.301 × 1.0 = 0.301 percent for sunlit surface.

Alternative Solution

Obstructed SC = 0.699 (Example 9 under sky component). Angle of elevation of the obstruction from the given point = 12°

Mean angle of elevation of the obstruction from the given point = 6°

From Table 15, $\frac{1}{BF} = 0.43$

Therefore

$$SF = SC \times \frac{1}{BF} = 0.699 \times 0.43 = 0.30$$

and ERC = 0.3 × 0.2
= 0.06 percent for non-sunlit and unobstructed surface

and ERC = 0.3 × 1.0
= 0.30 percent for sunlit surface

4.2.3 *Internal Reflected Component*

4.2.3.1 The internal reflected component varies slightly from point to point in a room depending upon the luminance distribution of different internal surfaces. However, for all practical purposes, an average value of internal reflected component is good enough. It depends upon the luminous flux entering the room which is proportional to the product of window area W and the percent window factor (C), the area A of all the internal surfaces of the room and the average reflectance R of the internal surfaces. Applying the principle of integrating sphere, the average internal reflected component is:

$$IRC_a = \frac{0.85\ W C R}{A(1-R)} \quad \ldots (11)$$

where 0.85 is the diffuse transmittance of 3 mm clear glass.

4.2.3.2 The product $W \times C \times R$ is the first reflected flux from all the internal surfaces of the room. It is regarded as made up of two parts; one of the flux reflected by the part of the room above mid-height of the window and the other from the lower part of the room.

$$WCR = W\,[C_1 \times R_{fw} + C_2 \times R_{cw}] \quad \ldots (12)$$

where C_1 and C_2 are the percentage window factors due to flux from above mid-height of the window and below it respectively. R_{fw} and R_{cw} are the average reflectances of the part of the room (excluding window wall) below mid-height of the window and above it respectively.

$$\text{IRC} = \frac{0.85\,W}{A\,(1-R)}\,(C_1\,R_{fw} + C_2\,R_{cw}) \quad \ldots (13)$$

For the ratio of ground luminance to design sky illuminance as 0.2, $C_2 = 18$ and in case of no obstruction above mid-height of the window, $C_1 = 78$.

4.2.3.3 The value of C_1 due to sky and an infinitely long external obstruction above mid-height of the window and parallel to it are given in Table 17 for the ratio of the luminance of the obstruction to the design sky illuminance as 0.2. The average reflectance R is determined by taking the weighted mean of reflectances over different internal surfaces. Thus

$$R = \frac{A_c\,R_c + A_f\,R_f + A_w\,R_w + A_g\,R_g}{A} \quad \ldots (14)$$

where A_c, A_f, A_w, A_g are the area of ceiling, floor wall and glass, and R_c, R_f, R_w, R_g are their respective reflectance. R_{cw} and R_{fw} can also be similarly estimated after dividing the room into two parts about a horizontal section passing through mid-height of the window. Here the window wall is excluded as it does not contribute to the first reflected flux.

Example 11

Determine the internal reflected component in a room 5.0 m × 3.0 m × 3.0 m provided with a window 2.0 m × 1.0 m on the shorter wall at a sill height of 0.5 m above floor when there is no obstruction in front of the window. The reflectances of ceiling, walls, floor and glass are 0.7, 0.5, 0.3 and 0.15 respectively.

Solution

$$A = 2\;(5 \times 3 + 5 \times 3 + 3 \times 3)$$
$$= 2\;(15 + 15 + 9)$$
$$= 2 \times 39 = 78\ \text{m}^2$$

$$R = \frac{15 \times 0.7 + 15 \times 0.3 + (48 - 2) \times 0.5 + 2 \times 0.15}{78}$$
$$= 0.491$$

or $1 - R = 0.509$

TABLE 17 PERCENTAGE WINDOW FACTORS DUE TO SKY AND INFINITELY LONG PARALLEL OBSTRUCTION

(*Clause* 4.2.3.3)

Angle of Obstruction at Mid-Height of the Window Degree	Window Factor (C_1) due to Sky and Obstruction Percent
5	68.9
10	59.9
15	50.6
20	42.5
25	36.2
30	30.8
35	26.7
40	22.9
45	20.1
50	17.7
55	15.8
60	14.1
65	12.9
70	11.7
75	11.1
80	10.3
85	10.0

Mid-height of the window above floor is 1.0 m. Considering the parts of the room above and below 1.0 m mid-height, and excluding the window wall

$$R_{cw} = \frac{15 \times 0.7 + (5 \times 2 + 3 \times 2 + 5 \times 2) \times 0.5}{15 + 26}$$
$$= 0.573$$

$$R_{fw} = \frac{15 \times 0.3 + (5 \times 1 + 5 \times 1 + 3 \times 1) \times 0.5}{15 + 13}$$
$$= 0.393$$

$$\text{IRC} = \frac{0.85\,W\,(78\,R_{fw} + 10\,R_{cw})}{A\,(1 - R)}$$
$$= \frac{0.85 \times 2\,(78 \times 0.393 + 10 \times 0.573)}{78 \times 0.509}$$
$$= 1.55 \text{ percent}$$

Example 12

Determine the internal reflected component in the same room as in Example 11 for a window of dimension 1.8 m × 1.5 m at a sill height of 0.75 m above floor when there is an obstruction due to opposite parallel blocks of height 2.6 m above ground at a distance of 1.0 m from the external surface of the window.

Solution

$$W = 1.8 \times 1.5 = 2.7\ \text{m}^2$$
$$A = 78\ \text{m}^2$$
$$R = 0.491$$

or $(1 - R) = 0.509$

Mid-height of the window is same as the mid-height of the room. Therefore, the room is to be divided into two equal halves about the mid-height level. Therefore,

$$R_{cw} = \frac{15 \times 0.7 + (5 \times 1.5 + 3 \times 1.5 + 5 \times 1.5) \times 0.5}{15 + 19.5}$$
$$= 0.413$$

$$R_{fw} = \frac{15 \times 0.3 + (5 \times 1.5 + 3 \times 1.5 + 5 \times 1.5) \times 0.5}{15 + 19.5}$$
$$= 0.413$$

Height of the obstruction above mid-height of the window = 2.60 − 1.50 = 1.10 m. Angle of obstruction above mid-height of the window is:

$$\tan^{-1}\left(\frac{1.10}{10}\right) = 6.5°$$

From Table 17, by interpolation C = 66.2 percent for 6.5° obstruction. Therefore,

$$\text{IRC} = \frac{0.85 \times W(66.2\ R_{fw} + 10\ R_{cw})}{A\,(1 - R)}$$

$$= \frac{0.85 \times 2.7\ \ (66.2 \times 0.413 + 10 \times 0.587)}{78 \times 0.509}$$
= 1.92 percent.

4.2.4 The calculated values of SC, ERC and IRC are to be reduced to account for the maintenance factor, the ratio of glazed area to gross window area, the reduction due to louvers and transmittance of glazing material. A suitable value of maintenance factor for clean locations and a cleaning schedule of three to six months is 0.8. For any other condition, appropriate value may be read from Table 8. The ratio of glazed area to gross window area may be taken as 0.85 for metallic window and 0.70 for wooden windows. The actual ratio can also be determined if the details of the window are known.

The louvers are accounted for in the method of computation of SC and ERC discussed above, but an appropriate value of transmittance of louver system is to be applied for obtaining the IRC. For usual vertical and horizontal parallel louvers and box type of louvers, the louver transmittance may be taken as 0.85. The values of SC and ERC are also reduced for the transmittance of glazing depending upon the angle of incidence. The angle of incidence is the angle between the direction of view of sky or obstruction from the given point and the normal to the window. The angles of incidence between 0° and 50° which cover most of the workplane area except regions very close or obliquely located with respect to the window, the transmittance for 3 mm clear glass may be taken as 0.9. The values of IRC are reduced by the diffuse transmittance of glazing which is 0.85 for 3 mm clear glass in equation (13). For any other glazing material the actual values of diffuse and directional transmittance should be used for correcting the computed values of IRC and SC or ERC respectively.

Based on above values of reduction factors for maintenance, glazed area to gross window area ratio, glazing transmittance (for SC), and diffuse transmittance of louvers (for IRC), the ultimate reduction factors are 0.8 × 0.85 × 0.9 = 0.6 for SC or ERC and 0.8 × 0.85 × 0.85 = 0.6 for IRC. By multiplying these ultimate reduction factors to the computed values, the expected sky component, external reflected component and internal reflected component can be obtained. The sum of these components gives the expected daylight factor.

4.3 Computations for Windows Glazed With Diffusing Materials

4.3.1 Light diffusing materials are, generally, recommended for roof lighting to reduce the effect of direct sunlight such as with pitched type of roof lights where direct sunlight is incident for most of the time. Diffusing glazing materials may also be used for side lighting where the direct view through windows is not important. For such glazing materials, the direct component of daylight is calculated with the help of sky factor given in Table 13 and 14, instead of separate calculation of SC and ERC. Sky factor multiplied by the ratio of luminance of glazing material (in equivalent illuminance units) to the design sky illuminance gives the direct component. The above multiplying factor is the product of window factor and transmittance T of glazing material. Hence,

Direct component = Sky factor × Window factor × Transmittance ... (15)

The method of calculation of internal reflected component or indirect component is the same as described under **4.1.**

Example 13

Determine the direct component in Example 7 if a diffusing glazing material of transmittance 0.5 is used and the window plane illuminance is twice the design sky illuminance.

Solution

Given, Window factor, $C = 2$
Transmittance, $T = 0.5$

From Equation (4) and Table 13,

$$(\text{SF})_{ABCD} = (\text{SE})_{NMCF} - (\text{SF})_{NMDE} - (\text{SF})_{NLBF} + (\text{SF})_{NLAE}$$
$$= 3.391 - 1.496 - 0.378 + 0.174 \text{ percent}$$
$$= 1.68 \text{ percent}$$

Direct component

$$= \text{SF} \times C \times T = 1.68 \times 2 \times 0.5$$
$$= 1.68 \text{ percent}$$

4.4 Protractors for Direct Component of Daylight Factor — Protractors 1, 2 and 3 (*see* Fig. 17 to 19) are provided for the determination of sky components from clear design sky at any point on a horizontal plane, a vertical plane normal to the window and a vertical plane parallel to the window respectively. For obtaining the values of external reflected components (or sky factors), the sky components are mutiplied by inverse brightness factors depending upon the mean angular height of external obstructions. Auxiliary protractor 4 (*see* Fig. 20) can be used for the determination of angular height of window (h/d), mean angular height of a window or an obstruction and corresponding inverse brightness factors. This auxiliary protractor is placed with its centre at the given point on the section and the 0-0 line is kept horizontal. The line of sight joining the point and the upper edge of the window opening indicates h/d value. Similarly, the mean angular height and inverse brightness factor can be read on the relevant line of sight.

The protractors 1, 2 and 3 consist of two halves about a solid base line for h/d ranges of 0.0-1.0 and 0.0-0.5. The appropriate half of a protractor is placed towards the window on the plan with its centre at the point in question and the base line parallel to the window wall. The values of sky component contours at the intersections of the lines of sight joining the given point and the outer edges of the window with the relevant h/d circles can be directly read. The sky component is obtained by subtracting the value for the nearer line of sight from the value for the farther line of sight.

Allowance should be made for the reduction due to glass transmittance, dust and glass area to gross window area ratio.

Example 14

Determine the sky component on a horizontal workplane at a point 3.0 m away from a window of size 1.8 m × 1.5 m when the sill above the workplane is 0.6 m and the horizontal displacement of the point from the nearest edge of the window is 0.9 m.

Solution

Place the auxilliary protractor 4 with its centre at the given point on the section (*see* Fig. 21A) keeping the diameter 0-0 horizontal. Read h/d values along the lines joining the given point with the upper and the lower edge of the window. The h/d values are found to be 0.7 and 0.2 respectively.

Now place the protractor 1 (for horizontal work-plane) with its centre at the given point on the plane (*see* Fig. 21B) keeping the solid diameter parallel to the window wall and h/d range of 0.0-1.0 towards the window. Note the sky components on the intersections of circles of h/d=0.7 and 0.2 with the lines joining the given point and the upper and lower edges of the window. These values are 5.8 and 2.5 for circle of h/d = 0.7 and 0.9, and 0.4 for circle of h/d = 0.2. Therefore, the sky components (SC) on the horizontal plane:

$$\begin{aligned} SC &= (5.8 - 2.5) - (0.9 - 0.4) \\ &= 3.3 - 0.5 = 2.8 \text{ percent.} \end{aligned}$$

Allowing for usual reduction factor of 60 percent for the glass transmittance, dust and glass to gross window area ratio, the expected sky component:

$$SC = 2.8 \times 0.6 = 1.68 \text{ percent}$$

Example 15

Determine the sky component if the window in example 14 is provided with a box type of louvre of width 0.6 m and the distance of the indoor point is 3.0 m from the outer plane of the window.

Solution

Here the h/d values for the upper and lower lines of sight obtained by using the auxiliary protractor 4 on the section (*see* Fig. 22A) are 0.7 and 0.25. The values of sky components on these h/d circles for the farther and nearer lines of sight on the plan (*see* Fig. 22B) as obtained with protractor 1 are 5.8, 2.8 and 0.9, 0.5 respectively. Therefore, the sky component on the horizontal plane becomes:

$$\begin{aligned} SC &= (5.8 - 2.8) - (0.9 - 0.5) \\ &= 3.0 - 0.4 = 2.6 \text{ percent.} \end{aligned}$$

Allowing for usual reduction factors, the expected sky component:

$$SC = 2.6 \times 0.6 = 1.56 \text{ percent.}$$

Example 16

Determine the direct component of daylight factor in Example 15 when the point lies along the perpendicular through one of the bottom corners of the window and there is a sunlit obstruction of height 1.6 m above the workplane due to parallel building blocks at a distance of 5 m from the window. Assume that the ratio of luminance of the obstruction to the design sky illuminance is unity.

Solution

The h/d values for the upper and lower lines of sight, obtained by using the auxiliary protractor 4 on the section (Fig. 23A) are 0.5 and 0.2 respectively. The mean angle of the obstruction above the given point and the corresponding inverse brightness factor is obtained from the protractor as 6° and 0.43 respectively.

The values of sky components on h/d = 0.5 and 0.2 for the farther and nearer line of sight on the plan (*see* Fig. 23B) as obtained with protractor 1 are 3.0, 0.7 and 0.9, 0.0 respectively, the values being zero along the normal. Therefore, the sky components (SC) and external reflected components (ERC) are:

$$\begin{aligned} SC &= (3.0 - 0.0) - (0.7 - 0.0) \\ &= 2.3 \text{ percent} \end{aligned}$$

$$\begin{aligned} ERC &= 0.6 \times 0.43 \times 1.0 \\ &= 0.3 \text{ percent} \end{aligned}$$

Net direct component = SC + ERC = 2.6 percent

Allowing for usual reduction factors, the expected direct component = 2.6 × 0.6 = 1.56 percent

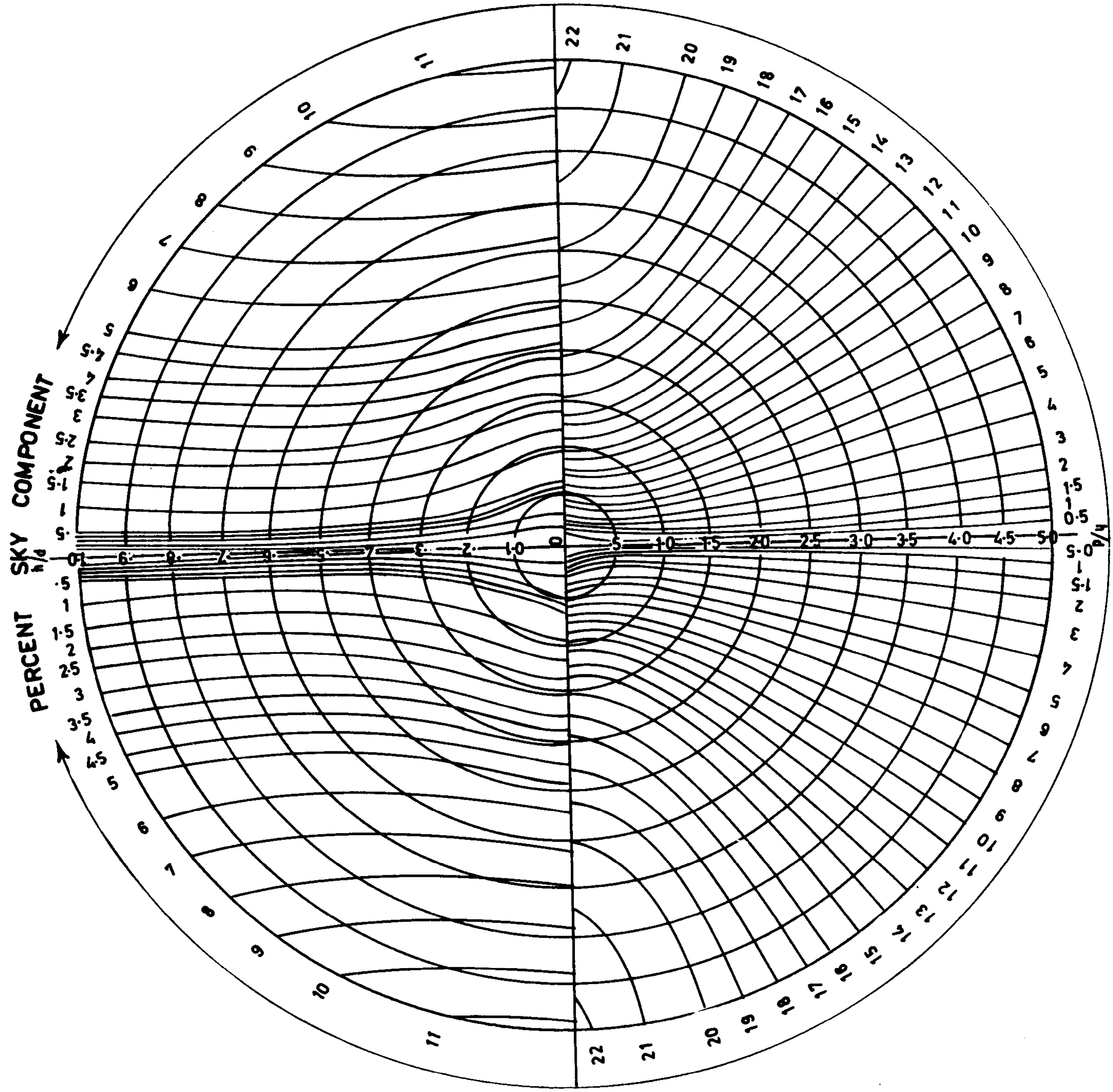

FIG. 17 SKY COMPONENT PROTRACTOR FOR A HORIZONTAL PLANE

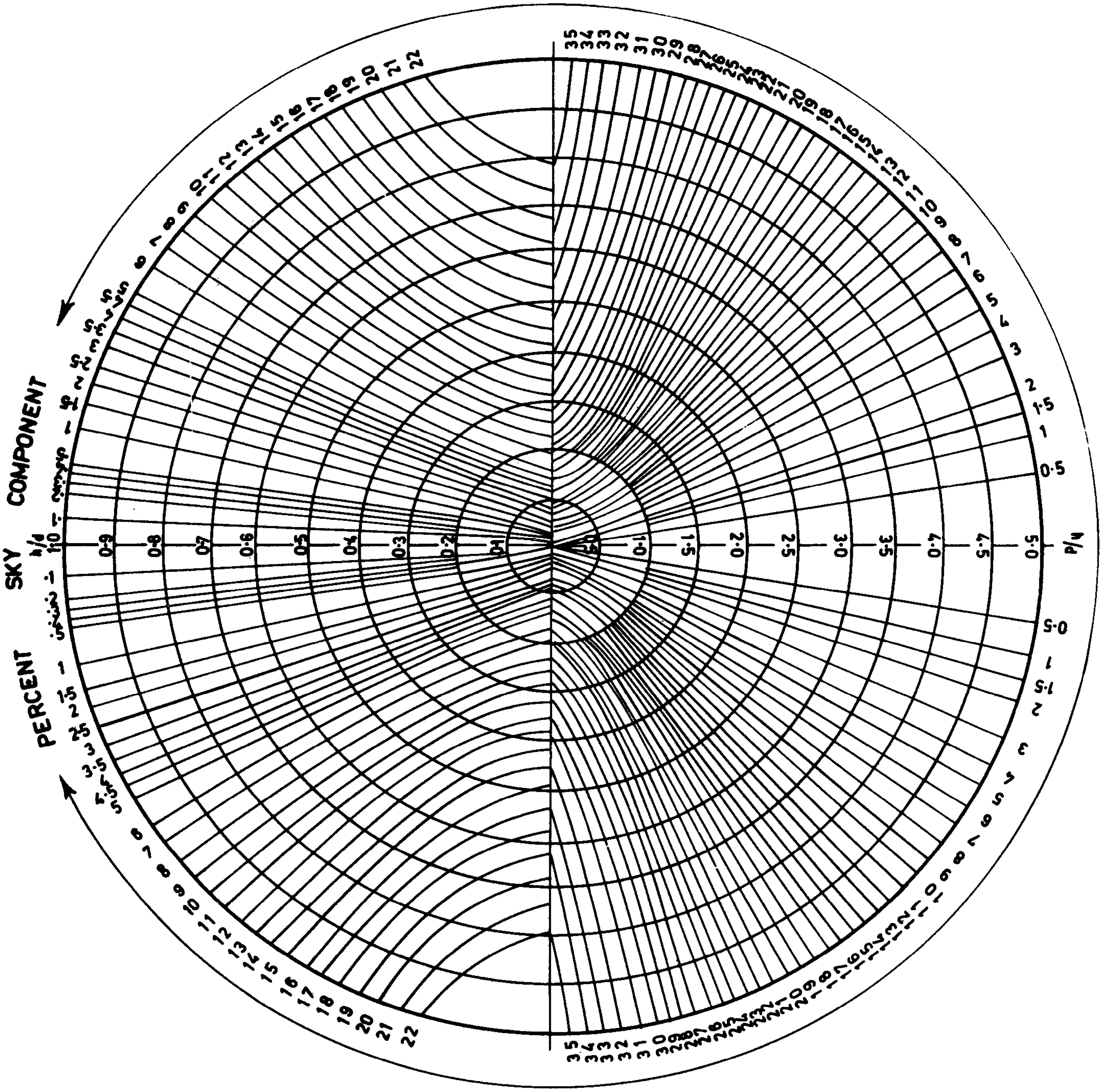

FIG. 18 SKY COMPONENT PROTRACTOR FOR A VERTICAL PLANE NORMAL TO WINDOW PLANE

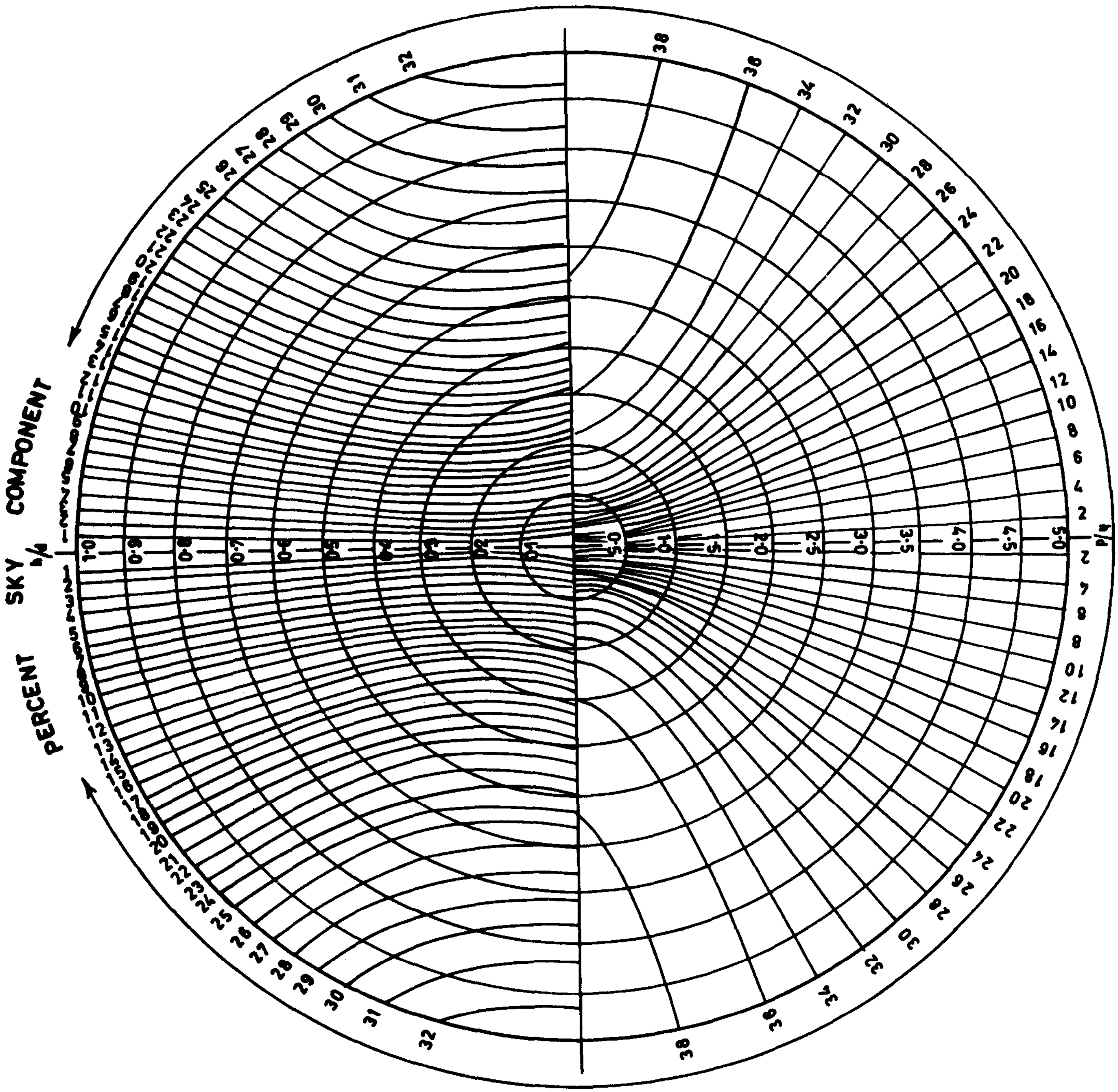

FIG. 19 SKY COMPONENT PROTRACTOR FOR A VERTICAL PLANE PARALLEL TO WINDOW PLANE

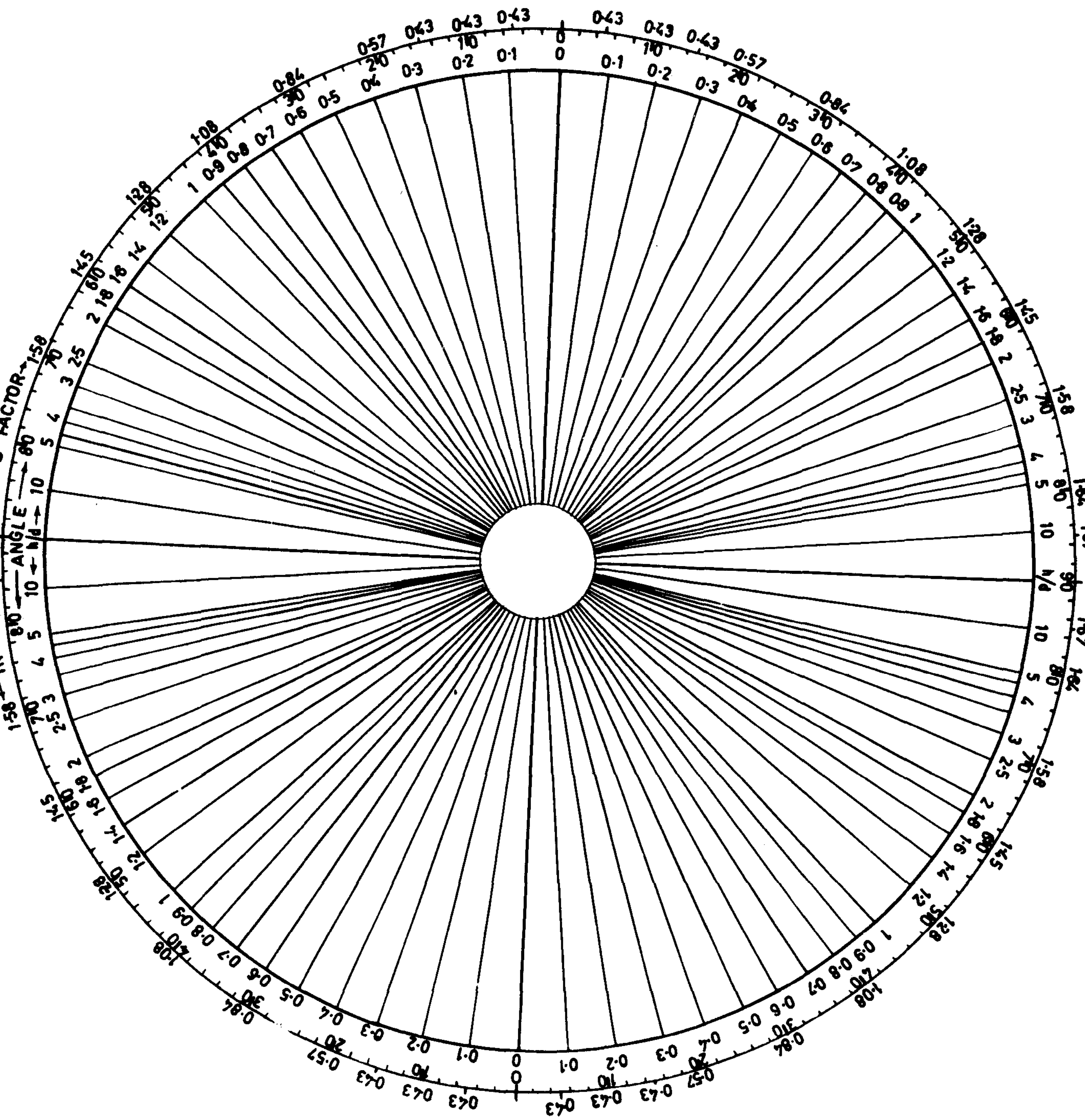

FIG. 20 AUXILIARY PROTRACTOR FOR DETERMINATION OF HEIGHT TO DISTANCE RATIO

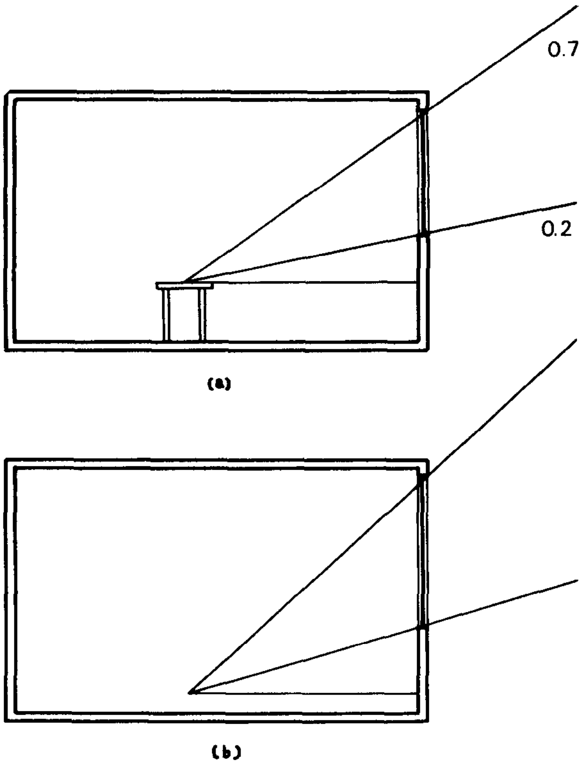

FIG. 21 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN OF A ROOM FOR A WINDOW WITHOUT LOUVRES (EXAMPLE 14)

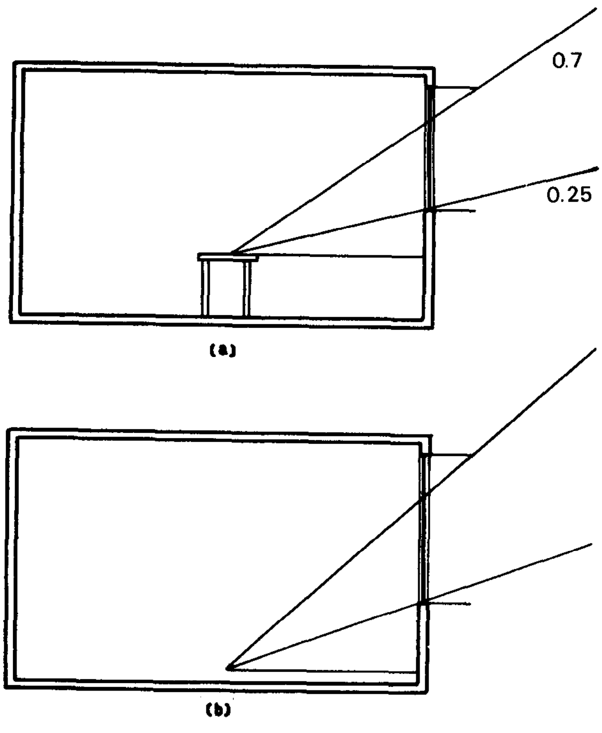

FIG. 22 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN OF A ROOM FOR A WINDOW WITH LOUVRES (EXAMPLE 15)

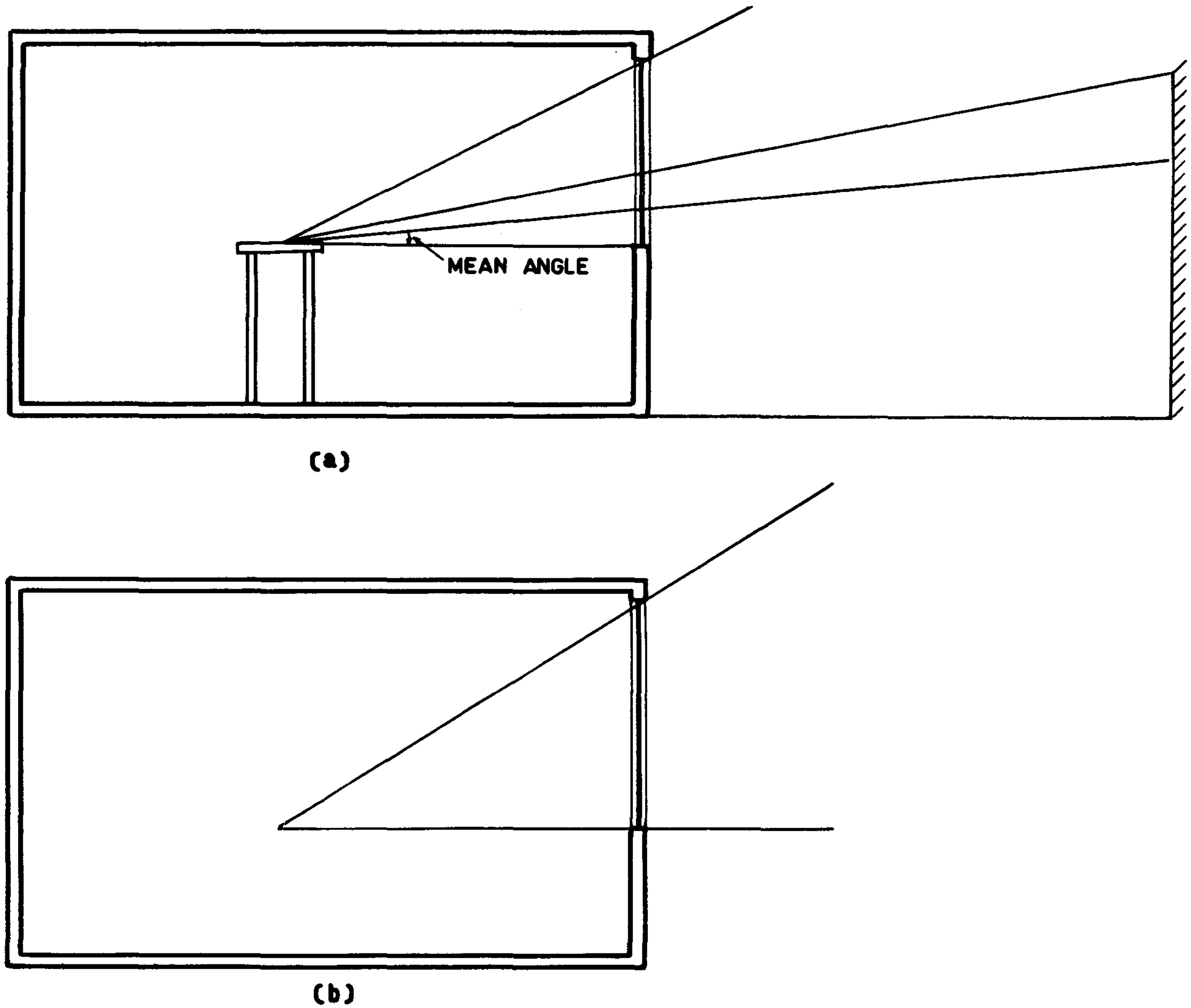

FIG. 23 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN IN PRESENCE OF EXTERNAL OBSTRUCTION (EXAMPLE 16)

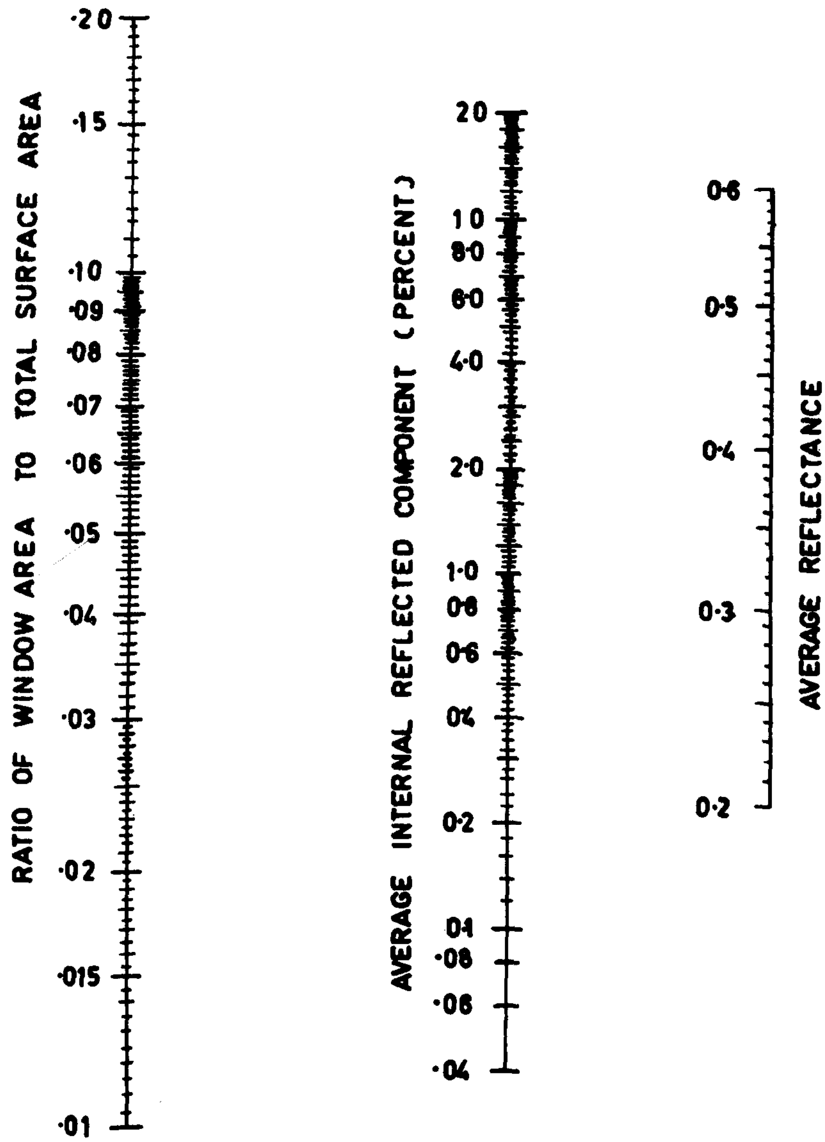

FIG. 24 NOMOGRAM FOR AVERAGE INTERNAL REFLECTED COMPONENT

Example 17

Determine the direct component on vertical planes: (a) perpendicular and (b) parallel to the window wall in Example 16.

Solution

i) h/d values for the upper and lower lines of sight on the section are 0.5 and 0.2 respectively: Using protractor 2 on the plan, note the sky components at the intersections of circles of $h/d = 0.5$ and 0.2 with the farther line of sight. These values are 3.8 and 2.0 respectively. Therefore, the direct component on a vertical plane perpendicular to the window wall, one finds:

$$\begin{aligned} SC &= (3.8 - 0.0) - (2.0 - 0.0) \\ &= 3.8 - 2.0 = 1.8 \text{ percent} \end{aligned}$$

$$\begin{aligned} ERC &= 2.0 \times 0.43 \times 1.0 \\ &= 0.86 \text{ percent} \end{aligned}$$

Direct component = 2.66 percent

Allowing for usual reduction factors, the expected direct component = 2.66 × 0.6 = 1.60 percent.

ii) Using protractor 3 on the plan, the values at the intersection of circles of $h/d = 0.5$ and 0.2 with the farther line of sight are 14.5 and 7.0 respectively. Therefore, for the direct component on a vertical plane parallel to the window wall, one finds:

$$\begin{aligned} SC &= (14.5 - 0.0) - (7.0 - 0.0) \\ &= 14.5 - 7.0 = 7.5 \text{ percent} \end{aligned}$$

$$\begin{aligned} ERC &= 7.0 \times 0.43 \times 1.0 \\ &= 3.0 \text{ percent} \end{aligned}$$

Net direct component = 10.5 percent

Allowing for usual reduction factors, the expected direct component = 10.5 × 0.6 = 6.3 percent.

4.5 Nomogram for Indirect Component of Daylight Factor — A nomogram for the average internal reflected component (IRC), based on equation (13) (which has been adopted in IS : 2440-1975), is given in Fig. 24, for any room with white ceiling and grey floor. For using this nomogram, the average reflectance of room surfaces and the ratio of window area to the total surface area of the room are required. These values are located on the respective scales and the line joining them gives the value of average internal reflected component on the middle scale.

Allowance should be made for the reduction factors due to louvers, dust and glass area to gross window area ratio. Since the glass transmittance and window factor in equation (13) are 0.85 and 88 percent (= 7 000 lux window plane illuminance) respectively, the IRC value obtained from the nomogram will have to be modified if the glass transmittance and the window plan illuminance are different from the above values. The corresponding multiplying factors respectively are glass transmittance/0.85 and window plane illuminance in lux/7 000 or window factor percent/88.

Example 18

Determine the average internal reflected component in a 5 m × 3 m × 3 m room due to a 2 m × 1 m window, when the reflectance of ceiling, walls, floor and glass are 0.7, 0.5, 0.3 and 0.15 respectively.

Solution

Window area, $W = 2 \times 1 = 2\text{m}^2$

Total surface area (ceiling, walls, floor and windows),

$A = 2\,(5 \times 3 + 5 \times 3 + 3 \times 3) = 78 \text{ m}^2$

$$\frac{W}{A} = \frac{2}{78} = 0.0256$$

Average surface reflectance, R = Average reflection factor of all surfaces in the room (ceiling, floor, walls and window)

$$R = \frac{15 \times 0.7 + 15 \times 0.3 + (48 - 2) \times 0.5 + 2 \times 0.15}{78}$$

$= 0.491$

Joining the points for:

$\frac{W}{A} = 0.025\,6$ and $R = 0.491$ on respective scales of the nomogram and reading on the middle scale,

Average IRC = 1.56 percent.

Allowing for usual reduction factors due to louvres, dust and glass area to gross window area ratio,

Average IRC = 1.56 × 0.6 = 0.94 percent.

4.6 Lux Grid for Side Windows

4.6.1 Lux grid is a perspective of window wall comprising a grid of square elements in which the contribution of each element to daylight on a horizontal workplane is marked as dots, crosses and stars. A dot, a cross and a star represents 0.5, 1 and 2 lux respectively (irrespective of the fact whether inside the circle or outside the circle). The dimension of square elements is one-tenth of the distance of the given point from the window wall at which the illuminance is required. The base line *WPW* of the grid represents the level of the workplane and the centre of *P* of the base line is the projection of the given point on to the window wall. Any window can be outlined to the scale on the grid with respect to the position of the given point. The summation of contributions of each element within the window outline gives the expected daylight at the given indoor point on a horizontal workplane. Since the contribution of any part of window openings below the workplane is insignificant to the workplane illuminance, only the window openings above the base line of the lux grid need be outlined.

4.6.2 The lux grid method enables the estimation of daylight due to given windows as well as the design of windows for any desired illuminance on the workplane. Lux grid I (*see* Fig. 25) is provided for unobstructed windows and Lux grid II (*see* Fig. 26) for windows facing external obstructions.

4.6.3 The values within the circles on Lux grid II corresponds to the obstructed parts of windows whereas the values outside the circles are for unobstructed parts. The reduction of daylight due to glass transmittance, maintenance, louvres and actual glass area to gross window area ratio has been accounted for in the Lux grids I and II.

4.6.4 Tables 18 and 19 give the correction factors for Lux grids I and II respectively for three sets of interior finish depending upon the floor area and the distance of the point from the window. The value obtained by the summation of dots, crosses and stars is algebraically added to the product of correction factor and the number of square elements within the window outline. Three sets of interior finish have been considered. These are:

a) Finish A—ceiling white, walls off white and floor grey;

b) Finish B—ceiling off white, walls off white and floor grey; and

c) Finish C—ceiling off white, walls dark coloured and floor grey.

Where the reflectances for white, off white, dark colours and dull grey range between 0.7-0.8, 0.45-0.55, 0.25-0.30 and 0.30 respectively. The finish of external obstruction is assumed to be between 0.4-0.6 and the ceiling height is assumed to be 2.75-3.05 m. Lux grid I is used when there is no obstruction in front of a window or when the distance (S) of the obstruction from the window is greater than three times its height (H) above the window centre. Lux grid II is used for obstructions at a distance between 0.5 H and 1.5 H ($0.5\ H < S \leqslant 1.5\ H$); the constribution of the obstructed part is given by the values within the circles and that due to unobstructed part of a window outline by the values outside the circles. For obstructions at a distance $S \leqslant 0.5\ H$, the contribution of the obstructed part is 0.5 times the value in the circles. Both the lux grids are used if the obstructions are at a distance between 1.5 H and 3 H (that is, $1.5\ H < S \leqslant 3\ H$). The contribution of the unobstructed portion of the window in this case is the mean of the values obtained from Lux grids I and II, and the contribution of the obstructed portion is 1.8 times the circle values on the Lux grid II.

Example 19

A room of size 6.0 × 4.8 × 3.0 m has a window of size 2.4 × 1.2 m, at a sill level of 0.6 m above the workplane such that the vertical edges of the windows are at distances of 1.8 and 0.6 m from the corresponding side walls. Determine the daylight on the workplane at a point 6.0 m from the window wall and displaced by 0.6 m from one of the vertical edges of the window for: (a) Finish A and (b) Finish B. There is no obstruction in front of the window.

Solution

Since the distance of the given point is 6.0 m from the window wall, the side of squares on the grid is 0.6 m. As there is no obstruction, Lux grid I is to be used. The workplane level is at the base line *WPW* and the point *P* is the projection of the given point. Since the sill level is 0.6 m above the workplane and one of the vertical edges of the window is 0.6 m away from the projection of the point, the window outline (*see* Fig. 27) will be one square element above the base line and one square element away from the *YP* line. The window outline contains 4 × 2 square elements on the lux grid, that is, 8 square elements in all. Counting the number of dots and stars within the outline of the window and converting to lux values, we have,

48 dots = 24 lux

32 stars = 64 lux

Total = 88 lux

a) Note from Table 18, the correction factor for $d = 6.0$ m and floor area 25-50 m^2, actual floor area being $6.0 \times 4.8 = 28.8$ m^2, for Finish A. The correction factor is zero. Therefore, the illuminance at the given point is 88 lux.

b) From Table 18, for $d = 6.0$ m, floor area 15-50 m^2 and Finish B, the correction factor is (−1.9). Therefore, the actual correction $= 8 \times (-1.9) = -15.2$ lux; here 8 is the number of squares contained within the window outline. Therefore, the illuminance at the given point is $88.0 - 15.2 = 72.8$ lux.

Example 20

In Example 19, determine the daylight at the given point when there is an obstruction upto 5 m above the workplane (that is, 3.8 m above the window centre) due to a parallel row of houses at a distance of 4 m from the window.

Solution

$S/H = 4/3.8 = 1.05$, Lux grid II will be used directly for this problem. The window is first outlined (*see* Fig. 28) on Lux grid II as in Example 19. The distance of opposite buildings from the indoor point is 10 m. Therefore, for projecting the opposite facades on the grid, the dimension of a square element will be $(1/10) \times 10 = 1$ m.

Since the height of the obstruction is 5 m above the workplane, its projection on the grid will shade 5 rows of squares above the base line *WPW*. This projection will shade the entire window on the lux grid. Therefore, the dots and crosses in the circles within the window outline have to be counted.

8 dots = 4 lux

24 crosses = 24 lux

Total = 28 lux

a) From Table 19, for Finish A, floor area 25-50 m^2 and $d = 6.0$ m, the correction factor is zero. Therefore, the daylight at the given point will be 28 lux.

b) For Finish B, floor area 25-50 m^2 and $d = 6.0$ m, the correction factor is (−0.8). The actual correction = 8 × (−0.8) = − 6.4 lux, where 8 is the number of square elements within the window outline. Therefore, the daylight at the given point is 28.0 − 6.4 = 21.6 lux.

Example 21

In Example 19, design a window for providing 150 lux at the given point for Finish A, assuming the window height as 1.2 m and sill level at 0.6 m above the workplane.

Solution

A window of height 1.2 m may be sketched over the entire wall of length 4.8 m on Lux grid I, that is, a window of size 4.8 m × 1.2 m (*see* Fig. 29). Counting the number of dots and stars within the window outline and coverting to lux values, we obtain:

92 dots = 46 lux

64 stars = 128 lux

Total = 174 lux

This exceeds the required value by 24 lux. So either the central part of the ends of the window can be filled by masonry. Assuming that 0.3 m on either side of the window be filled up by masonry, the dots and stars that would be covered are:

10 dots = 5 lux

8 stars = 16 lux

Total = 21 lux

Therefore, this solution gives a window size of 4.2 m × 1.2 m and the daylight will be 174-21 = 153 lux which is approximately the required illuminance. Alternatively, if two windows are provided with a central pillar of 0.6 m in between, the dots and stars that would be covered are:

12 dots = 6 lux

8 stars = 16 lux

Total = 22 lux

Therefore, according to this solution, two windows each of size 2.1 m × 1.2 m are to be provided and the daylight at the given point will be 174 − 22 = 152 lux. Similarly, for any other window height and sill height, a single window or multiple windows can be arrived at to give the required illuminance at the given point.

5. SUPPLEMENTARY ARTIFICIAL LIGHTING DESIGN

5.1 Supplementary lighting may be required either for the execution of a critical task in a small area or for boosting up the illuminance and surround luminance of and around large work areas. The calculation for the former to achieve a desired illuminance of the task can be carried out by point-by-point method. The latter, however, requires matching of brightness due to supplementary lights and daylight.

The need for general supplementary artificial lighting arises due to:

a) diminution of daylight beyond design hours (that is, for solar altitudes below 15°) for clear skies;

b) dark cloudy conditions (occurring occassionally);

c) unavoidable obstructions to incoming daylight;

d) provision of very deep rooms; and

e) improper design of windows.

For good distribution and integration of daylight and artificial lights, the following guidelines are recommended:

a) Employ cool daylight fluorescent tubes for supplementary artificial lighting,

b) Distribute luminaires with a separation of 2 to 3 m in each bay of 3-4 m width,

c) Provide more supplementary lights such as twin tube luminaires in the rear part of the room whereas single tube luminaires may be suitable near the windows, and

d) Provide windows of height 1.2 m or more in each bay at a sill height of 1.0 to 1.2 m.

It is well known that higher levels of prevailing brightness (that is, at higher brightness adaptation), the requirement of supplementary lighting increases with the increase of prevailing brightness. The role of supplementary lighting under such conditions is primarily to refine the lighting quality. But the improvement of lighting quality at high levels of prevailing brightness is costly. The latest findings indicate that the need for supplementary lighting during daytime is critical when the daylight on the workplane falls below 100 lux and and the surround luminance drops below 20 Cd/m^2. The visual conditions have been found to be satisfactory when the surround luminance is raised to 20 Cd/m^2 and the workplane illuminance to the range 100-150 lux.

The requirement of supplementary artificial lighting below the critical daylight level mentioned above increases with the decrease in daylight availability. Therefore, the condition

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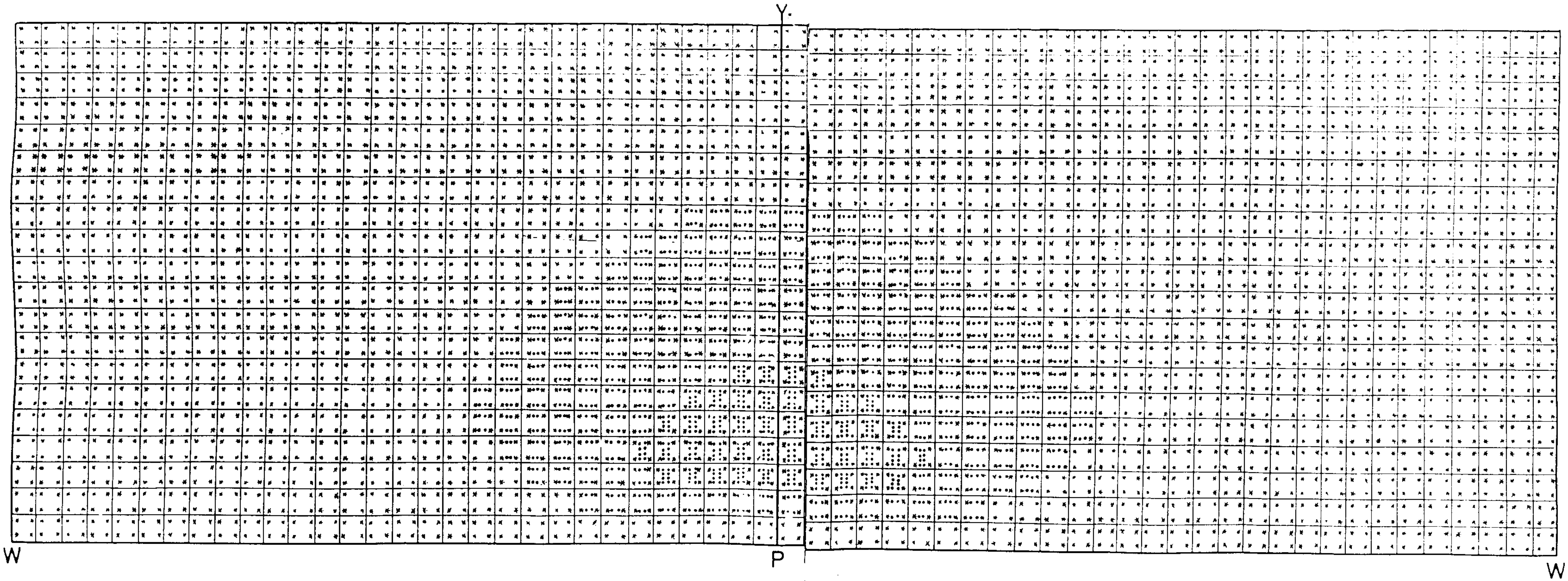

Fig. 28 Lux Grid for Daylighting Design of Side[illegible] Windows in Absence of External Obstructions

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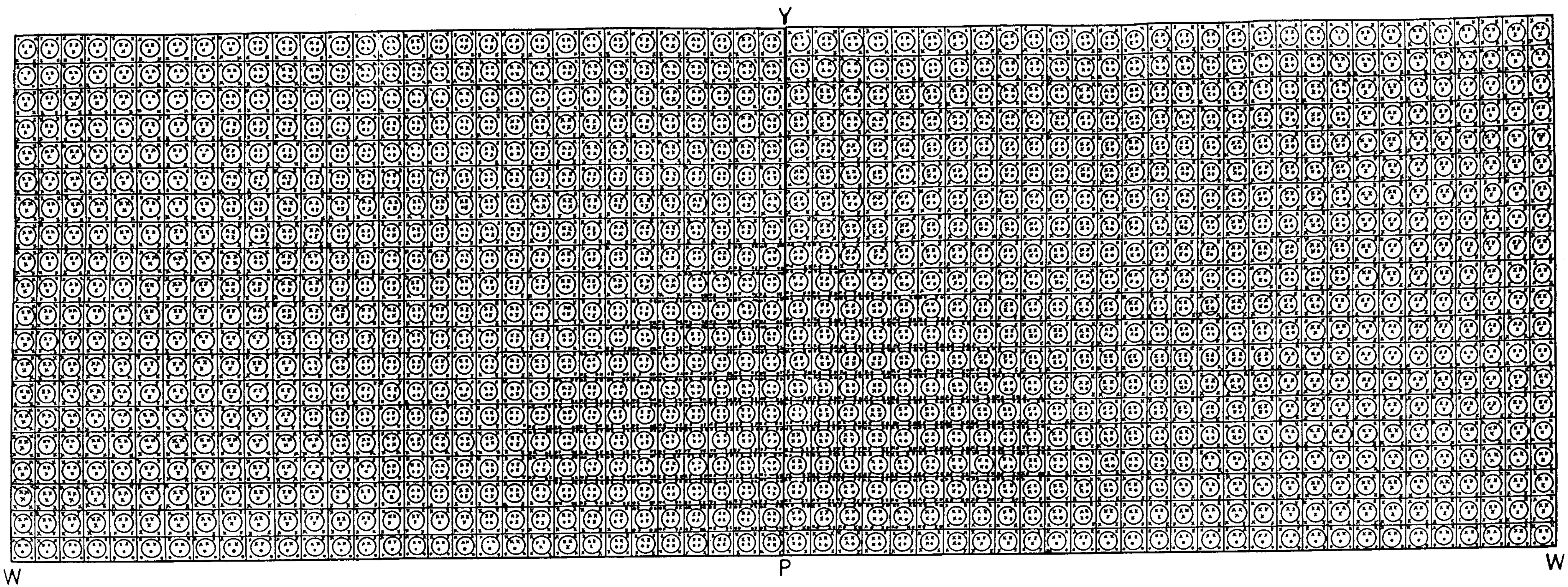


Fig. 26 Lux Grid II for Daylighting Design of Windows in Presence of External Obstruction

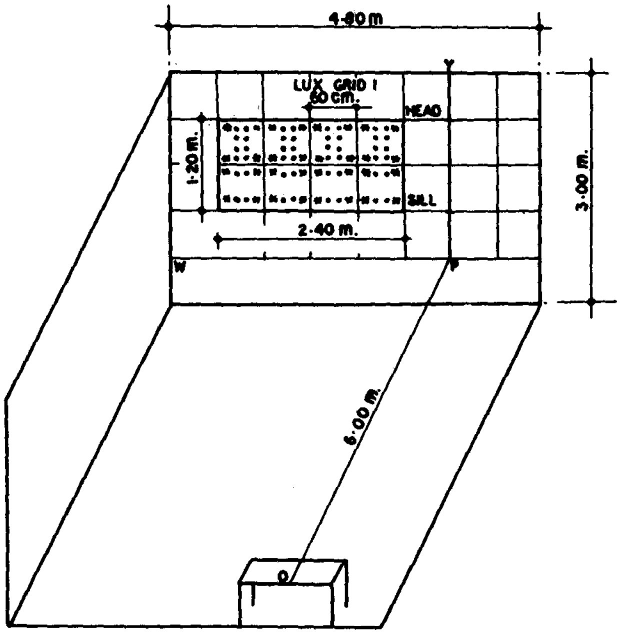


FIG. 27 ILLUSTRATION DEPICTING USE OF LUX GRID I FOR DETERMINATION OF DAYLIGHT ON THE WORKPLANE (EXAMPLE 19)

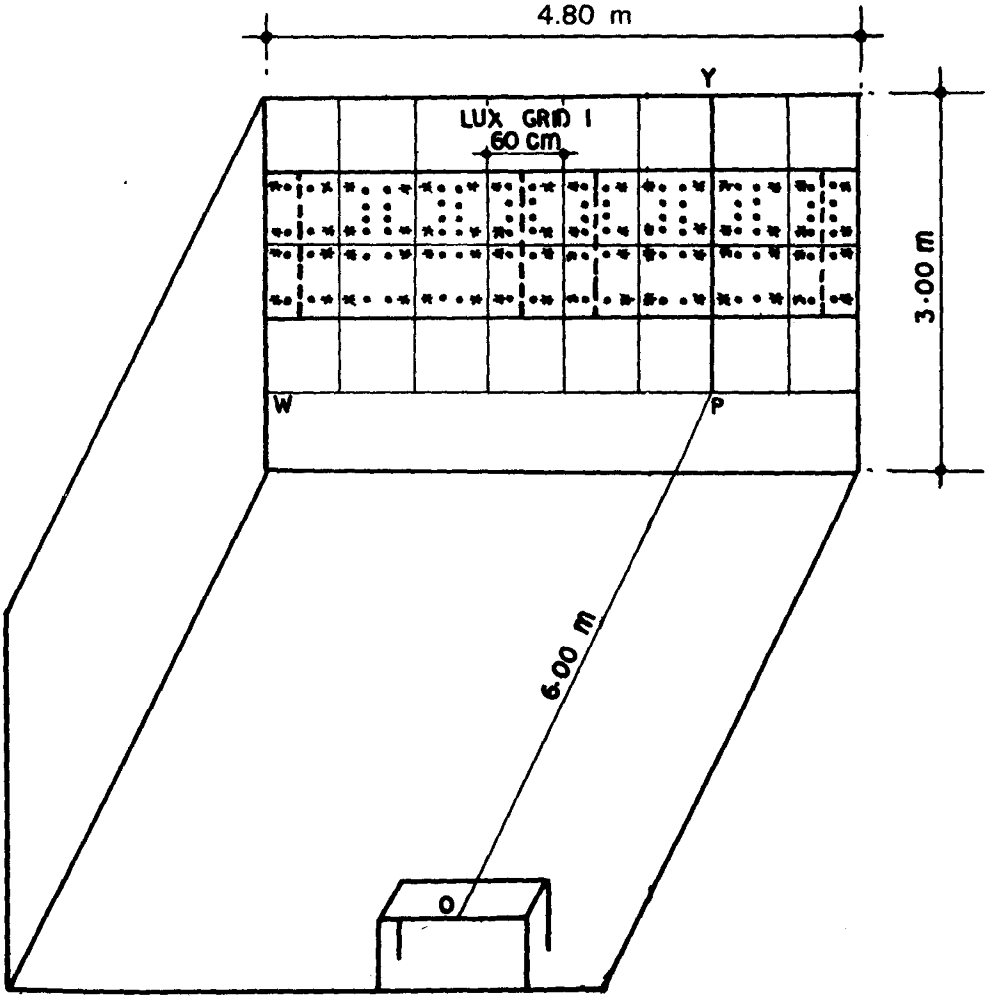


FIG. 28 ILLUSTRATION DEPICTING USE OF LUX GRADE II FOR DETERMINATION OF DAYLIGHT ON THE WORKING PLANE (EXAMPLE 20)

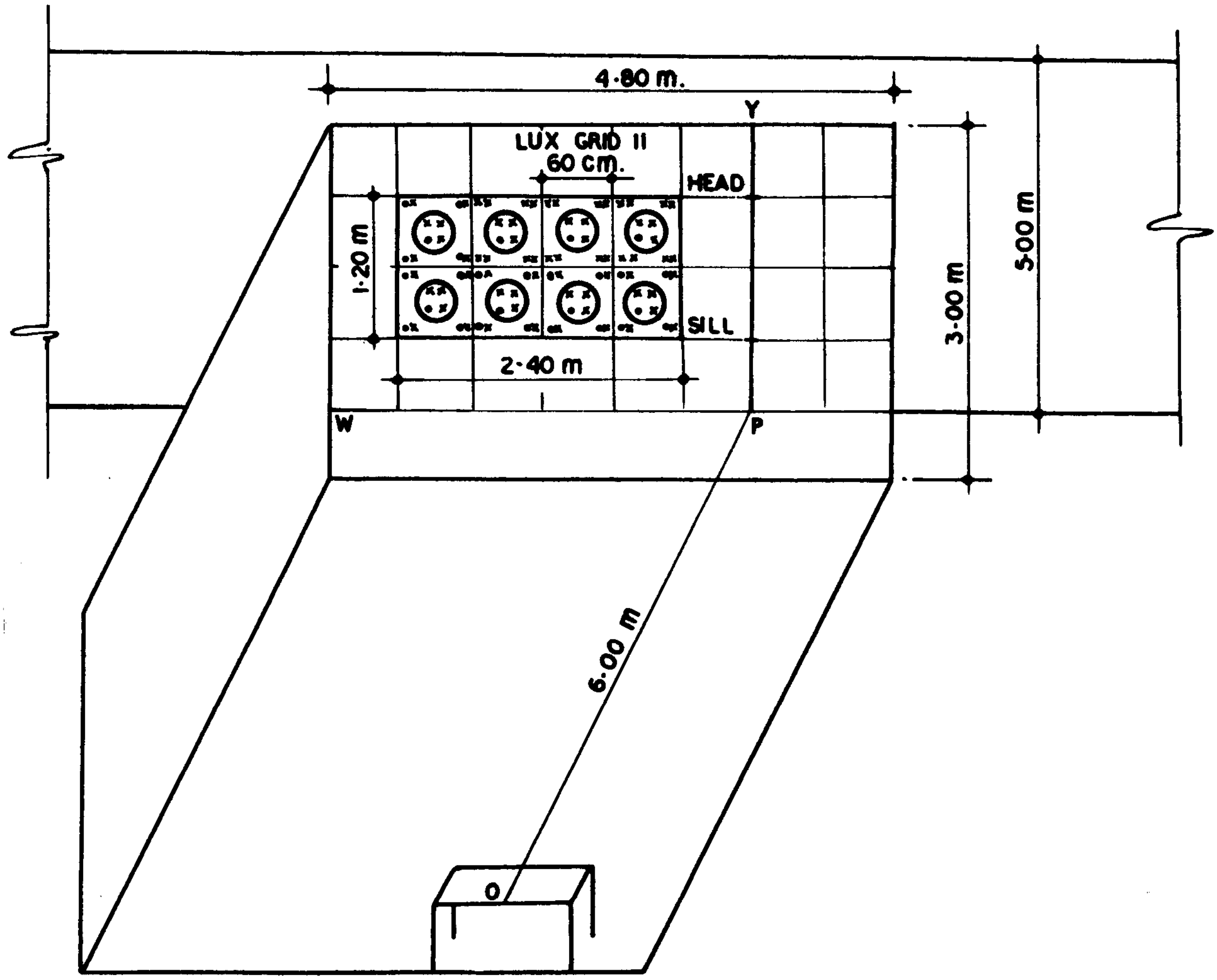


FIG. 29 ILLUSTRATION DEPICTING USE OF LUX GRID I FOR DAYLIGHTING DEsign of WINDOWS (EXAMPLE 21)

TABLE 18 CORRECTION FACTORS PER SQUARE ELEMENT OF LUX GRID I FOR INTERIOR FINISH A, B AND C

(*Clause* 4.6.4)

d	*a*	Floor Area m²								
		10-25			25-50			50-100		
		Finish			Finish			Finish		
cm	cm	A	B	C	A	B	C	A	B	C
900	90	+26.6	+18.0	+9.5	+9.5	+5.2	+1.0	+1.0	−1.2	−3.3
840	84	+22.2	+14.7	+7.3	+7.3	+3.6	0	0	−2.0	−3.9
780	78	+18.0	+11.7	+5.2	+5.2	+2.0	−1.2	−1.2	−2.8	−4.4
720	72	+14.3	+ 8.8	+3.3	+3.3	0	−2.1	−2.1	−3.5	−4.9
660	66	+10.8	+ 6.2	+1.6	+1.6	−0.7	−3.0	−3.0	−4.2	−5.3
600	60	+ 7.6	+ 3.8	0	0	−1.9	−3.8	−3.8	−4.8	−5.7
540	54	+ 4.7	+ 1.6	−1.4	−1.4	−3.0	−4.5	−4.5	−5.3	−6.1
480	48	+ 2.1	0	−2.7	−2.7	−4.0	−5.2	−5.2	−5.8	−6.4
420	42	0	− 2.0	−3.9	−3.9	−4.8	−5.7	−5.7	−6.2	−6.7
360	36	− 2.1	− 3.5	−4.9	−4.9	−5.5	−6.2	−6.2	−6.6	−6.9
300	30	− 3.8	− 4.8	−5.7	−5.7	−6.2	−6.7	−6.7	−6.9	−7.1
240	24	− 5.2	− 5.8	−6.4	−6.4	−6.7	−7.0	−7.0	−7.1	−7.3
180	18	− 6.2	− 6.6	−6.9	−7.1	−7.3	−7.3	−7.3	−7.3	−7.4
120	12	− 7.0	− 7.1	−7.3	−7.3	−7.4	−7.4	−7.4	−7.5	−7.5

a = side of one square in the gride.
d = distance of point from the window.

TABLE 19 CORRECTION FACTORS PER SQUARE ELEMENT OF LUX GRID II FOR INTERIOR FINISH A, B AND C

(*Clause* 4.6.4)

d	*a*	Floor Area m²								
		10-25			25-50			50-100		
		Finish			Finish			Finish		
cm	cm	A	B	C	A	B	C	A	B	C
900	90	+10.6	+7.2	+3.8	+3.8	+2.1	+0.4	+0.4	−0.5	−1.3
840	84	+ 8.9	+5.9	+2.9	+2.9	+1.4	0	0	−0.8	−1.6
780	78	+ 7.2	+4.7	+2.1	+2.1	+0.8	−0.5	−0.5	−1.1	−1.8
720	72	+ 5.7	+3.5	+1.3	+1.3	0	−0.9	−0.9	−1.4	−1.9
660	66	+ 4.3	+2.5	+0.6	+0.6	−0.3	−1.2	−1.2	−1.7	−2.1
600	60	+ 3.0	+1.5	0	0	−0.8	−1.5	−1.5	−1.9	−2.3
540	54	+ 1.9	+0.7	−0.6	−0.6	−1.2	−1.8	−1.8	−2.1	−2.4
480	48	+ 0.9	0	−1.1	−1.1	−1.6	−2.1	−2.1	−2.3	−2.6
420	42	0	−0.8	−1.6	−1.6	−1.9	−2.3	−2.3	−2.5	−2.7
360	36	− 0.9	−1.4	−1.9	−1.9	−2.2	−2.5	−2.5	−2.6	−2.8
300	30	− 1.5	−1.9	−2.3	−2.3	−2.5	−2.7	−2.7	−2.8	−2.9
240	24	− 2.1	−2.3	−2.6	−2.6	−2.7	−2.8	−2.8	−2.9	−2.9
180	18	− 2.5	−2.6	−2.8	−2.8	−2.8	−2.9	−2.9	−2.9	−3.0
120	12	− 2.8	−2.9	−2.9	−2.9	−2.9	−3.0	−3.0	−3.0	−3.0

a = side of one square in the gride.
d = distance of point from the window.

near sunset or sunrise or equivalent condition due to clouds or obstructions, etc, represents the worst condition, when the supplementary lighting is most needed. The most suitable conditions corresponds to a solar altitude of 5° below which the dominance of daylight is lost. The window factor for the solar altitude is one-tenth of the value for the clear design sky or the window plane illuminance is 800 lux; the window plane illuminance for the clear design sky being 8 000 lux. The brightness factors for converting the sky components corresponding to the clear design to those corresponding to a solar altitude of 5° are also of the order of 1/10. It is, therefore, possible to estimate the indirect and direct illuminance due to daylight around sunset or sunrise. The amount of supplementary artificial lighting can be estimated from the criterion that, under the conditions stated above, the indirect illuminance due to daylight and supplementary lights is 60 lux. The location of supplementary lights is determined from the criterion that the total workplane illuminance over principal work areas is within the range 100-150 lux. The point-by-point method is used for this purpose.

5.2 Design Graph Method — Day time supplementary artificial lighting for reading/writing purposes such as in offices and educational buildings can be worked out from design graph given in Fig. 30.

Example 22

A room of size 5 m × 3 m × 3 m has a window 1.5 m × 1.0 m. Determine the number of 40 watt fluorescent tubes for supplementing daylight when the reflectance of ceiling, walls and floor are 0.7, 0.5 and 0.3 respectively.

Solution

Floor area = 5 × 3 = 15 m^2

Percent fenestration of floor area

$$= \frac{1.5 \times 1.0 \times 100}{5 \times 3}$$

$$= 10 \text{ percent}$$

Referring to the broken curve for 10 percent fenestration in Fig. 30, read on the ordinate corresponding to 15 m^2 floor area on the abscissa. The required number of 40 watt fluorescent tubes is found to be approximately two. Therefore a twin lamp luminaire will be appropriate. This should be mounted in the rear region of the room so as to provide good illuminance over the principal work area.

Example 23

Determine the number of 40 watt fluorescent tubes for supplementing daylight in a large hall of size 15 m × 10 m × 3 m provided with five windows each of size 1.5 m × 1.0 m evenly distributed on the longer walls. The finish of ceiling, walls and floor are 0.7, 0.5 and 0.3 respectively.

Solution

Floor area = 15 × 10 = 150 m^2

Percent fenestration of floor area

$$= \frac{5 \times 1.5 \times 1.0}{15 \times 10} \times 100$$

$$= 5 \text{ percent}$$

Referring to broken curve for 5 percent fenestration in Fig. 30, read on the ordinate corresponding to 150 m^2 floor area on the abscissa. The number of 40 watt fluorescent tubes required is 13. Since the hall has five bays, this number should be adjusted to 15 for uniform distribution of lamps over all the bays. Therefore, a combination of a twin lamp luminaire and a single lamp luminaire will be appropriate for each bay. Since the daylight diminishes as the distance from the windows increases, a twin lamp luminaire will be required in the rear half of a bay and a single lamp luminaire in the centre of a bay.

The mounting height and actual location of luminaires can be integrated with night time lighting requirement. If there is no provision for elaborate night lighting, the location of luminaries can be adjusted according to principal work areas.

5.3 Nomograph Method — A nomograph has been provided here for obtaining wattage of fluorescent tube lights as watt per m^2 of the floor area to satisfy task illumination for different separation to height ratios of nearby external obstructions such as opposite buildings (*see* Fig. 31).

5.3.1 The nomograph consists of horizontal lines indicating fenestration percentage of floor area and vertical lines indicating the separation to height ratio of external obstructions such as opposite buildings. Any vertical line for separation to height ratio other than already shown in the nomograph (1.0, 2.0 and 3.0) can be drawn by designer, if required. For cases where there is no obstruction, the ordinate corresponding to the value 3.0 may be used. The value of percentage fenestration and separation to height ratio are marked on left hand ordinate and abscissa respectively. The illumination levels are marked on the right hand ordinate and the wattage of fluorescent tubes required per square metre of the floor area for different illumination levels is shown on each curve.

5.3.2 Following assumptions have been made in the construction of the nomograph:

a) An average interior finish with ceiling white, walls off white and floor grey has been assumed,

b) Ceiling height of 3 m and room depths up to

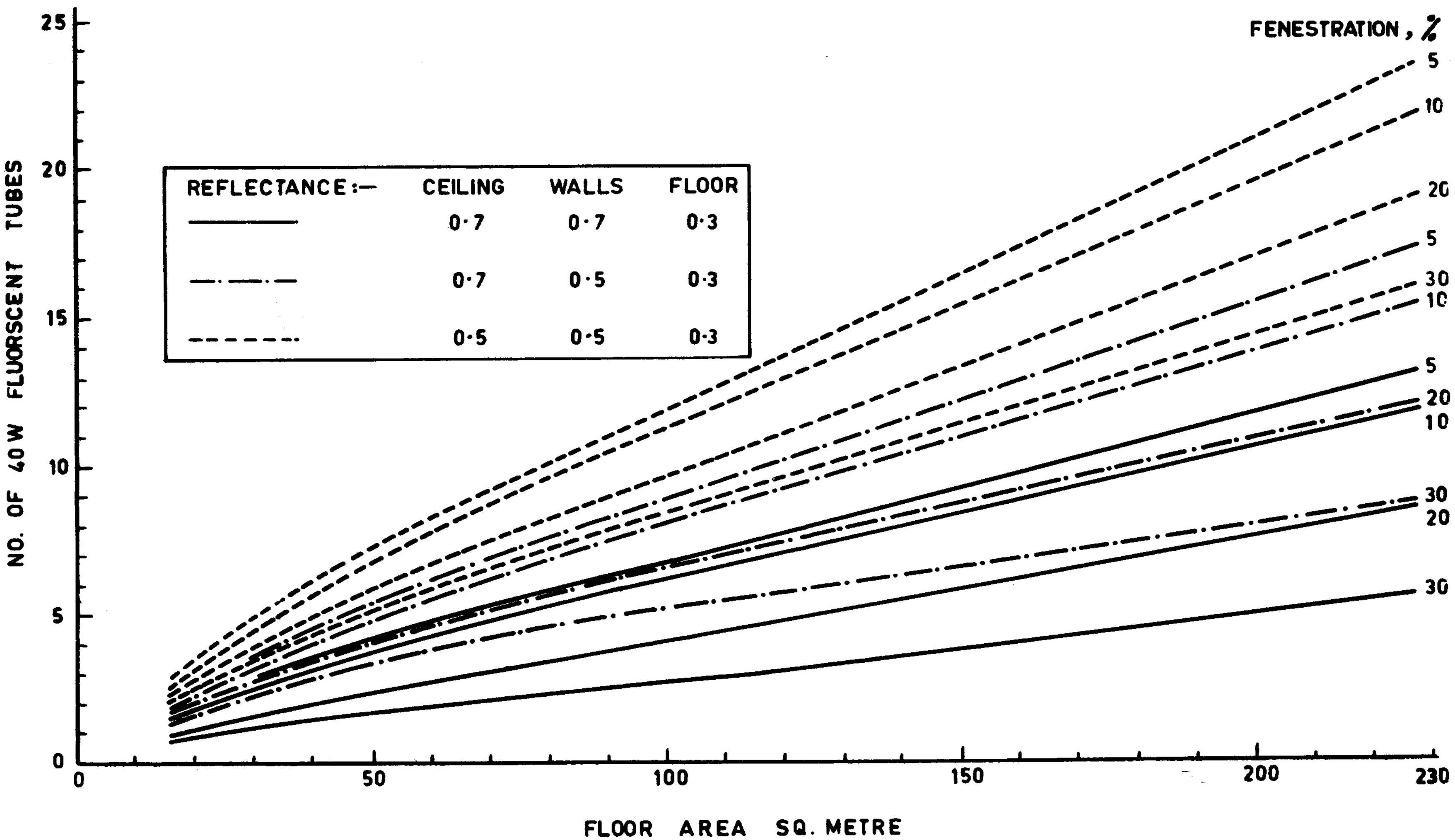


FIG. 30 DESIGN CURVES FOR DAYTIME SUPPLEMENTARY ARTIFICIAL LIGHTING FOR DIFFERENT ROOM SIZES AND WINDOW SIZES

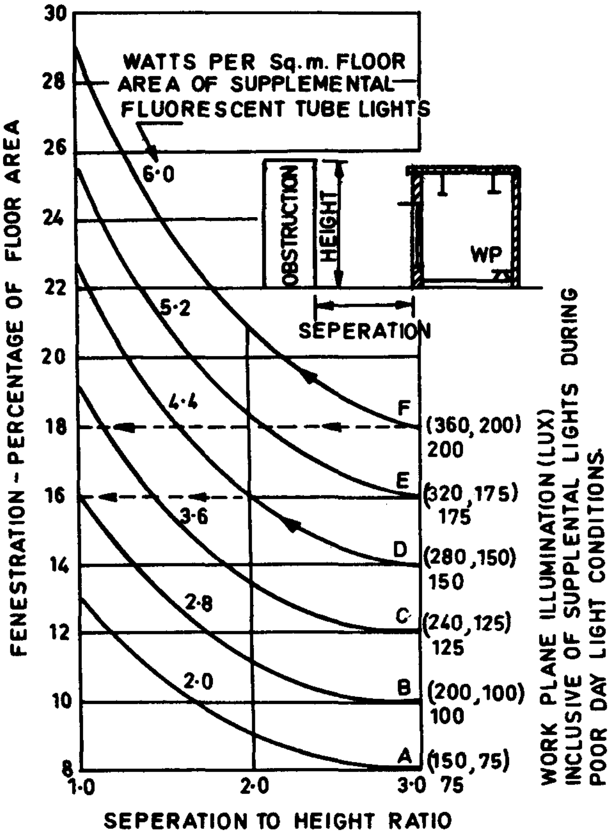


FIG. 31 NOMOGRAPH FOR DAYTIME SUPPLEMENTARY LIGHTING DESIGN

10 m and floor area between 30-50 m² have been assumed. For floor area beyond 50 m² and less than 30 m², the values of percent fenestration as well as wattage per m² should be modified by a factor of 0.85 and 1.15 respectively,

c) It is assumed that windows are of metallic sashes with louvers of width up to 60 cm. For wooden sashes, the window area should be increased by a factor of about 1.1, and

d) Luminaires emanating more light in the downward direction than upward direction (such as reflectors with or without diffusing plastics) and mounted at a height of 1.5 to 2.0 m above the workplane have been considered.

5.3.3 *Method of Use*

Step 1 — Decide the desired illumination level depending upon the task illumination requirement in the proposed room and read the value of watts per m² on the curve corresponding to the required illumination level.

Step 2 — Fix the vertical line corresponding to the given separation to height ratio of opposite buildings on the abscissa. From the point of intersection of this vertical line and the above curve move along horizontal, and read the value of fenestration percent on the left hand ordinate.

Step 3 — If the floor area is greater than 50 m² and less than 30 m², the value of watts per m² as well as fenestration percent obtained from steps (1) and (2) should be multiplied by a factor of 0.85 and 1.15 respectively.

5.3.3.1 Following the steps (1), (2) and (3), the required watts per m² of floor area and fenestration percent can be easily determined for adequate daylighting and supplemental artificial lighting for design purposes. However, if the fenestration provided is less than the required value, the wattage of supplementary artificial lights should be increased proportionately to make up for the deficiency of natural illumination.

Example 24

Determine the requirement of supplementary artificial lights and fenestration percentage for a large five bay drawing office of size 15 m × 10 m for separation to height ratio of external obstruction as more than 3.0.

Solution

Step 1 — For the required illumination (task illumination *F*), the top curve gives watts per m² as 6.0.

Step 2 — The vertical line corresponding to separation to height ratio of 3.0 or more is the right hand ordinate. The particular curve giving watt per m^2 is the one starting from the task illumination, F on this ordinate. Moving along the horizontal from the intersection of this curve and the ordinate at F, the percentage fenestration on the left hand ordinate is read as 18 percent. Since the floor area is $15 \times 10 = 150$ m^2, that is, more than 50 m^2, the required fenestration percentage is $18 \times 0.85 = 15$ percent. The required watt per m^2 will be $6.0 \times 0.85 = 5.1$ watt/m^2.

Total wattage = $5.1 \times 150 = 765$ watts
Wattage per day = $765/5 = 153$ watts.
No. of 40 watt tube lights per bay = $153/40 = 4$

Therefore, two single tube liminaires and a twin lamp luminaire may be evenly distributed along room depth with twin lamp luminaire in the rear part of each bay.

Example 25

Determine the requirement of supplementary artificial lights and fenestration percentage for providing 150 lux in office rooms of size 5 m × 3 m when the separation to height ratio of opposite building obstruction is 2.0.

Solution

Step 1 — The required illumination is 150 lux. For this task illumination (D), the corresponding curve of watts per m^2 gives 4.4 watts/m^2.

Step 2 — The vertical line corresponding to separation to height ratio of 2.0 is the middle ordinate. From the intersection of 4.4 watt/m^2 curve and this ordinate, moving along horizontal, the percentage fenestration on the left hand ordinate is read as 16 percent. Since the floor area is less than 30 m^2. The required fenestration will be $1.15 \times 16 = 18$ percent.

Floor area being $5 \times 3 = 15$ m^2, the total wattage will be $4.4 \times 15 \times 1.15 = 76$.

No. of 40 watt fluorescent tubes should be $76/40 = 2$.

Therefore, two single tube luminaires will be adequate.

6 ARTIFICIAL LIGHTING DESIGN

6.1 Two methods are used for the calculation of artificial lighting of buildings. One for the average illuminance of the workplane and the other for point-by-point distribution over a given area. The formar is called the 'Lumen method' and the latter 'point-by-point method'.

6.2 Lumen Method

6.2.1 Recommended illuminance levels for different visual tasks in building interiors is given in Table 1. The limiting values of glare index are also included in Table 1. If E is the desired general illuminance in lux over A m^2 area of the workplane, the maintained luminous flux must be $E.A$ lumens. The luminous flux reaching the workplane depends upon:

a) lumen output of the lamps.

b) type of luminaire,

c) proportion of the room,

d) reflectance of internal surfaces of the room,

e) depreciation in the lumen output of the lamps after burning their rated life, and

f) depreciation due to dirt collection on luminaires and room surfaces.

6.2.2 The initial lumen output of a few incandescent lamps and fluorescent tubes are given in Table 20.

6.2.3 Luminaires are classified into five categories, namely,

a) Direct,

b) Semi-direct,

c) General-diffuse,

d) Semi-indirect, and

e) Indirect in accordance with the flux output above and below the horizontal as given in Table 21.

TABLE 20 INITIAL LUMEN OUTPUT OF LAMPS AFTER 100 BURNING HOURS

(*Clause* 6.2.2)

TYPE OF LAMP	WATTS	INITIAL LUMENS
(1)	(2)	(3)
Vacuum type single coil incandescent lamp	25	220
	40	425
Gas filled type coiled coil incandescent lamps	60	720
	100	1 380
	200	2 920
	500	8 300
	1 000	18 600
Warm white fluorescent tube	40	2 770
Cool day light fluorescent tube	40	2 440
High pressure mercurcy vapour lamp	80	3 400
	125	5 800
	250	12 500
	400	22 500
	1 000	55 000
Halogen lamp	1 000	22 000
High pressure sodium vapour lamp	50	3 300
	70	5 800
	150	14 000
	250	25 000
	400	47 000
	1 000	1 20 000

TABLE 21 LUMINAIRE CLASSIFICATION

(*Clause* 6.2.3)

Type	Distribution of Flux Emitted as Percentage of Total Flux Output	
	Upward	Downward
Direct	0-10	90-100
Semi-direct	10-40	60-90
General-diffusing	40-60	40-60
Semi-indirect	60-90	10-40
Indirect	90-100	0-10

6.2.4 The relative dimensions of a room may be expressed as a room index. For direct, semi-direct and general-diffuse luminaires,

$$\text{Room index } (k_r) = \frac{L \times W}{(L + W)\, H_m} \quad \ldots(16)$$

where L, W are the room length and width, and H_m is the mounting height of luminaire above the workplane. For semi-indirect and indirect luminaries.

$$\text{Room index } (k_r) = \frac{3\ L \times W}{2\ (L + W)\, H_c} \quad \ldots(17)$$

where H_c is the ceiling height above the workplane.

6.2.5 The ratio of the flux reaching the workplane and the flux generated by the lamps is known as coefficient of utlization and is denoted by μ. Table 22 gives the coefficients of utilization, μ for different types of luminaires and several room indices with different ceiling and wall reflectances, and a constant floor reflectance of 0.1. The maintanance factor accounts for depreciation in the lumen output of lamps and collection of dirt on reflecting surfaces. The values of maintenance factors are given in Table 22 of coefficient of utilization for good, medium and poor maintenance conditions. The ratio of maximum permissible spacing between luminaires (centre-to-centre distance) and either the mounting height above the floor, H_m or ceiling height above the floor, H_c are also given in Table 22 for direct, semi-direct and general diffuse luminaires or indirect and semi-indirect luminaires respectively. The distance between luminaires and the wall should not exceed half the maximum permissible spacing between the luminaires. Table 23 gives the multiplying factors for obtaining the coefficients of utilization for a floor reflectance of 0.3.

6.2.6 The lumens reaching the workplane due to number of lamps would be:

$$N_{lamp} \times \phi_{lamp} \times \mu \times d \quad \ldots(18)$$

or

$$N_{luminaire} \times \phi_{luminaire} \times \mu \times d \quad \ldots(19)$$

These must be equal to the luminous flux $E \times A$, the product of required illuminance and floor area, to be maintained on the workplane.

$$\text{Therefore, } N_{lamp} = \frac{E \times A}{\mu \times d \times \phi_{lamp}} \quad \ldots(20)$$

or

$$N_{luminaire} = \frac{E \times A}{\mu \times d \times \phi_{luminaire}} \quad \ldots(21)$$

where

ϕ_{lamp}, $\phi_{luminaire}$ = luminous flux of each lamp or luminaire in lumens,

μ = the utilization factor in new conditions, and

d = maintenance factor.

6.3 Worked Examples

6.3.1 *Residential Buildings Hotel*

Example 26

A 5 m × 3 m × 3 m room in a hotel has ceiling, wall and floor reflectances as 0.7, 0.5 and 0.1 respectively. Determine the number of twin lamp luminaires fitted with 40 watt cool daylight fluorescent tubes and diffusing plastics enclosure for providing 150 lux on the workplane 0.75 m above the floor for good maintenance conditions. It is proposed to mount the luminaires at a height of 2.25 m above the floor.

Solution

Type of luminaire chosen is semi-direct (Sl No. 13, Table 22). Proposed mounting height above workplane = 2.25 − 0.75 = 1.5 m.

$$\text{Room index} = \frac{L \times W}{(L + W) H_m}$$

$$= \frac{5 \times 3}{(5 + 3) \times 1.5} = 1.25$$

From Table 20, the lumen output per lamp = 2 440 lumens. From Table 22, the coefficient of utilization = 0.30 and maintenance factor = 0.70. Therefore, from Equation (21), the number of lamps required is,

$$N_{lamp} = \frac{EA}{\mu\, d\, \Phi_{lamp}}$$

$$= \frac{150 \times (5 \times 3)}{2\,440 \times 0.30 \times 0.70} = 4$$

$$\text{Number of twin lamp luminaires} = \frac{4}{2} = 2$$

Maximum permissible spacing between luminaires = 1.0 H = 2.25 m

Maximum distance between luminaires and the wall

$$= \frac{2.25}{2} = 1.13 \text{ m}$$

Making a slight adjustment, the separation between luminaires may be kept as 2.5 m and distance from the wall as 1.25 m (*see* Fig. 32).

Example 27

Determine the number of luminaires for a hall (lounge) of size 15 m × 10 m × 3 m having five bays, all other specifications being same as in Example 26.

Solution

Type of luminaire chosen is semi-direct (Sl No. 29, Table 22). Proposed mounting height above workplane

$$= 2.25 - 0.75 = 1.5 \text{ m}$$

$$\text{Room index} = \frac{L \times W}{(L + W)H_m}$$

$$= \frac{15 \times 10}{(15 + 10) \times 1.5} = 4.00$$

From Table 20, the lumen output per lamp = 2 440 lumens.

From Table 22, coefficient of utilization = 0.48 and maintenance factor = 0.70

Therefore, from Equation (21), the number of lamps required is

$$N_{lamp} = \frac{EA}{\Phi_{lamp}\, \mu\, d}$$

$$= \frac{150 \times (15 \times 10)}{2\,440 \times 0.48 \times 0.70} = 27$$

For equal distribution of lamps in all the five bays, the number of lamps calculated above may be decreased by two, that is, the total number of lamps required will be 25. Therefore, 10 twin lamp luminaires and 5 single lamp luminaires of similar type may be chosen; thus 2 twin lamp luminaires and 1 single lamp luminaire may be fitted in each bay. However, the maximum permissible spacing between the luminaires and the end walls being 2.25 m and 1.13 m respectively for the proposed mounting height of 2.25 m above the floor, cannot be satisfied for 3 luminaires per bay (2 two-lamp luminaire and 1 single lamp luminaire per bay). Therefore, a satisfactory solution will be to take all single lamp luminaires and fix them 2 m apart from each other and 1 m apart from the window wall and the opposite wall in each bay (*see* Fig. 33).

Alternative solution will be to increase the mounting height and mount the luminaires near the ceiling. Supposing the height above the floor is taken as 3.0 m, then the mounting height above the workplane will be 2.25 m and

$$\text{Room index} = \frac{15 \times 10}{(15 \times 10) \times 2.25} = 2.7$$

From Table 22, the coefficient of utilization = 0.44. Hence

$$\text{Number of lamps} = \frac{150 \times (15 \times 10)}{2\,440 \times 0.4 \times 0.7} = 30$$

The maximum permissible spacing between the luminaires and that between the luminaires from the window wall and the opposite wall for 3.0 m mounting height above floor is 3.0 and 1.5 m respectively. The arrangement for 3 twin lamps luminaires per bay for the above mounting height is shown in Fig. 34.

6.3.2 *Institutional Buildings*

Example 28

Determine the number of luminaires for a two bay pathological laboratory of size 6 m × 5 m × 3 m for good maintenance conditions. The reflectances of ceiling, walls and floor are 0.7, 0.5 and 0.1 respectively. The illuminance of 300 lux is required on the workplane 0.9 m above the floor level. The proposed mounting height above floor is 2.4 m.

Solution

Type of luminaire chosen is two lamp aluminium luminaire with louvres (Sl No. 2 Table 22) fitted with 40 watt cool daylight lamps. Proposed mounting height above workplane = 2.4 − 0.9 = 1.5 m.

$$\text{Room index} = \frac{L \times W}{(L + W)H_m} = \frac{6 \times 5}{(6 + 5) \times 1.5} = 1.8$$

For the room index and the given surface reflectances, the coefficient of utilization (*see* Table 22) is 0.43 and the maintenance factor for good maintenance is 0.75.

Therefore, the number of 40 W lamps required is

$$N_{lamp} = \frac{EA}{\Phi_{lamp}\, \mu\, d} = \frac{300 \times (6 \times 5)}{2\,440 \times 0.43 \times 0.75} = 11$$

This may be increased by one so that 3 two-lamp luminaires may be provided in each bay. The maximum permissible spacing between luminaires is 0.8 H = 0.8 × 2.4 = 1.92 m. Hence the luminaires can be located 1.7 m apart parallel to 6 m long wall with a distance from the end walls as 0.8 m.

NOTE — Luminaires are placed parallel to long wall.

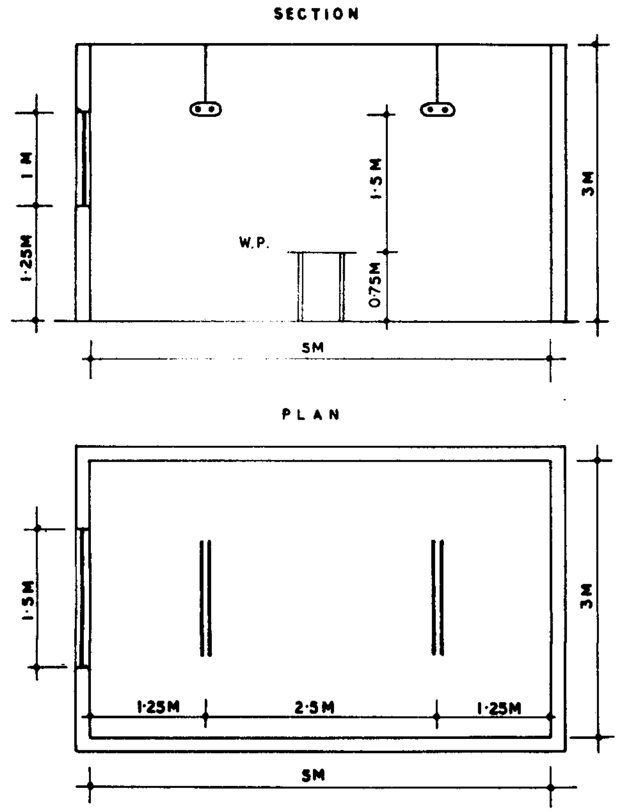


FIG. 32 DISTRIBUTION OF TWIN LAMP LUMINAIRES ON SECTION AND PLAN (EXAMPLE 26)

6.3.3 *Assembly buildings*

Example 29

Determine the number of luminaires for providing 150 lux of general illuminance on tables 0.9 m above floor level in an exhibition hall of size 15 m × 10 m × 3 m having five bays. The reflectances of ceiling, walls and floor are 0.7, 0.5 and 0.1 respectively. The type of luminaire chosen is single lamp aluminium troffer with baffles and the maintenance condition is poor. The proposed mounting height above floor is 2.4 m.

Solution

Mounting height above workplane = 2.4 − 0.9 = 1.5 m

Room index, as in Example 27, is = 4.0

Coefficient of utilisation from Table 22 (Sl. No. 1) = 0.58 and maintenance factor is = 0.65.

The number of 40 watt cool daylight lamps

$$N_{\text{lamp}} = \frac{EA}{\Phi_{\text{lamp}}\ \mu\ d} = \frac{150 \times (15 \times 10)}{2\,440 \times 0.58 \times 0.65} = 24.5$$

This may be rounded off to 25 so that five luminaires may be suitably mounted in each bay of the hall as in Example 27, maximum permissible spacing between luminaires being $0.8 \times H = 0.8 \times 2.4 \simeq 2$ m.

6.3.4 *Business Buildings*

Example 30

Determine the number of two-lamp luminaires of diffusing sides and prismatic bottom to be fitted with cool daylight lamps for producing 300 lux at table tops 0.75 m above floor level in a two-bay library of size 6 m × 5 m × 3 m for good maintenance conditions. The proposed mounting height above floor is 2.25 m and the ceiling, walls and floor reflectances are 0.7, 0.5 and 0.1 respectively.

Solution

Mounting height above workplane
= 2.25 − 0.75 = 1.5 m

Room index, as in Example 28, is 1.8.

The coefficient of utilization (Sl No. 15, Table 22) is 0.53 and maintenance factor is 0.70. Therefore, the number of 40 watt cool daylight lamps required is

$$N_{\text{lamp}} = \frac{EA}{\Phi_{\text{lamp}}\ \mu\ d} = \frac{300 \times (6 \times 5)}{2\,440 \times 0.53 \times 0.70} = 10$$

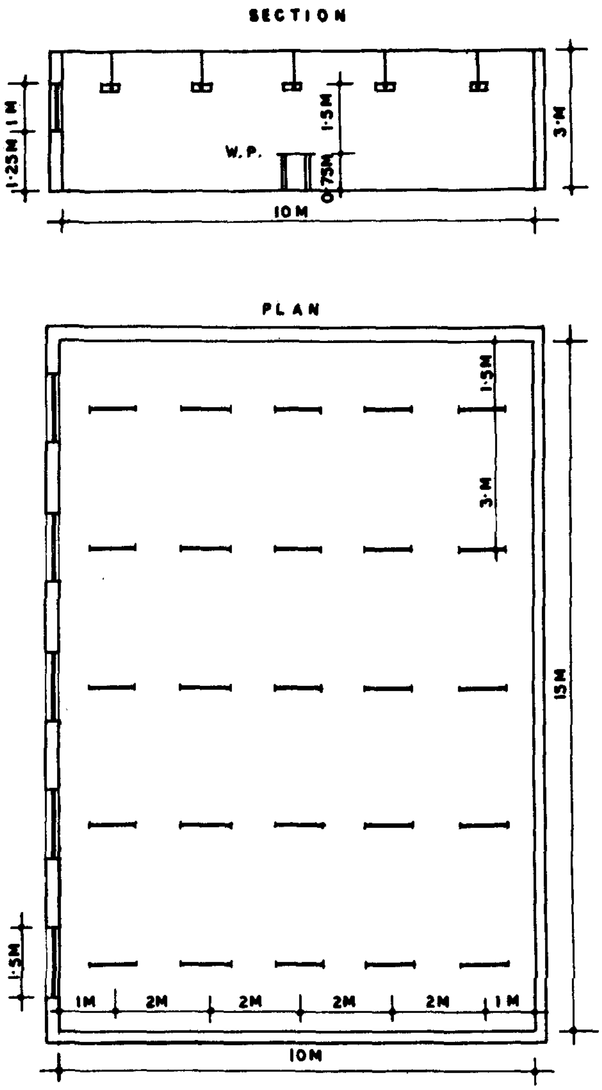


Fig. 33 Distribution of Single Lamp Luminaires on Section and Plan (Example 27)

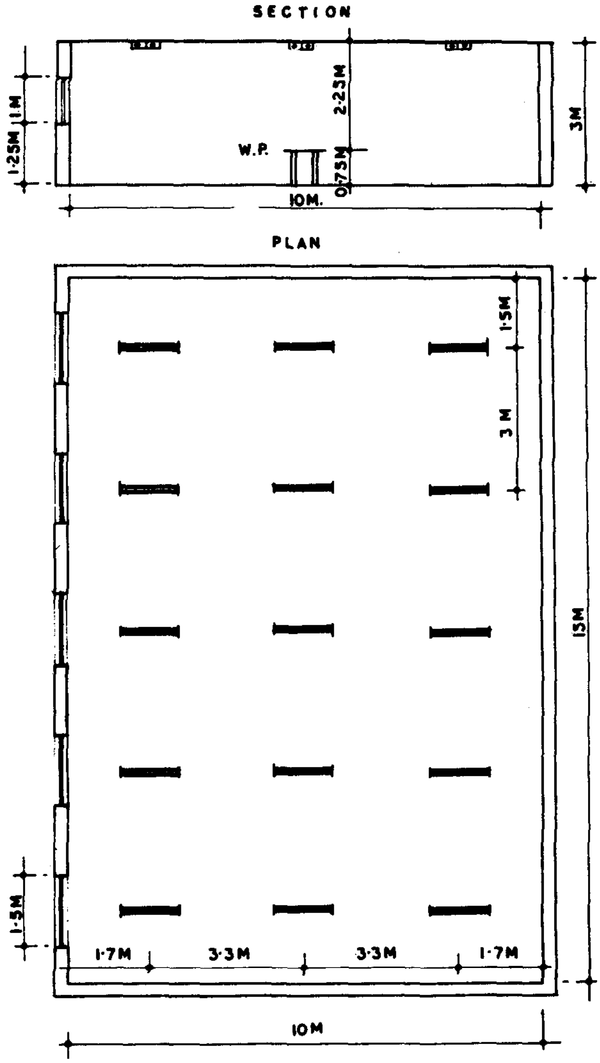


Fig. 34 Distribution of Twin Lamp Luminaires on Sfction and Plan (Example 27)

Hence 2 two-lamp luminaire may be provided in each bay and 1 two-lamp luminaire in the centre of the room. The maximum parmissible spacing between luminaire is $1.1 \times H = 1.1 \times 2.25 = 2.5$ m, which is very well satisfied.

6.4 Point-by-Point Method — The lumen method gives an average illuminance over the entire workplane area. If illuminance at specific points is desired, calculations are made by the point-by-point method. It requires the computation of direct illuminance due to given light sources at specific points. Total illuminance at any point is obtained by adding the indirect illuminance due to inter-reflection to the value of direct illuminance at that point. The integrating sphere formula is generally used for the calculation of indirect illuminance.

6.4.1 Tables 13 and 14, giving percentage sky factors, can be used for determining illuminance at any point due to uniformly diffusing plane surface sources.

6.4.2 To obtain the illuminance at a point, the value of sky factor at that point due to a given surface source is multiplied by the luminaire emittance, that is, luminous flux per unit area emanating out of the surface.

6.4.3 Figure 35 depicts the distribution of direct illuminance on the workplane due to a twin 40 watt fluorescent tube luminaire of semi-direct type.

6.4.4 Precomputed values of illuminance for different mounting heights and different locations on a horizontal plane are given in Table 24 for an assumed intensity of 100 candela in any direction. Multiplying these values by one-hundredth of the actual intensity in a given direction, the lux values can be obtained for any point source. The intensity of a light source in a given direction can be obtained from the candle power distribution of the source.

6.5 Glare Index

6.5.1 The glare index due to any number of light sources in a room is given by:

$$\text{Glare index (GI)} = 10 \log_{10} \Sigma G \qquad \ldots (22)$$

where G is glare constant for a light source and ΣG is the sum of glare constants for all the light sources in a lighting environment. The recommended values of glare index are given in Table 1. The glare constant for a light source is given by Hopkinson's formula:

$$G = k \frac{B_s^{1.6}\, \omega^{0.8}}{B_b} \frac{1}{p^{1.6}} \qquad \ldots (23)$$

where

B_s = brightness of the source;

B_b = surround brightness;

ω = apparent size of the source in steradians;

p = position factor of the source; and

k = A factor depending upon the units of brightness.

For brightness in foot-lamberts, k is unity and for brightness in apostilbs, k is 0.24.

The source brightness B_s is taken as the average within the confines of the source boundary. The surround brightness is considered as uniform brightness over the whole field and is taken as numerically equal to the average internal reflected illuminance. The solid angle subtended by the source at the eye of the observer is given by:

$$\omega = \frac{A \cos \delta \,.\, \cos \epsilon}{r^2} \qquad \ldots (24)$$

where

A = area of the source;

r = distance of the source from the eye; and

δ, ϵ = angle between the normal to the source and the direction of the source from the observer in the vertical and horizontal planes respectively.

The position factor can be determined from Table 25 depending upon the angular displacement (*see* Fig. 36) of the source from the direction of viewing. Where the direction of viewing is not fixed, the position factor is not included in the calculations.

Example 31

Calculate the glare index due to a 100 watt lamp fitted in a diffusing globe of radius 5 cm and emitting 1 000 lumens uniformly in all the directions, when the globe is mounted at a horizontal distance of 2 m from the observer and 1 m above the eye level in the vertical plane containing the horizontal direction of view. The size of the room is 5 m × 3 m × 3 m and the average reflectance of room surfaces is 0.5 and there are no other light sources in the room.

Solution

$$\text{Source brightness, } B_s = \frac{\text{Luminous flux}}{\text{Surface area of globe} \times \pi}$$

$$= \frac{1\,000}{4\,(0.05)^2 \times \pi^2}$$

$$= \frac{31\,800}{\pi} \text{ candela/m}^2$$

Solid angle, ω = Solid angle subtended at the eye by a circular disc of radius 5 cm located at the source centre

$$= \frac{A}{r^2}$$

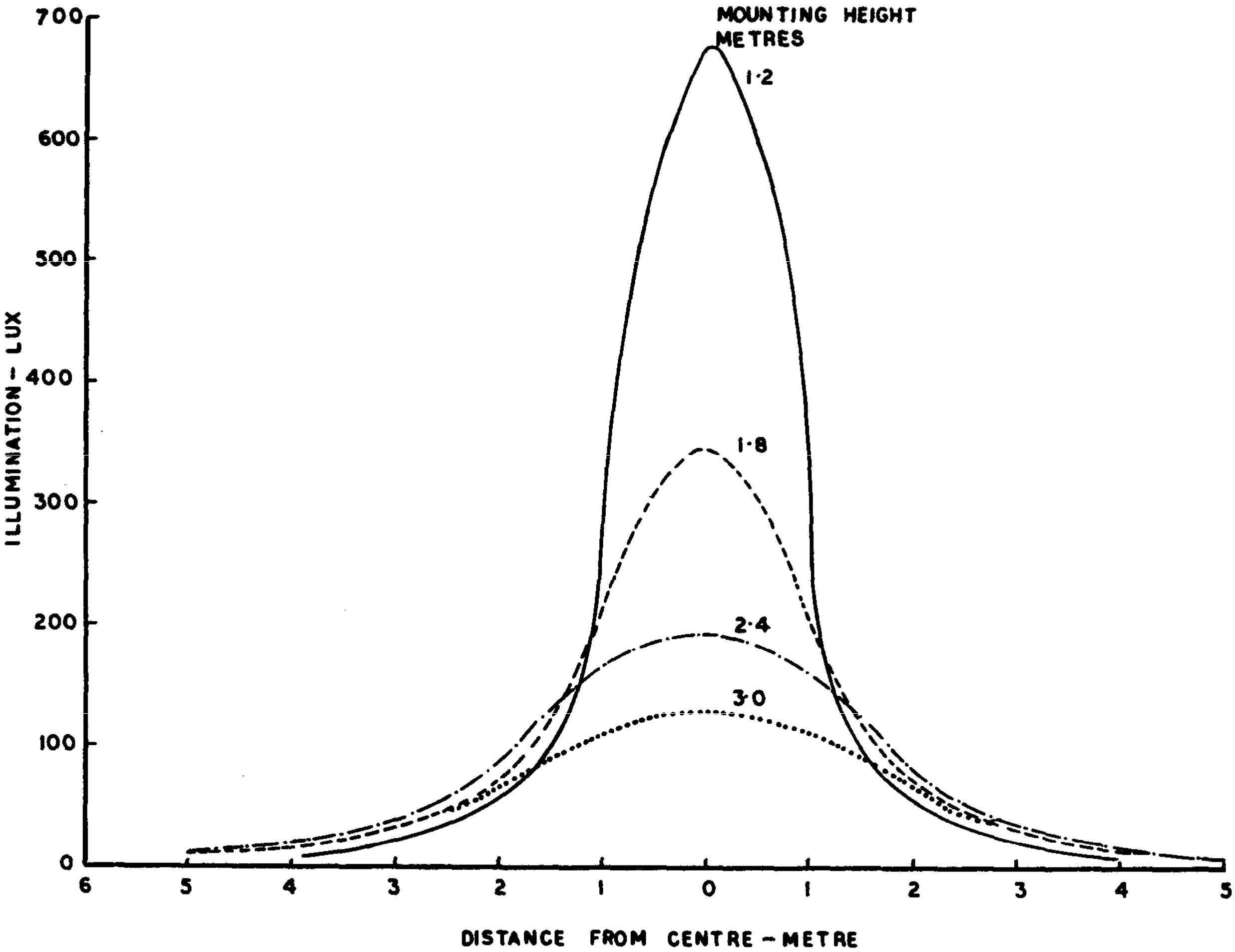


FIG. 35 DISTRIBUTION OF DIRECT ILLUMINATION ON A WORKPLANE DUE TO TWIN 40 W FLUORESCENT TUBE

$$= \frac{\pi\,(0.05)^2}{(2^2 + 1^2)}$$

$$= 0.001\,57 \text{ steradians.}$$

Surround brightness, B_b

$$= \frac{\text{Luminous flux} \times \text{Av. reflectance}}{\text{Room surface area} \times (- \text{Av. reflectance}) \times \pi}$$

$$= \frac{1\,000 \times 0.5}{2\,(5 \times 3 + 5 \times 3 + 3 \times 3)\,(1 - 0.5) \times \pi}$$

$$= \frac{12.8}{\pi} \text{ candela/m}^2$$

$$\text{Position factor}, p = 0.35, \text{ for } \frac{h}{d} = \frac{1}{2} = 0.5$$

$$\text{and } l/d = 0$$

$$\text{Glare index, } G = 10 \log_{10} \frac{0.24\,B_s^{1.6} \cdot \omega^{0.8}}{B_b} \; \frac{1}{p^{1.6}}$$

$$= 10 \log_{10} \frac{0.24 \times (31\,800)^{1.6} \times (0.001\,57)^{0.8} \times 0.35}{12.8}$$

$$= 27.8$$

6.5.2 *IES Glare Index System* — The glare index for any installation may be derived from the basic formula, but the procedure is lengthy. Where, however, the fittings are arranged in a substantially regular pattern as in most general lighting installations, the glare index system may be obtained quickly and simply from the following information:

a) *Lighting fittings*

1) Light distribution expressed as a British Zonal (BZ) Classification. The classifications of many fittings are available; those of other fittings may be determined by the method given in IS : 3646 (Part 3)-1968.

2) Total light output from the fitting (in lumens).

3) Flux fractions (that is, proportions in upper and lower hemispheres).

4) Luminous area A of the fitting which is defined as follows:

i) *BZ 1 to BZ 8* : The orthogonally projected luminous area (in cm^2) at 0°; that is, as seen from vertically beneath the fitting.

ii) *BZ 9 to BZ 10* : The maximum orthogonally projected luminous area (in cm^2) at 90°, that is, when viewed horizontally from the side.

5) Mounting height H (in metres) above a 1.2 m eye level.

b) *Room surfaces* — Reflection factors of ceiling, walls and floor.

c) *Room dimensions* — The dimensions X and Y as shown in Tables 26 to 35 across and parallel respectively to the line of sight and expressed in terms of the mounting height H above a 1.2 m eye level.

Tables 26 to 35 give values of initial glare index computed for a basic installation for the ten defined light distributions, three flux fractions and selected combinations of room dimensions and reflection factors. The ten polar curves of light distribution, for which data are given, are shown in Fig. 37. Each of the tables relates to one distribution and to the corresponding British Zonal Classification of the lighting fitting (BZ 1 to BZ 10).

The initial glare index for an installation derived from Tables 26 to 35 should be converted into the final glare index by applying the conversion terms of Table 36 which take into account the luminous area A, the downward flux F and the height H above the 1.2 m eye level of the fittings actually used or proposed for use.

The glare experienced by an occupant of a room depends on his position in the room and the tabulated data have been computed to give the glare index for the installation assuming a horizontal line of sight with the observer seated at the mid-point of one wall and looking towards the centre of the opposite wall.

6.5.3 *Procedure for Determining Glare Index* — The following procedure is used to determine the glare index for an existing or proposed installation:

a) The table appropriate to the BZ classification of the fittings is selected from Tables 26 to 35.

b) The room dimensions X and Y are determined in terms of the fitting height H above 1.2 m eye level.

The BZ classification relates to the lower hemisphere only; the polar curves above are scaled to give 1 000 lumens in the lower hemisphere for purposes of comparison.

c) The value of the initial glare index for the particular room dimensions, flux fractions and room reflection factors is read from the selected table, interpolating where necessary.

d) When linear fittings are used, having different end-wise and cross-wise distributions (that is, linear fittings with BZ classifications 4, 6, 7 and 8), the appropriate conversion term given on the right-hand side of the table is added to or subtracted from the initial glare index as indicated.

e) Conversion terms from Table 36 corresponding to the luminous area A, downward flux F and mounting height H above 1.2 m eye level of the fittings actually used are added to or subtracted from the initial glare index as indicated in the notes to Table 36.

The value resulting from operations (a) to (e) is the glare index for the installation. Examples of the procedure are given in **6.5.4**.

NOTE — It should be emphasized that these data give a correct value of glare index only when applied to a completely designed installation with all conversion terms taken into account. Any attempt to extract the effect of single variables will be misleading.

6.5.4 *Examples of Glare Index Compution*

Example 32

It is proposed to light a general office 18.3 m × 7.3 m and 3 m high with 0.61 m square diffusing fluorescent fittings mounted flush with the ceiling. The proposed reflection factors of the room surfaces are:

Walls	: 50 percent
Ceiling	: 50 percent
Floor	: 14 percent

The data for the fittings are:

BZ classification	: BZ 5
Flux fractions	: $\frac{0 \text{ percent}}{100 \text{ percent}}$
Downward flux (F)	: 2 000 lumens
Luminous area (A)	: 3 716 cm^2

As the mounting height is 3 m,
$H = 1.8$ m

For symmetrical fittings, the worst glare is for the longest line of sight so that

$Y = 18.3$ m $= 10\ H$

$X = 7.4$ m $= 4\ H$

The initial glare index is obtained from Table 30 and is 26.3, by interpolation between 26.0 for $Y = 8\ H$ and 26.5 for $Y = 12\ H$.

The conversion terms from Table 36 are:

Downward flux (F) = 2 000 + 1.8

Area (A) = 3 716 − 6.1

(interpolate between 500 and 700)

Height (H) = 6 − 0.6

Algebraic sum: = − 4.9

The glare index is then 26.3 − 4.9 = 21.4

The value of 21.4 is greater than the limiting glare index of 19 for offices and it is, therefore, necessary to change the design. The method proposed is to use similar fittings, but to replace the diffusing panel by a louvered panel which will have a BZ 4 classiciation instead of BZ 5 for the fitting; the design of the installation is otherwise unchanged.

Repeating the calculation, the initial glare index from Table 29 is 23.1 (by interpolation), the conversion terms are unchanged and the glare index is 23.1 − 4.9 = 18.2, which is satisfactory.

Example 33

An installation similar to that described in the first part of Example 32 is proposed for a smaller office, measuring 7.3 m × 3.7 m and 3 m high. In the same way as before, $H = 1.8$ m, $X = 3.7$ m $= 2\ H$ and $Y = 7.3 = 4\ H$.

The initial glare index from Table 30 is 22.4. The conversion terms are as before and the glare index is 22.4 − 4.9 = 17.5.

The diffusing fittings which were not acceptable for the larger office in Example 32 are thus acceptable for use in this smaller office.

Example 34

The same office, as in Example 32, is to be lit with single lamp diffusing fluorescent fittings mounted on the ceiling and equipment with 1.52 m 80 watt lamps. As these are linear fittings, it will be necessary in computing the glare index to bring in the additional conversion term. It is proposed to mount the fittings in lines parallel to the short walls.

The data for the fittings are:

BZ classification	: BZ 6
Flux fractions	: $\frac{25 \text{ percent}}{75 \text{ percent}}$
Total flux	: 2 800 lumens
Downward flux (F)	: 2 100 lumens
Luminous area (A)	: 4 516 cm^2

The initial glare index is read from Table 31 taking the condition of worst glare, that is, when the fittings are viewed crosswise and the line of sight is parallel to the long walls. The dimension Y is then 18.3 m; H is 1.8 m as before and, therefore, $Y = 10\ H$ and $X = 4\ H$.

The initial glare index, without the conversion term for linear fittings is 24.2, by interpolation between 23.8 for $Y = 8\ H$ and 24.6 for $Y = 12\ H$.

The conversion terms from Table 31 and 36 are:

Crosswise viewing (interpolate between 8 H and 12 H)		+ 1.7	
Downward flux (F) = 2 100	: + 1.9	− 5.5	From Table 11
Area (A) = 4 516 cm^2	: − 6.8		
Height (H) = 1.8 m	: − 0.6		
Algebraic sum		− 3.8	

The glare index is then 24.2 − 3.8 = 20.4.

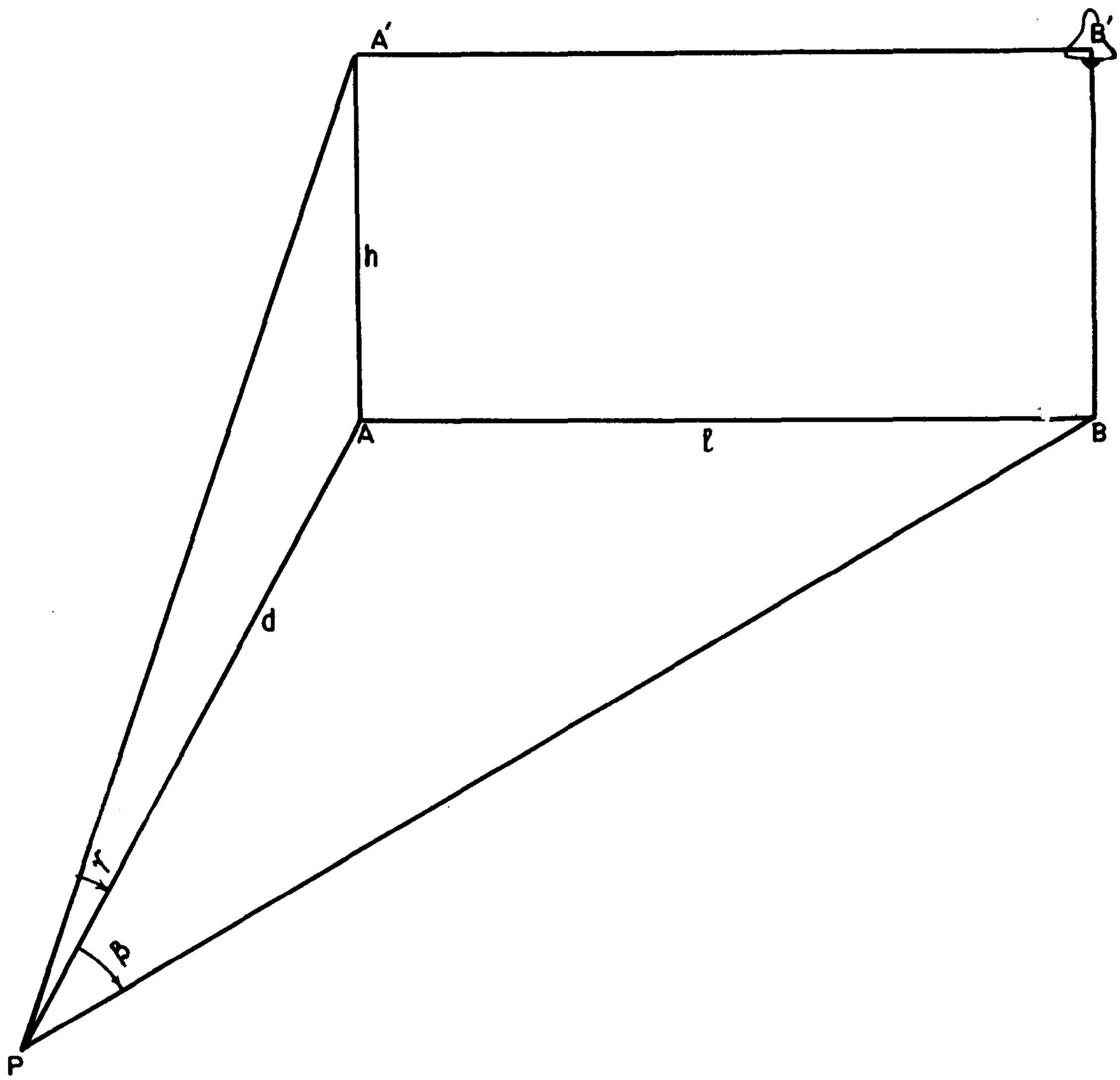
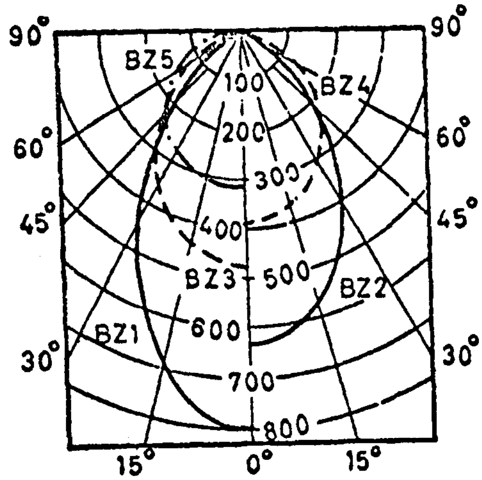
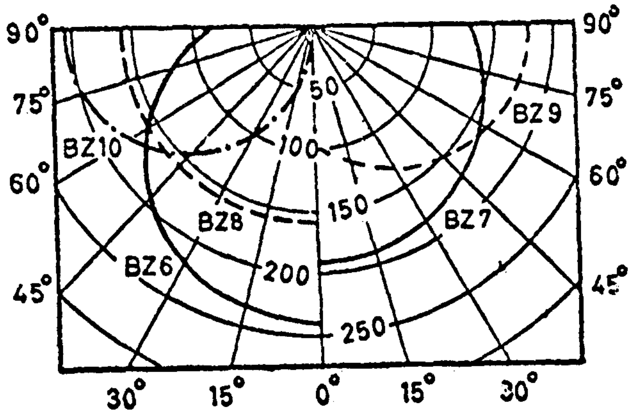


FIG. 36 ANGULAR DISPLACEMENT OF THE SOURCE FROM THE DIRECTION OF VIEWING



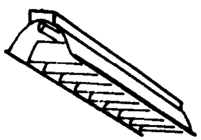
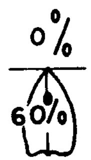
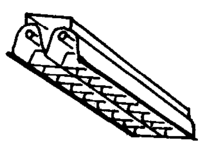
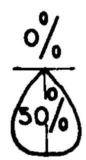


BZ 1 I $\propto \cos^4\theta$	BZ 6 I $\propto (1+2\cos\theta)$
BZ 2 I $\propto \cos^3\theta$	BZ 7 I $\propto (2+\cos\theta)$
BZ 3 I $\propto \cos^2\theta$	BZ 8 I Constant
BZ 4 I $\propto \cos^{1.5}\theta$	BZ 9 I $\propto (1+\sin\theta)$
BZ 5 I $\propto \cos\theta$	BZ 10 I $\propto \sin\theta$

FIG. 37 POLAR CURVES IN THE BZ CLASSIFICATION

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS

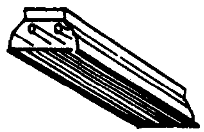
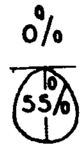
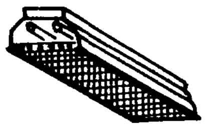
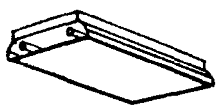
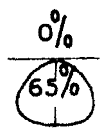
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Single Lamp Aluminium Troffer with Baffles			0.6	0.30	0.26	0.25	0.29	0.26	0.23	0.29	0.26	0.23	0.25	0.23	0.22		
			0.8	0.36	0.32	0.29	0.35	0.32	0.29	0.35	0.31	0.29	0.31	0.29	0.27	Good	0.75
			1.0	0.43	0.40	0.37	0.43	0.40	0.37	0.42	0.39	0.37	0.39	0.37	0.36		
			1.25	0.47	0.44	0.42	0.47	0.44	0.41	0.46	0.43	0.41	0.43	0.41	0.40	Medium	0.70
		0.8 *H*	1.5	0.50	0.47	0.44	0.50	0.47	0.44	0.49	0.46	0.44	0.46	0.44	0.43		
			2.0	0.53	0.50	0.49	0.53	0.50	0.48	0.51	0.50	0.48	0.49	0.47	0.46	Poor	0.65
			2.5	0.55	0.53	0.51	0.55	0.53	0.51	0.54	0.52	0.50	0.51	0.50	0.49		
			3.0	0.57	0.54	0.53	0.56	0.54	0.52	0.55	0.53	0.51	0.52	0.51	0.50		
			4.0	0.59	0.57	0.55	0.58	0.56	0.55	0.56	0.55	0.54	0.54	0.53	0.52		
			5.0	0.60	0.58	0.57	0.59	0.57	0.56	0.57	0.56	0.56	0.56	0.54	0.53		
Two Lamp Aluminium Troffer with Louvers			0.6	0.27	0.24	0.21	0.27	0.23	0.21	0.27	0.23	0.21	0.23	0.21	0.20		
			0.8	0.33	0.29	0.26	0.32	0.29	0.26	0.32	0.28	0.26	0.28	0.26	0.25	Good	0.75
			1.0	0.36	0.33	0.30	0.36	0.33	0.30	0.35	0.32	0.30	0.32	0.30	0.29		
			1.25	0.40	0.36	0.34	0.39	0.36	0.34	0.38	0.36	0.34	0.36	0.34	0.33	Medium	0.70
		0.8 *H*	1.5	0.42	0.39	0.37	0.42	0.39	0.37	0.41	0.38	0.36	0.38	0.36	0.35		
			2.0	0.45	0.42	0.40	0.44	0.42	0.40	0.44	0.42	0.40	0.41	0.40	0.39	Poor	0.65
			2.5	0.47	0.44	0.43	0.46	0.44	0.42	0.45	0.44	0.42	0.43	0.42	0.41		
			3.0	0.48	0.46	0.44	0.47	0.46	0.44	0.47	0.45	0.44	0.44	0.43	0.42		
			4.0	0.50	0.48	0.40	0.49	0.48	0.46	0.48	0.47	0.46	0.46	0.45	0.44		
			5.0	0.50	0.49	0.48	0.50	0.49	0.48	0.49	0.48	0.47	0.47	0.46	0.45		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

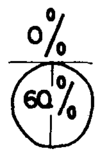
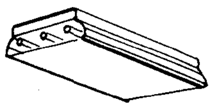
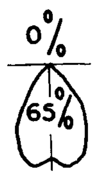
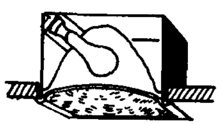
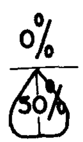
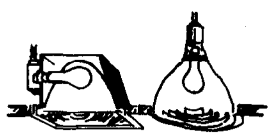
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Two Lamp 30 cm Wide			0.6	0.26	0.23	0.20	0.26	0.22	0.20	0.25	0.22	0.20	0.22	0.20	0.19	Louver	Enclosed
Troffer Glass, Plastic			0.8	0.32	0.29	0.26	0.32	0.29	0.26	0.31	0.29	0.26	0.28	0.26	0.25	Good 0.75	0.70
or 30° Louver			1.0	0.37	0.34	0.31	0.37	0.33	0.30	0.36	0.32	0.30	0.32	0.30	0.29		
			1.25	0.41	0.37	0.35	0.41	0.37	0.35	0.40	0.37	0.34	0.36	0.34	0.33	Medium 0.70	0.65
		0.9 *H*	1.5	0.44	0.40	0.37	0.43	0.40	0.37	0.42	0.40	0.37	0.39	0.37	0.36		
			2.0	0.47	0.44	0.42	0.47	0.44	0.41	0.46	0.43	0.41	0.42	0.41	0.40	Poor 0.65	0.55
			2.5	0.50	0.47	0.45	0.49	0.47	0.45	0.48	0.46	0.44	0.45	0.43	0.42		
			3.0	0.51	0.49	0.47	0.51	0.48	0.46	0.50	0.47	0.46	0.47	0.45	0.44		
			4.0	0.53	0.51	0.49	0.53	0.51	0.49	0.51	0.50	0.48	0.49	0.47	0.46		
			5.0	0.55	0.53	0.52	0.54	0.53	0.51	0.53	0.52	0.51	0.51	0.50	0.48		
Two Lamp 30 cm Wide			0.6	0.24	0.21	0.19	0.24	0.21	0.19	0.23	0.21	0.19	0.20	0.19	0.18		
Troffer with 45°			0.8	0.29	0.26	0.24	0.29	0.26	0.24	0.28	0.26	0.24	0.26	0.24	0.23	Good 0.75	
Metal Louver			1.0	0.32	0.29	0.27	0.32	0.29	0.27	0.32	0.29	0.27	0.29	0.27	0.26		
			1.25	0.36	0.32	0.31	0.35	0.32	0.31	0.34	0.32	0.30	0.32	0.30	0.29	Medium 0.70	
		0.6 *H*	1.5	0.38	0.35	0.33	0.38	0.35	0.33	0.37	0.34	0.32	0.34	0.32	0.32		
			2.0	0.41	0.38	0.37	0.40	0.38	0.36	0.39	0.38	0.36	0.37	0.36	0.35	Poor 0.65	
			2.5	0.43	0.40	0.38	0.42	0.40	0.38	0.41	0.39	0.38	0.39	0.38	0.37		
			3.0	0.44	0.42	0.40	0.43	0.42	0.40	0.42	0.41	0.36	0.40	0.39	0.38		
			4.0	0.45	0.44	0.42	0.45	0.43	0.42	0.44	0.43	0.42	0.42	0.41	0.40		
			5.0	0.47	0.45	0.44	0.46	0.45	0.44	0.45	0.44	0.43	0.43	0.42	0.41		
Two Lamp 60 cm Wide			0.6	0.31	0.27	0.24	0.31	0.27	0.24	0.30	0.27	0.24	0.27	0.24	0.23		
Troffer with Prismatic			0.8	0.39	0.34	0.31	0.38	0.34	0.31	0.38	0.34	0.31	0.34	0.31	0.30	Good 0.70	
Lens			1.0	0.44	0.40	0.37	0.44	0.40	0.36	0.43	0.39	0.36	0.39	0.36	0.35		
			1.25	0.49	0.45	0.41	0.49	0.44	0.41	0.47	0.43	0.41	0.43	0.41	0.39	Medium 0.65	
		0.9 *H*	1.5	0.52	0.49	0.45	0.52	0.48	0.45	0.51	0.47	0.45	0.47	0.45	0.43		
			2.0	0.56	0.53	0.51	0.56	0.52	0.50	0.54	0.52	0.50	0.51	0.49	0.48	Poor 0.55	
			2.25	0.59	0.56	0.53	0.58	0.56	0.53	0.57	0.54	0.52	0.54	0.52	0.51		
			3.0	0.61	0.58	0.56	0.60	0.58	0.55	0.58	0.56	0.54	0.56	0.54	0.53		
			4.0	0.63	0.61	0.58	0.62	0.60	0.58	0.61	0.59	0.58	0.58	0.56	0.55		
			5.0	0.65	0.63	0.61	0.63	0.62	0.60	0.62	0.61	0.60	0.60	0.58	0.57		

(*Continued*)

TABLE 22 COEFFICIFNTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

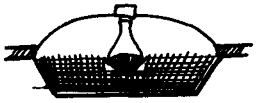
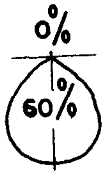
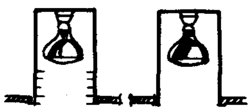
(*Clause* 6.2.5)

Luminaire	Flux Distribution	Max. Spacing	Surface Reflectance													Maintenance Factor	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Three Lamp 60 cm Wide Troffer with Diffusing Plastic			0.6	0.26	0.20	0.17	0.26	0.20	0.17	0.25	0.20	0.17	0.20	0.17	0.15		
			0.8	0.32	0.26	0.22	0.32	0.26	0.22	0.31	0.26	0.22	0.25	0.22	0.21	Good 0.70	
			1.0	0.37	0.31	0.27	0.36	0.31	0.27	0.35	0.30	0.27	0.30	0.27	0.26		
			1.25	0.42	0.36	0.32	0.41	0.36	0.32	0.40	0.35	0.32	0.35	0.32	0.30	Medium 0.65	
		0.9 *H*	1.5	0.45	0.40	0.36	0.44	0.39	0.38	0.43	0.38	0.35	0.38	0.35	0.34		
			2.0	0.49	0.44	0.41	0.48	0.44	0.42	0.47	0.43	0.40	0.42	0.40	0.38	Poor 0.55	
			2.5	0.52	0.48	0.44	0.51	0.47	0.44	0.49	0.46	0.43	0.45	0.43	0.42		
			3.0	0.54	0.50	0.47	0.53	0.50	0.47	0.51	0.49	0.46	0.48	0.46	0.44		
			4.0	0.56	0.54	0.51	0.56	0.53	0.51	0.54	0.52	0.50	0.51	0.49	0.48		
			5.0	0.58	0.56	0.54	0.58	0.56	0.54	0.56	0.54	0.53	0.53	0.53	0.50		
Medium Distribution Reflector and Lens			0.6	0.40	0.35	0.32	0.39	0.35	0.32	0.39	0.35	0.32	0.35	0.32	0.31		
			0.8	0.46	0.42	0.39	0.46	0.42	0.39	0.45	0.41	0.39	0.41	0.39	0.38	Good 0.70	
			1.0	0.50	0.46	0.44	0.50	0.46	0.44	0.49	0.46	0.45	0.46	0.45	0.42		
			1.25	0.54	0.51	0.48	0.54	0.50	0.48	0.53	0.50	0.48	0.50	0.47	0.46	Medium 0.65	
		0.8 *H*	1.5	0.57	0.54	0.51	0.56	0.53	0.51	0.55	0.53	0.50	0.52	0.50	0.49		
			2.0	0.60	0.58	0.55	0.60	0.57	0.55	0.59	0.56	0.54	0.56	0.54	0.53	Poor 0.55	
			2.5	0.62	0.60	0.58	0.62	0.60	0.58	0.60	0.59	0.57	0.58	0.56	0.55		
			3.0	0.64	0.62	0.60	0.63	0.61	0.59	0.62	0.60	0.59	0.59	0.58	0.57		
			4.0	0.65	0.63	0.62	0.65	0.63	0.62	0.63	0.62	0.61	0.61	0.60	0.58		
			5.0	0.66	0.65	0.63	0.66	0.64	0.63	0.64	0.63	0.62	0.62	0.61	0.60		
Wide Distribution Reflector Lens			0.6	0.28	0.24	0.21	0.27	0.24	0.21	0.27	0.24	0.21	0.23	0.21	0.20		
or Louver			0.8	0.33	0.29	0.26	0.32	0.29	0.26	0.32	0.29	0.26	0.28	0.26	0.26	Good 0.80	0.75
			1.0	0.36	0.33	0.30	0.36	0.33	0.30	0.36	0.32	0.30	0.32	0.30	0.29		
			1.25	0.40	0.37	0.34	0.40	0.36	0.34	0.39	0.36	0.34	0.36	0.34	0.33	Medium 0.70	0.65
		0.8 *H*	1.5	0.42	0.39	0.37	0.42	0.39	0.37	0.41	0.39	0.36	0.38	0.36	0.35		
			2.0	0.45	0.43	0.40	0.44	0.42	0.40	0.44	0.42	0.40	0.41	0.40	0.39	Poor 0.65	0.55
			2.5	0.47	0.45	0.43	0.46	0.44	0.43	0.45	0.44	0.42	0.43	0.42	0.41		
			3.0	0.48	0.46	0.44	0.48	0.46	0.44	0.47	0.45	0.44	0.44	0.43	0.42		
			4.0	0.50	0.48	0.48	0.49	0.48	0.46	0.48	0.47	0.46	0.46	0.45	0.44		
			5.0	0.50	0.49	0.48	0.50	0.49	0.48	0.49	0.48	0.47	0.47	0.46	0.45		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

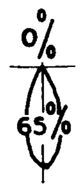
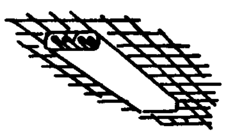
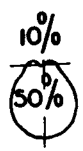
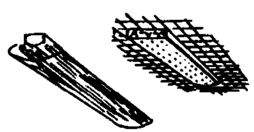
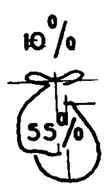
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Louvered Coffer With Silvered-Bowl Lamp			0.6	0.29	0.24	0.21	0.29	0.24	0.21	0.29	0.24	0.21	0.24	0.21	0.20		
			0.8	0.36	0.31	0.27	0.36	0.31	0.27	0.35	0.30	0.27	0.30	0.27	0.26	Good	0.70
			1.0	0.41	0.36	0.32	0.40	0.35	0.32	0.39	0.35	0.32	0.35	0.32	0.31		
			1.25	0.45	0.40	0.37	0.44	0.40	0.37	0.43	0.40	0.37	0.39	0.36	0.35	Medium	0.60
		0.9 *H*	1.5	0.48	0.44	0.41	0.47	0.44	0.40	0.46	0.43	0.40	0.42	0.40	0.39		
			2.0	0.52	0.48	0.45	0.51	0.48	0.45	0.50	0.47	0.45	0.46	0.44	0.43	Poor	0.55
			2.5	0.54	0.51	0.48	0.54	0.51	0.48	0.52	0.50	0.48	0.54	0.47	0.46		
			3.0	0.56	0.53	0.51	0.55	0.53	0.51	0.54	0.52	0.50	0.51	0.50	0.48		
			4.0	0.58	0.56	0.54	0.58	0.56	0.54	0.56	0.55	0.53	0.54	0.52	0.51		
			5.0	0.60	0.58	0.56	0.59	0.58	0.56	0.58	0.57	0.55	0.56	0.54	0.53		
PAR-38 Flood With Metal Louvers			0.6	0.53	0.50	0.48	0.53	0.50	0.48	0.52	0.50	0.48	0.49	0.48	0.47		
			0.8	0.57	0.55	0.53	0.57	0.55	0.53	0.57	0.55	0.53	0.54	0.53	0.52	Good	0.65
			1.0	0.60	0.57	0.55	0.60	0.57	0.55	0.60	0.57	0.55	0.57	0.55	0.54		
			1.25	0.63	0.60	0.58	0.62	0.60	0.58	0.62	0.60	0.58	0.59	0.57	0.56	Medium	0.60
		0.5 *H*	1.5	0.65	0.63	0.61	0.65	0.62	0.60	0.64	0.62	0.60	0.61	0.60	0.59		
			2.0	0.68	0.66	0.64	0.67	0.65	0.64	0.66	0.65	0.63	0.64	0.63	0.62	Poor	0.55
			2.5	0.69	0.67	0.66	0.68	0.67	0.65	0.67	0.66	0.65	0.65	0.64	0.63		
			3.0	0.70	0.69	0.67	0.69	0.78	0.67	0.68	0.67	0.66	0.66	0.65	0.64		
			4.0	0.71	0.70	0.68	0.70	0.69	0.68	0.69	0.68	0.67	0.67	0.66	0.65		
			5.0	0.72	0.71	0.70	0.70	0.70	0.69	0.70	0.69	0.68	0.68	0.67	0.66		
R-40 Flood in Baffled Cylinder			0.6	0.27	0.25	0.24	0.27	0.25	0.24	0.27	0.25	0.24	0.25	0.24	0.24		
			0.8	0.29	0.28	0.27	0.29	0.28	0.27	0.29	0.28	0.27	0.28	0.27	0.27	Good	0.70
			1.0	0.31	0.30	0.29	0.31	0.30	0.29	0.30	0.29	0.28	0.29	0.28	0.28		
			1.25	0.32	0.31	0.30	0.32	0.31	0.30	0.32	0.31	0.30	0.30	0.30	0.29	Medium	0.65
		0.5 *H*	1.5	0.33	0.32	0.31	0.33	0.32	0.31	0.32	0.32	0.31	0.31	0.31	0.30		
			2.0	0.34	0.33	0.32	0.34	0.33	0.32	0.34	0.33	0.32	0.32	0.32	0.31	Poor	0.60
			2.5	0.35	0.34	0.33	0.35	0.34	0.33	0.34	0.34	0.33	0.33	0.33	0.32		
			3.0	0.36	0.35	0.34	0.35	0.34	0.34	0.35	0.34	0.34	0.34	0.33	0.33		
			4.0	0.36	0.36	0.35	0.36	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.33		
			5.0	0.36	0.36	0.35	0.36	0.35	0.35	0.36	0.35	0.35	0.35	0.34	0.33		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

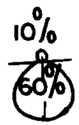
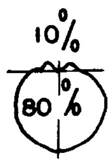
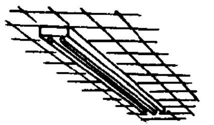
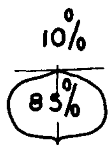
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRI-BUTION	MAX. SPAC-ING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor	0.1			0.1			0.1			0.1		0.1		
			Ceiling	0.8			0.7			0.5			0.3		0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
PAR-38 Flood in Baffled Cylinder			0.6	0.54	0.52	0.50	0.54	0.52	0.50	0.53	0.51	0.50	0.51	0.50	0.50		
			0.8	0.58	0.56	0.54	0.58	0.55	0.54	0.57	0.55	0.54	0.55	0.54	0.53	Good 0.70	
			1.0	0.60	0.58	0.56	0.60	0.58	0.56	0.59	0.57	0.56	0.57	0.56	0.55		
			1.25	0.62	0.60	0.58	0.60	0.59	0.58	0.61	0.59	0.58	0.59	0.58	0.57	Medium 0.65	
		0.5 *H*	1.5	0.63	0.61	0.60	0.63	0.61	0.60	0.62	0.60	0.59	0.60	0.59	0.58		
			2.0	0.65	0.63	0.62	0.64	0.63	0.62	0.63	0.62	0.61	0.61	0.61	0.60	Poor 0.60	
			2.5	0.66	0.65	0.63	0.65	0.64	0.63	0.64	0.63	0.62	0.63	0.62	0.61		
			3.0	0.67	0.66	0.64	0.66	0.65	0.64	0.63	0.64	0.63	0.63	0.63	0.62		
			4.0	0.68	0.67	0.66	0.67	0.66	0.65	0.66	0.65	0.64	0.64	0.64	0.62		
			5.0	0.68	0.67	0.66	0.68	0.67	0.66	0.66	0.66	0.66	0.65	0.64	0.63		
Diffusing Plastic Enclosed 2 and 4 Lamp			0.6	0.18	0.14	0.11	0.17	0.14	0.11	0.17	0.13	0.11	0.13	0.11	0.09		
			0.8	0.23	0.19	0.16	0.22	0.19	0.16	0.21	0.18	0.15	0.17	0.15	0.13	Good 0.70	
			1.0	0.27	0.23	0.20	0.26	0.22	0.20	0.25	0.21	0.19	0.20	0.18	0.16		
			1.25	0.31	0.27	0.24	0.30	0.26	0.23	0.28	0.25	0.22	0.23	0.21	0.19	Medium 0.65	
		1.0 *H*	1.5	0.34	0.30	0.27	0.33	0.29	0.26	0.30	0.27	0.25	0.26	0.23	0.21		
			2.0	0.38	0.34	0.31	0.37	0.33	0.31	0.34	0.31	0.29	0.29	0.27	0.24	Poor 0.55	
			2.5	0.40	0.37	0.34	0.45	0.36	0.33	0.36	0.34	0.32	0.31	0.30	0.26		
			3.0	0.42	0.39	0.36	0.40	0.38	0.35	0.37	0.35	0.34	0.33	0.31	0.28		
			4.0	0.45	0.41	0.39	0.43	0.40	0.38	0.40	0.37	0.36	0.35	0.34	0.30		
			5.0	0.46	0.44	0.42	0.45	0.43	0.40	0.42	0.40	0.38	0.37	0.36	0.32		
Prismatic Glass Enclosed or Diffusing Side and Louver Bottom			0.6	0.28	0.23	0.20	0.27	0.23	0.20	0.26	0.23	0.19	0.22	0.19	0.18	Enclosed	Louver
			0.8	0.34	0.31	0.26	0.34	0.29	0.26	0.32	0.29	0.26	0.28	0.25	0.24	Good 0.70	0.75
			1.0	0.39	0.34	0.31	0.38	0.34	0.31	0.37	0.32	0.29	0.32	0.29	0.27		
			1.25	0.45	0.38	0.36	0.44	0.38	0.36	0.41	0.37	0.34	0.36	0.34	0.32	Medium 0.66	0.70
		1.0 *H*	1.5	0.47	0.43	0.40	0.46	0.42	0.39	0.44	0.41	0.38	0.40	0.39	0.35		
			2.0	0.52	0.47	0.45	0.50	0.47	0.44	0.48	0.45	0.43	0.43	0.41	0.39	Poor 0.55	0.65
			2.5	0.54	0.51	0.47	0.53	0.50	0.47	0.50	0.48	0.46	0.47	0.44	0.42		
			3.0	0.57	0.53	0.51	0.55	0.51	0.49	0.52	0.50	0.48	0.48	0.46	0.44		
			4.0	0.59	0.55	0.53	0.58	0.55	0.53	0.55	0.53	0.50	0.50	0.49	0.46		
			5.0	0.61	0.58	0.56	0.59	0.57	0.55	0.57	0.55	0.54	0.52	0.51	0.48		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

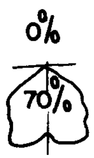
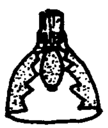
(*Clause* 6.2.5)

Luminaire	Flux Distribution	Max. Spacing	Surface Reflectance													Maintenance Factor	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Diffusing Sides and Prismatic Bottom			0.6	0.28	0.24	0.20	0.27	0.24	0.20	0.27	0.24	0.20	0.24	0.19	0.17		
			0.8	0.35	0.31	0.29	0.35	0.31	0.29	0.34	0.31	0.28	0.30	0.27	0.25	Good 0.70	
			1.0	0.41	0.37	0.34	0.40	0.37	0.34	0.40	0.36	0.34	0.35	0.33	0.31		
			1.25	0.46	0.41	0.39	0.46	0.41	0.39	0.45	0.40	0.38	0.39	0.37	0.35	Medium 0.65	
		1.1 *H*	1.5	0.50	0.46	0.43	0.49	0.45	0.42	0.48	0.45	0.41	0.43	0.40	0.38		
			2.0	0.56	0.51	0.49	0.55	0.51	0.48	0.54	0.50	0.47	0.48	0.46	0.43	Poor 0.55	
			2.5	0.59	0.55	0.51	0.58	0.54	0.51	0.55	0.52	0.50	0.51	0.48	0.45		
			3.0	0.62	0.58	0.55	0.60	0.57	0.54	0.58	0.55	0.53	0.54	0.51	0.48		
			4.0	0.65	0.61	0.59	0.63	0.60	0.58	0.60	0.58	0.56	0.56	0.54	0.50		
			5.0	0.66	0.63	0.61	0.64	0.62	0.60	0.63	0.60	0.59	0.58	0.57	0.53		
Bare Lamp Unit			0.6	0.30	0.24	0.19	0.29	0.24	0.19	0.29	0.23	0.19	0.22	0.18	0.17		
			0.8	0.39	0.29	0.27	0.38	0.31	0.26	0.37	0.31	0.25	0.29	0.25	0.23	Good 0.80	
			1.0	0.46	0.38	0.34	0.46	0.38	0.33	0.42	0.37	0.33	0.35	0.31	0.28		
			1.25	0.53	0.46	0.40	0.52	0.45	0.39	0.49	0.43	0.38	0.41	0.36	0.34	Medium 0.75	
		1.0 *H*	1.5	0.58	0.51	0.46	0.56	0.50	0.44	0.53	0.48	0.44	0.45	0.41	0.38		
			2.0	0.65	0.57	0.53	0.63	0.57	0.52	0.60	0.54	0.50	0.52	0.47	0.45	Poor 0.70	
			2.5	0.69	0.63	0.58	0.67	0.62	0.57	0.64	0.59	0.55	0.56	0.53	0.49		
			3.0	0.73	0.67	0.62	0.71	0.65	0.61	0.67	0.62	0.58	0.60	0.57	0.52		
			4.0	0.77	0.72	0.67	0.75	0.70	0.66	0.71	0.67	0.64	0.64	0.62	0.57		
			5.0	0.81	0.76	0.73	0.78	0.74	0.71	0.74	0.71	0.68	0.68	0.66	0.61		
Procelain Enameled Standard Dome Incandescent			0.6	0.34	0.30	0.25	0.33	0.30	0.26	0.33	0.29	0.25	0.29	0.25	0.23	Vent.	Non-vent.
			0.8	0.42	0.38	0.34	0.42	0.37	0.34	0.42	0.37	0.34	0.37	0.34	0.31	Good 0.80	0.75
			1.0	0.50	0.44	0.40	0.49	0.44	0.40	0.48	0.44	0.40	0.43	0.40	0.36		
			1.25	0.56	0.51	0.48	0.56	0.51	0.47	0.55	0.50	0.47	0.50	0.47	0.42	Medium 0.75	0.65
		1.0 *H*	1.5	0.61	0.56	0.53	0.61	0.56	0.52	0.60	0.55	0.52	0.55	0.52	0.47		
			2.0	0.69	0.63	0.60	0.68	0.63	0.60	0.67	0.63	0.59	0.62	0.59	0.54	Poor 0.65	0.55
			2.5	0.72	0.68	0.64	0.72	0.68	0.64	0.70	0.67	0.64	0.66	0.63	0.59		
			3.0	0.75	0.71	0.68	0.75	0.71	0.68	0.73	0.70	0.67	0.69	0.67	0.63		
			4.0	0.79	0.75	0.73	0.79	0.75	0.73	0.77	0.74	0.72	0.73	0.71	0.68		
			5.0	0.80	0.78	0.77	0.80	0.78	0.76	0.79	0.77	0.75	0.75	0.74	0.70		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

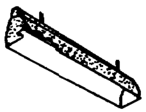
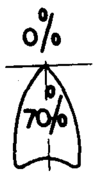
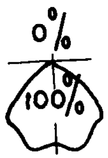
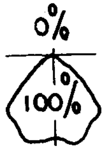
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Enclosed Reflector			0.6	0.39	0.35	0.32	0.38	0.34	0.32	0.38	0.34	0.32	0.34	0.32	0.31		
With Incandescent			0.8	0.48	0.43	0.40	0.47	0.40	0.43	0.46	0.45	0.40	0.42	0.40	0.39	Good 0.80	
Lamp			1.0	0.53	0.49	0.46	0.52	0.48	0.46	0.52	0.48	0.45	0.48	0.45	0.44		
			1.25	0.58	0.54	0.51	0.57	0.53	0.50	0.56	0.53	0.50	0.52	0.50	0.49	Medium 0.75	
		1.0 *H*	1.5	0.61	0.57	0.54	0.60	0.56	0.54	0.59	0.56	0.54	0.56	0.53	0.52		
			2.0	0.65	0.62	0.59	0.64	0.61	0.59	0.63	0.61	0.59	0.60	0.58	0.57	Poor 0.70	
			2.5	0.68	0.65	0.62	0.67	0.64	0.62	0.66	0.63	0.61	0.63	0.61	0.59		
			3.0	0.69	0.67	0.65	0.68	0.66	0.64	0.67	0.65	0.64	0.64	0.63	0.61		
			4.0	0.72	0.69	0.68	0.71	0.68	0.67	0.69	0.68	0.66	0.67	0.66	0.64		
			5.0	0.73	0.71	0.69	0.72	0.70	0.69	0.70	0.69	0.68	0.68	0.67	0.65		
Improved Colour Mercury			0.6	0.35	0.32	0.30	0.35	0.32	0.30	0.35	0.32	0.30	0.32	0.30	0.29	400 W	1 000 W
Aluminium or Glass			0.8	0.43	0.39	0.37	0.43	0.39	0.37	0.42	0.39	0.37	0.39	0.37	0.36	Good 0.65	0.60
Medium Distribution			1.0	0.48	0.45	0.42	0.48	0.44	0.42	0.47	0.44	0.42	0.43	0.41	0.41		
High Bay (Ventilated)			1.25	0.53	0.50	0.47	0.52	0.50	0.47	0.52	0.49	0.47	0.48	0.46	0.46	Medium 0.60	0.55
		0.9 *H*	1.5	0.57	0.53	0.50	0.56	0.53	0.50	0.55	0.52	0.50	0.52	0.50	0.49		
			2.0	0.61	0.57	0.55	0.60	0.57	0.55	0.59	0.57	0.54	0.56	0.54	0.53	Poor 0.60	0.55
			2.5	0.64	0.61	0.59	0.63	0.60	0.58	0.62	0.60	0.58	0.59	0.57	0.56		
			3.0	0.66	0.63	0.61	0.65	0.62	0.60	0.63	0.61	0.60	0.61	0.59	0.58		
			4.0	0.68	0.66	0.63	0.67	0.65	0.63	0.66	0.64	0.63	0.63	0.62	0.61		
			5.0	0.69	0.67	0.66	0.68	0.67	0.65	0.67	0.66	0.64	0.65	0.63	0.62		
Improved Colour Mercury			0.6	0.36	0.32	0.29	0.35	0.32	0.29	0.35	0.31	0.29	0.31	0.29	0.28	400 W	1 000 W
Porcelain Enameled			0.8	0.43	0.39	0.36	0.43	0.39	0.37	0.43	0.39	0.37	0.39	0.37	0.35	Good 0.65	0.60
Wide Distribution			1.0	0.50	0.46	0.43	0.49	0.45	0.42	0.49	0.45	0.42	0.45	0.42	0.41		
High Bay (Ventilated)			1.25	0.55	0.51	0.47	0.55	0.51	0.47	0.54	0.50	0.47	0.50	0.47	0.46	Medium 0.60	0.55
		1.0 *H*	1.5	0.59	0.55	0.53	0.59	0.55	0.52	0.58	0.54	0.52	0.54	0.51	0.50		
			2.0	0.64	0.61	0.58	0.64	0.60	0.58	0.63	0.60	0.57	0.59	0.57	0.55	Poor 0.55	0.50
			2.5	0.67	0.64	0.62	0.67	0.64	0.61	0.66	0.68	0.61	0.62	0.60	0.58		
			3.0	0.70	0.67	0.64	0.69	0.60	0.64	0.68	0.60	0.63	0.65	0.63	0.61		
			4.0	0.74	0.70	0.68	0.73	0.70	0.68	0.71	0.69	0.67	0.68	0.67	0.64		
			5.0	0.75	0.72	0.71	0.74	0.72	0.70	0.73	0.71	0.69	0.70	0.69	0.66		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS—*Contd.*

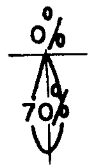
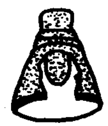
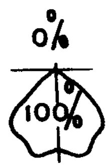
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
3-kW Mercury in Aluminium Reflector			0.6	0.36	0.32	0.28	0.36	0.32	0.28	0.36	0.31	0.28	0.31	0.28	0.28		
			0.8	0.44	0.39	0.36	0.44	0.39	0.36	0.43	0.39	0.36	0.39	0.36	0.35	Good	0.60
			1.0	0.50	0.45	0.42	0.49	0.45	0.41	0.48	0.44	0.41	0.44	0.41	0.39		
			1.25	0.54	0.50	0.47	0.54	0.50	0.47	0.55	0.49	0.46	0.49	0.46	0.43	Medium	0.55
		1.0 *H*	1.5	0.58	0.54	0.50	0.57	0.53	0.50	0.56	0.53	0.50	0.52	0.50	0.46		
			2.0	0.62	0.59	0.56	0.62	0.58	0.56	0.60	0.58	0.55	0.57	0.55	0.51	Poor	0.50
			2.5	0.65	0.60	0.59	0.64	0.61	0.59	0.63	0.60	0.58	0.60	0.58	0.53		
			3.0	0.67	0.64	0.62	0.66	0.63	0.62	0.64	0.62	0.60	0.62	0.60	0.55		
			4.0	0.69	0.67	0.65	0.68	0.66	0.64	0.67	0.65	0.63	0.64	0.63	0.58		
			5.0	0.70	0.68	0.67	0.70	0.68	0.66	0.68	0.67	0.65	0.66	0.65	0.59		
Wide Distribution Including Reflector Lamp in Protective Reflector (Based on 0.4 S/H Ratio)			0.6	0.51	0.45	0.42	0.51	0.45	0.41	0.50	0.45	0.41	0.45	0.41	0.40		
			0.8	0.62	0.56	0.52	0.61	0.56	0.52	0.60	0.55	0.51	0.55	0.51	0.50	Good	0.80
			1.0	0.69	0.63	0.59	0.68	0.63	0.59	0.67	0.62	0.59	0.62	0.59	0.57		
			1.25	0.75	0.70	0.66	0.75	0.70	0.66	0.73	0.69	0.66	0.68	0.66	0.64	Medium	0.75
		1.0 *H*	1.5	0.80	0.75	0.71	0.79	0.75	0.71	0.78	0.74	0.70	0.73	0.70	0.68		
			2.0	0.86	0.81	0.78	0.85	0.80	0.77	0.83	0.80	0.77	0.79	0.76	0.75	Poor	0.70
			2.5	0.89	0.85	0.82	0.88	0.85	0.82	0.87	0.83	0.81	0.83	0.80	0.78		
			3.0	0.92	0.83	0.85	0.90	0.87	0.85	0.89	0.80	0.84	0.85	0.83	0.81		
			4.0	0.95	0.92	0.89	0.94	0.91	0.88	0.92	0.90	0.88	0.88	0.86	0.85		
			5.0	0.97	0.94	0.92	0.95	0.93	0.91	0.94	0.92	0.90	0.91	0.89	0.87		
Wide Distribution Including Reflector Lamp in Protective Reflector (Based on 1.0 S/H Ratio)			0.6	0.56	0.51	0.47	0.56	0.51	0.47	0.56	0.50	0.47	0.50	0.47	0.46		
			0.8	0.66	0.60	0.57	0.66	0.60	0.57	0.65	0.60	0.57	0.60	0.57	0.56	Good	0.80
			1.0	0.73	0.67	0.64	0.73	0.67	0.64	0.72	0.67	0.64	0.67	0.64	0.62		
			1.25	0.78	0.73	0.70	0.78	0.73	0.70	0.77	0.73	0.69	0.72	0.69	0.68	Medium	0.75
		1.0 *H*	1.5	0.82	0.78	0.74	0.82	0.77	0.74	0.80	0.76	0.74	0.76	0.73	0.72		
			2.0	0.88	0.83	0.80	0.87	0.83	0.80	0.85	0.82	0.79	0.81	0.79	0.77	Poor	0.70
			2.5	0.90	0.87	0.84	0.90	0.86	0.83	0.88	0.85	0.83	0.84	0.82	0.81		
			3.0	0.93	0.89	0.87	0.92	0.89	0.86	0.90	0.88	0.86	0.87	0.85	0.83		
			4.0	0.96	0.93	0.90	0.95	0.92	0.90	0.93	0.91	0.89	0.90	0.88	0.86		
			5.0	0.97	0.95	0.93	0.97	0.94	0.92	0.96	0.93	0.91	0.92	0.90	0.88		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS— *Contd.*

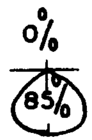
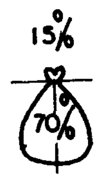
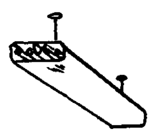
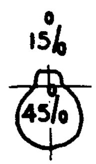
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor	0.1			0.1			0.1			0.1		0.1		
			Ceiling	0.8			0.7			0.5			0.3		0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Mercury High Bay Reflector			0.6	0.57	0.54	0.51	0.56	0.53	0.51	0.56	0.53	0.51	0.52	0.51	0.49		
			0.8	0.63	0.60	0.57	0.62	0.59	0.57	0.61	0.58	0.56	0.58	0.56	0.54	Good 0.65	
			1.0	0.67	0.63	0.61	0.66	0.62	0.61	0.64	0.62	0.60	0.60	0.59	0.57		
			1.25	0.71	0.67	0.65	0.70	0.66	0.64	0.67	0.65	0.63	0.63	0.62	0.60	Medium 0.60	
		0.6 *H*	1.5	0.73	0.70	0.67	0.72	0.69	0.67	0.69	0.67	0.65	0.65	0.64	0.62		
			2.0	0.76	0.73	0.71	0.75	0.72	0.70	0.72	0.70	0.68	0.67	0.66	0.64	Poor 0.50	
			2.5	0.78	0.75	0.73	0.77	0.74	0.72	0.74	0.72	0.70	0.69	0.68	0.65		
			3.0	0.79	0.77	0.75	0.72	0.76	0.74	0.75	0.73	0.72	0.70	0.69	0.66		
			4.0	0.81	0.79	0.77	0.79	0.78	0.76	0.76	0.75	0.74	0.72	0.71	0.67		
			5.0	0.82	0.80	0.79	0.80	0.78	0.77	0.77	0.75	0.75	0.72	0.71	0.68		
Improved Colour Mercury in Low Bay Reflector			0.6	0.39	0.35	0.32	0.38	0.34	0.32	0.38	0.34	0.31	0.33	0.31	0.30		
			0.8	0.48	0.43	0.40	0.47	0.42	0.40	0.46	0.42	0.39	0.41	0.38	0.37	Good 0.65	
			1.0	0.53	0.49	0.46	0.52	0.48	0.45	0.61	0.47	0.45	0.46	0.44	0.41		
			1.25	0.58	0.54	0.51	0.57	0.53	0.50	0.55	0.51	0.49	0.50	0.48	0.45	Medium 0.60	
		1.0 *H*	1.5	0.62	0.58	0.54	0.61	0.57	0.54	0.58	0.55	0.52	0.53	0.51	0.48		
			2.0	0.66	0.62	0.59	0.64	0.61	0.58	0.61	0.59	0.57	0.56	0.55	0.52	Poor 0.55	
			2.5	0.68	0.65	0.63	0.67	0.64	0.62	0.64	0.61	0.60	0.59	0.57	0.54		
			3.0	0.70	0.67	0.65	0.69	0.66	0.64	0.65	0.63	0.61	0.60	0.59	0.56		
			4.0	0.72	0.70	0.68	0.70	0.69	0.67	0.67	0.66	0.64	0.63	0.61	0.58		
			5.0	0.73	0.71	0.70	0.71	0.70	0.68	0.68	0.67	0.66	0.64	0.63	0.59		
Narrow Distribution Including Reflector Lamp in Protective Reflector			0.6	0.66	0.62	0.60	0.66	0.62	0.60	0.65	0.62	0.59	0.62	0.59	0.58		
			0.8	0.75	0.71	0.68	0.75	0.71	0.68	0.74	0.71	0.68	0.70	0.68	0.67	Good 0.80	
			1.0	0.80	0.76	0.73	0.80	0.76	0.73	0.79	0.76	0.73	0.76	0.73	0.72		
			1.25	0.85	0.81	0.80	0.85	0.81	0.80	0.84	0.81	0.78	0.80	0.78	0.77	Medium 0.75	
		0.7 *H*	1.5	0.88	0.86	0.82	0.88	0.85	0.82	0.88	0.84	0.82	0.84	0.82	0.81		
			2.0	0.94	0.90	0.88	0.93	0.90	0.88	0.92	0.89	0.87	0.88	0.87	0.85	Poor 0.70	
			2.5	0.96	0.93	0.92	0.96	0.93	0.91	0.94	0.92	0.90	0.91	0.89	0.88		
			3.0	0.99	0.95	0.94	0.98	0.95	0.93	0.96	0.94	0.92	0.93	0.91	0.89		
			4.0	1.01	0.99	0.96	1.00	0.98	0.96	0.98	0.97	0.95	0.95	0.94	0.92		
			5.0	1.02	1.01	0.99	1.01	1.00	0.98	1.00	0.98	0.97	0.97	0.96	0.94		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

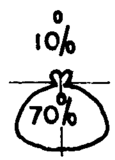
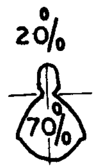
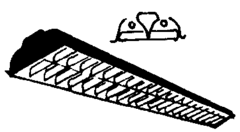
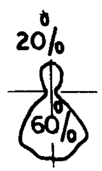
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Improved Colour Mercury Semi-Reflector Lamp in Porcelain Enamelled Ventilated Reflector			0.6	0.37	0.32	0.29	0.37	0.32	0.29	0.37	0.32	0.29	0.32	0.29	0.28	400 W	10000 W
			0.8	0.47	0.42	0.38	0.46	0.42	0.38	0.46	0.41	0.38	0.41	0.38	0.37	Good 0.65	0.60
			1.0	0.54	0.48	0.45	0.54	0.48	0.45	0.53	0.48	0.45	0.48	0.45	0.43		
			1.25	0.60	0.56	0.52	0.60	0.55	0.52	0.60	0.55	0.52	0.54	0.52	0.50	Medium 0.60	0.55
		1.1 *H*	1.5	0.66	0.61	0.57	0.65	0.60	0.57	0.64	0.60	0.57	0.59	0.56	0.55		
			2.0	0.72	0.67	0.64	0.71	0.67	0.64	0.70	0.66	0.63	0.66	0.63	0.62	Poor 0.55	0.50
			2.5	0.76	0.71	0.68	0.75	0.71	0.68	0.73	0.71	0.68	0.70	0.67	0.65		
			3.0	0.79	0.75	0.72	0.78	0.75	0.71	0.77	0.73	0.71	0.72	0.71	0.69		
			4.0	0.82	0.79	0.77	0.81	0.79	0.76	0.80	0.77	0.75	0.76	0.75	0.73		
			5.0	0.84	0.82	0.79	0.83	0.81	0.78	0.82	0.79	0.77	0.78	0.77	0.75		
Improved Colour Mercury Semi-Reflector Lamp in Open Top Aluminium Reflector			0.6	0.41	0.37	0.34	0.40	0.36	0.34	0.40	0.36	0.34	0.36	0.33	0.32		
			0.8	0.49	0.44	0.42	0.49	0.44	0.42	0.47	0.44	0.41	0.43	0.41	0.40	Good 0.65	0.60
			1.0	0.55	0.51	0.48	0.54	0.51	0.47	0.53	0.49	0.47	0.46	0.45	0.44		
			1.25	0.59	0.56	0.53	0.59	0.56	0.53	0.57	0.54	0.52	0.52	0.50	0.48	Medium 0.60	0.55
		1.0 *H*	1.5	0.64	0.60	0.57	0.64	0.59	0.57	0.61	0.57	0.56	0.56	0.55	0.52		
			2.0	0.69	0.65	0.64	0.68	0.64	0.62	0.65	0.62	0.59	0.60	0.58	0.55	Poor 0.55	0.50
			2.5	0.72	0.68	0.65	0.70	0.67	0.65	0.67	0.64	0.62	0.63	0.60	0.57		
			3.0	0.74	0.71	0.69	0.73	0.70	0.67	0.70	0.67	0.64	0.64	0.62	0.59		
			4.0	0.76	0.74	0.71	0.75	0.72	0.70	0.71	0.70	0.67	0.65	0.64	0.60		
			5.0	0.79	0.76	0.74	0.76	0.75	0.72	0.72	0.71	0.70	0.67	0.65	0.68		
Plastic Enclosed with Apertured Top			0.6	0.18	0.14	0.11	0.17	0.14	0.11	0.17	0.14	0.11	0.14	0.11	0.10		
			0.8	0.23	0.19	0.16	0.23	0.19	0.16	0.22	0.18	0.16	0.18	0.15	0.14	Good 0.70	
			1.0	0.28	0.24	0.20	0.27	0.23	0.19	0.26	0.23	0.19	0.21	0.19	0.18		
			1.25	0.33	0.28	0.24	0.31	0.27	0.24	0.30	0.26	0.24	0.25	0.23	0.21	Medium 0.60	
		1.0 *H*	1.5	0.36	0.31	0.28	0.35	0.31	0.28	0.33	0.30	0.26	0.28	0.27	0.23		
			2.0	0.41	0.36	0.32	0.40	0.36	0.32	0.37	0.33	0.31	0.32	0.29	0.27	Poor 0.50	
			2.5	0.44	0.39	0.36	0.43	0.38	0.35	0.40	0.36	0.34	0.34	0.32	0.29		
			3.0	0.46	0.43	0.39	0.45	0.41	0.38	0.42	0.39	0.37	0.37	0.34	0.32		
			4.0	0.50	0.46	0.43	0.48	0.45	0.42	0.45	0.42	0.41	0.39	0.38	0.34		
			5.0	0.52	0.49	0.46	0.50	0.48	0.45	0.47	0.44	0.43	0.41	0.40	0.36		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS—*Contd.*

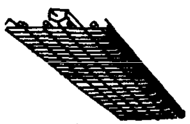
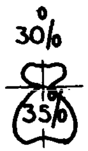
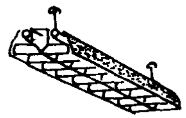
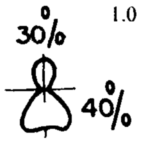
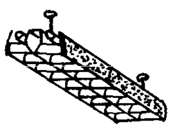
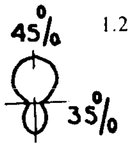
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE												MAINTENANCE FACTOR	
			Floor	0.1			0.1			0.1			0.1		0.1		
			Ceiling	0.8			0.7			0.5			0.3		0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Porcelain Enamelled Industrial with 13° Crosswise Shielding 		1.0 *H*	0.6	0.31	0.25	0.23	0.31	0.25	0.23	0.29	0.25	0.21	0.25	0.21	0.20		
			0.8	0.40	0.34	0.30	0.39	0.34	0.30	0.38	0.33	0.30	0.33	0.30	0.28	Good	0.75
			1.0	0.47	0.41	0.37	0.47	0.40	0.37	0.45	0.40	0.36	0.39	0.36	0.34		
			1.25	0.54	0.48	0.44	0.54	0.48	0.43	0.52	0.46	0.43	0.45	0.42	0.40	Medium	0.70
			1.5	0.60	0.54	0.49	0.58	0.53	0.49	0.56	0.51	0.48	0.50	0.47	0.45		
			2.0	0.67	0.61	0.57	0.65	0.60	0.56	0.62	0.58	0.54	0.56	0.54	0.50	Poor	0.65
			2.5	0.71	0.65	0.61	0.69	0.64	0.60	0.66	0.62	0.59	0.60	0.58	0.54		
			3.0	0.74	0.69	0.65	0.72	0.67	0.65	0.69	0.66	0.62	0.62	0.61	0.57		
			4.0	0.78	0.74	0.70	0.75	0.73	0.69	0.73	0.69	0.67	0.67	0.64	0.61		
			5.0	0.81	0.77	0.75	0.79	0.76	0.74	0.76	0.72	0.70	0.70	0.67	0.64		
Porcelain Enamelled Industrial with 30° Crosswise Shielding 		1.0 *H*	0.6	0.32	0.27	0.24	0.31	0.26	0.23	0.30	0.25	0.22	0.25	0.22	0.21		
			0.8	0.41	0.36	0.32	0.40	0.35	0.31	0.38	0.34	0.30	0.33	0.30	0.27	Good	0.75
			1.0	0.49	0.43	0.39	0.47	0.42	0.38	0.45	0.40	0.37	0.38	0.36	0.32		
			1.25	0.56	0.50	0.45	0.54	0.48	0.44	0.51	0.46	0.43	0.44	0.41	0.36	Medium	0.70
			1.5	0.61	0.55	0.50	0.59	0.53	0.49	0.55	0.51	0.47	0.48	0.45	0.40		
			2.0	0.68	0.62	0.58	0.65	0.60	0.56	0.61	0.57	0.53	0.54	0.51	0.44	Poor	0.65
			2.5	0.72	0.67	0.63	0.69	0.65	0.61	0.66	0.61	0.58	0.57	0.55	0.47		
			3.0	0.75	0.71	0.67	0.72	0.68	0.65	0.67	0.64	0.61	0.60	0.58	0.49		
			4.0	0.79	0.75	0.72	0.76	0.73	0.70	0.71	0.78	0.66	0.63	0.62	0.54		
			5.0	0.82	0.79	0.76	0.78	0.76	0.73	0.73	0.71	0.69	0.66	0.64	0.53		
Porcelain Enamelled Industrial with 30° Crosswise and Lengthwise Shielding Reflector 		0.9 *H*	0.6	0.31	0.26	0.23	0.30	0.25	0.22	0.28	0.24	0.22	0.24	0.22	0.20		
			0.8	0.39	0.34	0.31	0.38	0.33	0.28	0.36	0.32	0.28	0.31	0.27	0.25	Good	0.75
			1.0	0.45	0.40	0.37	0.44	0.39	0.36	0.41	0.31	0.35	0.36	0.34	0.31		
			1.25	0.52	0.46	0.42	0.49	0.45	0.41	0.46	0.43	0.40	0.41	0.38	0.35	Medium	0.70
			1.5	0.55	0.50	0.46	0.54	0.49	0.46	0.50	0.47	0.44	0.41	0.41	0.39		
			2.0	0.61	0.56	0.52	0.59	0.55	0.51	0.55	0.52	0.49	0.49	0.47	0.43	Poor	0.60
			2.5	0.65	0.60	0.57	0.62	0.59	0.56	0.58	0.55	0.53	0.52	0.50	0.45		
			3.0	0.68	0.64	0.60	0.65	0.62	0.59	0.61	0.58	0.56	0.54	0.52	0.47		
			4.0	0.71	0.68	0.65	0.68	0.65	0.63	0.63	0.61	0.57	0.57	0.55	0.49		
			5.0	0.73	0.70	0.68	0.60	0.68	0.68	0.65	0.63	0.62	0.69	0.57	0.51		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

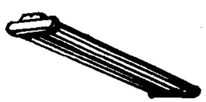
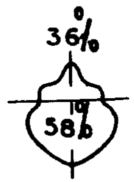
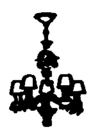
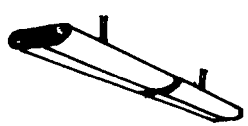
(*Clause* 6.2.5)

Luminaire	Flux Distribution	Max. Spacing	Surface Reflectance													Maintenance Factor	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Direct-Indirect With Opaque Side Panels and Louver Bottom			0.6	0.20	0.16	0.13	0.20	0.16	0.13	0.19	0.16	0.13	0.15	0.13	0.12		
			0.8	0.25	0.22	0.18	0.25	0.20	0.18	0.23	0.19	0.17	0.19	0.17	0.16	Good	0.75
			1.0	0.31	0.27	0.24	0.30	0.26	0.23	0.28	0.24	0.22	0.22	0.21	0.18		
			1.25	0.35	0.31	0.28	0.34	0.30	0.28	0.30	0.28	0.26	0.26	0.24	0.21	Medium	0.70
		1.1 *H*	1.5	0.37	0.33	0.30	0.36	0.32	0.29	0.32	0.30	0.27	0.27	0.25	0.23		
			2.0	0.42	0.38	0.35	0.40	0.37	0.34	0.37	0.33	0.31	0.31	0.29	0.25	Poor	0.65
			2.5	0.44	0.41	0.39	0.42	0.40	0.37	0.39	0.36	0.34	0.33	0.32	0.27		
			3.0	0.47	0.44	0.41	0.45	0.42	0.40	0.40	0.38	0.36	0.34	0.33	0.28		
			4.0	0.50	0.47	0.45	0.47	0.45	0.43	0.42	0.40	0.39	0.36	0.35	0.29		
			5.0	0.51	0.49	0.47	0.49	0.47	0.46	0.43	0.42	0.40	0.39	0.36	0.30		
Direct-Indirect With Metal or Dense Diffusing Sides and 40° Louver Shielding			0.6	0.22	0.18	0.16	0.21	0.18	0.16	0.20	0.17	0.15	0.16	0.15	0.15		
			0.8	0.29	0.24	0.29	0.27	0.24	0.21	0.25	0.23	0.20	0.22	0.19	0.18	Good	0.75
			1.0	0.33	0.29	0.26	0.33	0.29	0.25	0.31	0.27	0.24	0.26	0.23	0.21		
			1.25	0.39	0.34	0.31	0.37	0.33	0.31	0.35	0.31	0.29	0.29	0.28	0.24	Medium	0.70
		1.0 *H*	1.5	0.43	0.38	0.35	0.41	0.36	0.34	0.38	0.34	0.32	0.32	0.36	0.36		
			2.0	0.48	0.44	0.40	0.46	0.42	0.39	0.41	0.39	0.35	0.34	0.33	0.22	Poor	0.65
			2.5	0.51	0.47	0.44	0.49	0.45	0.43	0.44	0.40	0.38	0.37	0.32	0.30		
			3.0	0.53	0.50	0.48	0.51	0.47	0.45	0.46	0.44	0.41	0.40	0.38	0.32		
			4.0	0.57	0.53	0.51	0.53	0.50	0.49	0.48	0.46	0.45	0.41	0.40	0.34		
			5.0	0.59	0.56	0.54	0.55	0.53	0.51	0.49	0.47	0.46	0.42	0.41	0.35		
Direct-Indirect With Metal or Dense Diffusing Sides and 35° C×45° Louver Shielding			0.6	0.24	0.19	0.16	0.23	0.19	0.16	0.22	0.18	0.15	0.17	0.14	0.13		
			0.8	0.31	0.26	0.22	0.30	0.25	0.21	0.27	0.24	0.20	0.22	0.19	0.17	Good	0.75
			1.0	0.37	0.30	0.27	0.34	0.29	0.26	0.32	0.27	0.24	0.25	0.23	0.19		
			1.25	0.42	0.36	0.32	0.40	0.35	0.32	0.56	0.32	0.29	0.29	0.26	0.22	Medium	0.70
		1.2 *H*	1.5	0.46	0.40	0.35	0.44	0.39	0.34	0.38	0.35	0.31	0.31	0.28	0.23		
			2.0	0.53	0.46	0.42	0.49	0.44	0.40	0.43	0.39	0.35	0.34	0.33	0.26	Poor	0.65
			2.5	0.57	0.51	0.47	0.52	0.48	0.45	0.47	0.43	0.40	0.37	0.34	0.28		
			3.0	0.60	0.55	0.50	0.56	0.51	0.48	0.49	0.45	0.43	0.39	0.37	0.29		
			4.0	0.63	0.59	0.55	0.59	0.56	0.53	0.51	0.49	0.45	0.41	0.40	0.30		
			5.0	0.66	0.63	0.60	0.62	0.58	0.57	0.53	0.51	0.49	0.43	0.42	0.32		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

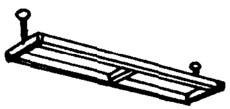
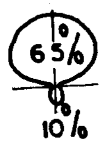
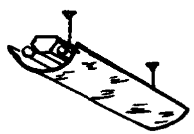
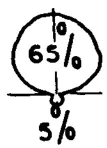
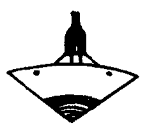
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE												MAINTENANCE FACTOR	
			Floor	0.1												
			Ceiling	0.8			0.7			0.5			0.3		0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
4 Bare Lamps in a Line			0.6	0.25	0.18	0.15	0.24	0.18	0.15	0.23	0.18	0.14	0.17	0.14	0.12		
			0.8	0.32	0.26	0.21	0.31	0.25	0.21	0.29	0.24	0.20	0.23	0.19	0.17	Good	0.80
			1.0	0.40	0.32	0.27	0.38	0.31	0.26	0.36	0.30	0.25	0.27	0.24	0.21		
			1.25	0.46	0.39	0.33	0.45	0.38	0.32	0.40	0.35	0.32	0.33	0.29	0.25	Medium	0.75
		1.0 *H*	1.5	0.51	0.43	0.41	0.49	0.41	0.37	0.45	0.39	0.34	0.35	0.32	0.28		
			2.0	0.58	0.52	0.45	0.56	0.50	0.44	0.51	0.46	0.41	0.41	0.38	0.33	Poor	0.70
			2.5	0.63	0.57	0.51	0.62	0.55	0.50	0.56	0.50	0.46	0.45	0.42	0.36		
			3.0	0.69	0.62	0.56	0.65	0.60	0.55	0.59	0.57	0.50	0.48	0.45	0.38		
			4.0	0.74	0.69	0.63	0.70	0.65	0.60	0.63	0.59	0.56	0.53	0.51	0.42		
			5.0	0.77	0.74	0.68	0.74	0.69	0.66	0.67	0.63	0.61	0.56	0.54	0.45		
Chandelier With Opaque or Dense Diffusing Shades			0.6	0.17	0.13	0.11	0.16	0.15	0.11	0.15	0.12	0.10	0.12	0.10	0.08		
			0.8	0.23	0.18	0.16	0.21	0.18	0.15	0.19	0.17	0.14	0.15	0.14	0.11	Good	0.80
			1.0	0.27	0.22	0.20	0.25	0.22	0.19	0.23	0.20	0.18	0.18	0.16	0.13		
			1.25	0.31	0.27	0.24	0.30	0.26	0.23	0.27	0.23	0.21	0.21	0.19	0.15	Medium	0.75
		1.0 *H*	1.5	0.34	0.30	0.26	0.32	0.29	0.25	0.29	0.25	0.23	0.22	0.20	0.17		
			2.0	0.39	0.35	0.32	0.37	0.34	0.31	0.32	0.29	0.27	0.25	0.23	0.19	Poor	0.70
			2.5	0.43	0.41	0.35	0.39	0.36	0.34	0.35	0.32	0.30	0.28	0.26	0.20		
			3.0	0.45	0.42	0.38	0.42	0.39	0.36	0.36	0.34	0.32	0.29	0.28	0.21		
			4.0	0.48	0.45	0.42	0.44	0.42	0.40	0.39	0.36	0.34	0.31	0.30	0.23		
			5.0	0.49	0.47	0.44	0.46	0.44	0.42	0.39	0.38	0.36	0.32	0.31	0.23		
Translucent Bottom and Sides			0.6	0.16	0.11	0.07	0.15	0.10	0.06	0.12	0.08	0.06	0.07	0.06	0.03		
			0.8	0.21	0.15	0.12	0.19	0.15	0.12	0.16	0.12	0.08	0.09	0.07	0.04	Good	0.70
			1.0	0.26	0.20	0.16	0.23	0.19	0.15	0.19	0.15	0.12	0.12	0.10	0.05		
			1.25	0.32	0.25	0.20	0.28	0.23	0.19	0.23	0.18	0.15	0.14	0.12	0.06	Medium	0.60
		1.2 *H*	1.5	0.36	0.30	0.24	0.33	0.26	0.22	0.25	0.21	0.18	0.16	0.13	0.07		
			2.0	0.42	0.36	0.31	0.38	0.33	0.27	0.29	0.25	0.22	0.18	0.16	0.08	Poor	0.50
			2.5	0.46	0.40	0.36	0.41	0.36	0.33	0.32	0.29	0.25	0.20	0.19	0.09		
			3.0	0.50	0.44	0.40	0.44	0.40	0.36	0.34	0.31	0.28	0.22	0.20	0.09		
			4.0	0.54	0.50	0.45	0.48	0.44	0.41	0.37	0.34	0.32	0.25	0.22	0.10		
			5.0	0.57	0.53	0.50	0.51	0.48	0.44	0.39	0.36	0.34	0.25	0.25	0.10		

(Continued)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS—*Contd.*

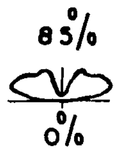
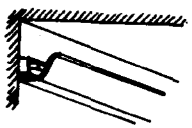
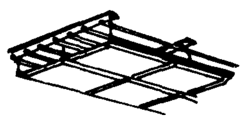
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING		SURFACE REFLECTANCE												MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Luminous-Indirect Fluorescent Grid			0.6	0.16	0.11	0.08	0.15	0.10	0.07	0.13	0.09	0.06	0.08	0.06	0.03		
			0.8	0.22	0.16	0.12	0.20	0.15	0.11	0.17	0.13	0.10	0.10	0.08	0.04	Good	0.70
			1.0	0.27	0.21	0.17	0.25	0.19	0.15	0.20	0.16	0.13	0.12	0.10	0.05		
			1.25	0.32	0.26	0.21	0.29	0.24	0.19	0.23	0.19	0.16	0.15	0.12	0.06	Medium	0.60
		1.2 *H*	1.5	0.37	0.30	0.26	0.33	0.28	0.23	0.26	0.22	0.19	0.16	0.14	0.07		
			2.0	0.43	0.37	0.32	0.39	0.34	0.29	0.30	0.26	0.23	0.19	0.16	0.08	Poor	0.50
			2.5	0.48	0.42	0.36	0.43	0.38	0.34	0.33	0.29	0.26	0.21	0.19	0.09		
			3.0	0.51	0.46	0.39	0.46	0.41	0.38	0.35	0.33	0.39	0.22	0.21	0.09		
			4.0	0.56	0.51	0.43	0.49	0.46	0.43	0.38	0.35	0.33	0.25	0.24	0.10		
			5.0	0.58	0.55	0.51	0.52	0.49	0.46	0.39	0.37	0.35	0.36	0.25	0.10		
Luminous-Indirect Fluorescent			0.6	0.11	0.07	0.04	0.10	0.07	0.04	0.08	0.06	0.03	0.05	0.03			
			0.8	0.14	0.10	0.07	0.13	0.09	0.07	0.10	0.07	0.06	0.06	0.04		Good	0.70
			1.0	0.19	0.14	0.10	0.17	0.13	0.09	0.13	0.10	0.07	0.08	0.05			
			1.25	0.23	0.18	0.15	0.21	0.16	0.14	0.15	0.13	0.10	0.09	0.07		Medium	0.60
		1.2 *H*	1.5	0.26	0.20	0.17	0.24	0.19	0.16	0.18	0.14	0.12	0.10	0.08			
			2.0	0.31	0.26	0.28	0.28	0.24	0.20	0.20	0.18	0.16	0.12	0.11		Poor	0.50
			2.5	0.35	0.30	0.26	0.31	0.26	0.24	0.24	0.20	0.28	0.13	0.12			
			3.0	0.37	0.34	0.29	0.33	0.30	0.26	0.25	0.21	0.20	0.14	0.13			
			4.0	0.39	0.37	0.34	0.36	0.38	0.30	0.27	0.25	0.23	0.16	0.16			
			5.0	0.44	0.40	0.37	0.37	0.35	0.33	0.27	0.26	0.25	0.17	0.17			
Luminous-Indirect Incandescent			0.6	0.15	0.09	0.06	0.13	0.08	0.05	0.10	0.07	0.04	0.05	0.03	0.01		
			0.8	0.20	0.13	0.09	0.19	0.12	0.08	0.15	0.09	0.07	0.07	0.04	0.01	Good	0.70
			1.0	0.25	0.18	0.13	0.23	0.17	0.12	0.17	0.13	0.09	0.09	0.06	0.01		
			1.25	0.30	0.23	0.19	0.27	0.22	0.17	0.20	0.16	0.12	0.11	0.08	0.02	Medium	0.60
		1.2 *H*	1.5	0.35	0.28	0.23	0.31	0.25	0.20	0.23	0.19	0.15	0.12	0.10	0.20		
			2.0	0.42	0.35	0.30	0.38	0.31	0.26	0.28	0.28	0.19	0.14	0.12	0.20	Poor	0.50
			2.5	0.47	0.41	0.35	0.41	0.36	0.31	0.31	0.26	0.23	0.15	0.14	0.02		
			3.0	0.51	0.46	0.41	0.45	0.40	0.36	0.32	0.29	0.27	0.18	0.15	0.02		
			4.0	0.56	0.51	0.46	0.49	0.45	0.41	0.35	0.32	0.31	0.20	0.19	0.30		
			5.0	0.59	0.55	0.50	0.51	0.48	0.45	0.37	0.35	0.32	0.21	0.20	0.03		

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS — *Contd.*

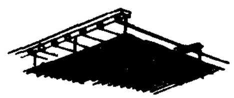
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRI-BUTION	MAX. SPAC-ING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Silvered-Bowl Indirect			0.6	0.14	0.08	0.04	0.13	0.07	0.04	0.11	0.06	0.03	0.05	0.02	0.00		
			0.8	0.19	0.12	0.07	0.17	0.11	0.07	0.14	0.09	0.05	0.07	0.04	0.00	Good	0.75
			1.0	0.24	0.16	0.11	0.22	0.15	0.11	0.17	0.12	0.18	0.09	0.05	0.00		
			1.25	0.30	0.22	0.16	0.27	0.20	0.14	0.21	0.15	0.10	0.10	0.06	0.01	Medium	0.70
		1.2 *H*	1.5	0.35	0.26	0.20	0.31	0.24	0.18	0.23	0.17	0.13	0.11	0.08	0.01		
			2.0	0.42	0.34	0.28	0.37	0.30	0.24	0.27	0.22	0.17	0.14	0.11	0.01	Poor	0.65
			2.5	0.48	0.40	0.34	0.41	0.35	0.31	0.29	0.25	0.21	0.16	0.13	0.01		
			3.0	0.52	0.45	0.38	0.45	0.39	0.34	0.32	0.27	0.25	0.17	0.15	0.01		
			4.0	0.57	0.52	0.46	0.50	0.45	0.41	0.36	0.32	0.29	0.20	0.18	0.01		
			5.0	0.61	0.56	0.51	0.52	0.49	0.45	0.40	0.35	0.32	0.21	0.20	0.01		
Fluorescent Cove Without Reflector			0.6	0.11	0.09	0.06	0.09	0.07	0.06	0.07	0.06	0.04					
		30 cm	0.8	0.15	0.12	0.10	0.13	0.10	0.08	0.09	0.07	0.06				Good	0.70
		to	1.0	0.18	0.15	0.12	0.16	0.18	0.10	0.10	0.09	0.07					
		40 cm	1.25	0.22	0.18	0.16	0.20	0.16	0.14	0.13	0.11	0.10				Medium	0.60
		below	1.5	0.25	0.21	0.19	0.21	0.19	0.17	0.15	0.13	0.11					
		ceil-	2.0	0.29	0.26	0.22	0.25	0.22	0.20	0.17	0.15	0.14				Poor	0.50
		ing	2.5	0.33	0.30	0.28	0.22	0.26	0.24	0.20	0.19	0.17					
			3.0	0.35	0.32	0.30	0.31	0.28	0.26	0.21	0.20	0.19					
			4.0	0.36	0.34	0.32	0.32	0.30	0.28	0.22	0.21	0.20					
			5.0	0.39	0.38	0.36	0.38	0.34	0.32	0.24	0.23	0.23					
				NOTE — Due to poor reflectance, system is not advocated.													
Diffusing Glass or Plastics Extended Area System			0.6	0.19	0.15	0.13	Ceiling cavity reflectance 75 percent										
			0.8	0.25	0.22	0.19	Plastic or glass reflectance 45 percent									Good	0.65
			1.0	0.31	0.26	0.23	Plastic or glass transmittance 45 percent										
			1.25	0.35	0.32	0.29	In the use of these tables consideration									Medium	0.55
			1.5	0.40	0.35	0.33	must be given to the fact that the										
			2.0	0.45	0.42	0.38	coefficients of utilization shown are									Poor	0.45
			2.5	0.49	0.46	0.42	based on a single set of representative										
			3.0	0.52	0.49	0.46	consisions. The efficiency of wall to-wall										
			4.0	0.56	0.54	0.53	lighting systems varies greatly with cavity										
			5.0	0.58	0.57	0.55	proportion and replectances, the type of										
							lighting equipment used, and with the										
							reflection and transmission ciracteristics										
							of the shieiding medium.										

(*Continued*)

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS—*Contd.*

(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor		0.1			0.1			0.1			0.1	0.1		
			Ceiling		0.8			0.7			0.5			0.3	0.0		
			Walls	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0.0		
			Room Index	Coefficient of Utilization													
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Opaque Louver			0.6	0.19	0.16	0.15	Ceiling cavity reflectance 75%										
(White) Extended			0.8	0.23	0.20	0.19	Louvre surface reflectance 75%									Good	0.70
Area System			1.0	0.25	0.22	0.21	In the use of these tables consider-										
			1.25	0.27	0.25	0.24	ation rust be given to the fact that									Medium	0.65
			1.5	0.30	0.26	0.25	the coefficients of utilization shown										
			2.0	0.32	0.30	0.29	are based on a single set of representa-									Poor	0.55
			2.5	0.33	0.31	0.30	tive conditions. The efficiency of wall										
			3.0	0.34	0.32	0.32	to wall lighting systems varies greatly										
			4.0	0.35	0.34	0.33	with cavity proportion and reflectances,										
			5.0	0.36	0.35	0.34	the type of lighting equipment used, and										
							with the reflection and transmission										
							characteristics of the shielding medium.										

NOTE — The above tabulations are based on floors of 10 percent effetive reflectance and take into account reflectances and obstructions below the workplane (machinery, furniture, etc). Higher effective reflectances, naturally, will tend to increase utilization, especially in high ratio rooms. Table 30, giving approximate correction factors for floors of 30 percent reflectance.

TABLE 23 APPROXIMATE MULTIPLYING FACTORS FOR 30 PERCENT FLOOR REFLECTANCE

(*Clause* 6.2.5)

CEILING	80 percent			70 percent			50 percent			30 percent		
WALLS ROOM RATIO	50 percent	30 percent	10 percent	50 percent	30 percent	10 percent	50 percent	30 percent	10 percent	50 percent	30 percent	10 percent
0.6	1.03	1.02	1.01	1.03	1.02	1.01	1.02	1.02	1.00	1.02	1.01	1.00
0.8	1.04	1.02	1.01	1.04	1.02	1.01	1.03	1.02	1.01	1.02	1.01	1.01
1.0	1.05	1.03	1.02	1.04	1.03	1.02	1.04	1.02	1.01	1.03	1.02	1.01
1.25	1.06	1.04	1.02	1.05	1.04	1.02	1.04	1.03	1.04	1.03	1.02	1.01
1.5	1.07	1.06	1.03	1.07	1.05	1.03	1.05	1.04	1.02	1.03	1.02	1.02
2.0	1.09	1.07	1.05	1.08	1.06	1.04	1.05	1.04	1.03	1.04	1.03	1.02
2.5	1.10	1.08	1.06	1.09	1.08	1.06	1.07	1.05	1.04	1.04	1.04	1.03
3.0	1.12	1.10	1.08	1.10	1.09	1.07	1.08	1.06	1.04	1.05	1.04	1.03
4.0	1.14	1.12	1.10	1.12	1.10	1.08	1.08	1.07	1.06	1.05	1.04	1.04
5.0	1.15	1.13	1.11	1.13	1.11	1.10	1.09	1.08	1.07	1.05	1.05	1.04

TABLE 24 ANGLE SUBTENDED BY THE DIRECTION OF LIGHT WITH VERTICAL AXIS AND LUX VALUES ON THE HORIZONTAL AT DIFFERENT LOCATIONS FOR AN ASSUMED INTENSITY OF 100 CANDELA IN THE GIVEN DIRECTION

(*Clause* 6.4.4)

h \ *d*	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
1.0	0°0′	27°	45°	56°	68°	68°	71°	74°	76°	78°	79°	80°	81°	81°	82°	82°	83°
	100.000	71.400	35.400	17.100	8.980	5.192	3.208	2.112	1.420	1.020	0.760	0.568	0.452	0.360	0.280	0.232	0.19
1.5	0°0′	18°	34°	45°	53°	59°	63°	67°	69°	72°	73°	75°	76°	77°	78°	79°	80°
	44.440	38.000	25.600	15.732	9.600	6.088	4.000	2.720	1.908	1.424	1.056	0.820	0.644	0.504	0.400	0.336	0.28
2.0	0°0′	14°	27°	37°	45°	51°	56°	60°	63°	66°	68°	70°	72°	73°	74°	75°	76°
	25.000	22.828	17.888	12.800	8.840	0.996	4.264	3.056	2.236	1.676	1.280	0.996	0.792	0.636	0.520	0.428	0.36
2.5	0°0′	11°	22°	31°	39°	45°	50°	54°	58°	61°	63°	66°	67°	69°	70°	72°	73°
	16.000	15.084	12.808	10.088	7.616	5.656	4.200	3.140	2.380	1.832	1.432	1.132	0.912	0.740	0.608	0.504	0.42
3.0	0°0′	9°	18°	27°	34°	40°	45°	49°	53°	56°	59°	61°	63°	66°	67°	68°	69°
	11.112	10.692	9.488	7.948	6.400	5.040	3.928	3.064	2.400	1.896	1.512	1.220	0.996	0.820	0.680	0.568	0.48
3.5	0°0′	8°	16°	23°	30°	36°	41°	45°	49°	52°	55°	58°	60°	62°	63°	65°	66°
	8.164	7.920	7.256	6.340	5.344	4.400	3.572	2.888	2.332	1.892	1.540	1.264	1.044	0.872	0.732	0.616	0.52
4.0	0°0′	7°	14°	21°	27°	32°	37°	41°	45°	48°	51°	54°	56°	58°	60°	62°	63°
	6.252	6.108	5.708	5.132	4.472	3.812	3.200	2.688	2.208	1.832	1.524	1.272	1.068	0.900	0.764	0.652	0.56
4.5	0°0′	6°	13°	18°	24°	29°	34°	38°	42°	45°	48°	51°	53°	55°	57°	59°	61°
	4.940	4.848	4.592	4.216	3.772	3.300	2.844	2.428	2.060	1.748	1.480	1.256	1.068	0.912	0.784	0.672	0.58

(*Continued*)

TABLE 24 ANGLE SUBTENDED BY THE DIRECTION OF LIGHT WITH VERTICAL AXIS AND LUX VALUES ON THE HORIZONTAL AT DIFFERENT LOCATIONS FOR AN ASSUMED INTENSITY OF 100 CANDELA IN THE GIVEN DIRECTION —*Contd.*

h \ *d*	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
5.0	0°0′ 4.000	5°43′ 3.940	11° 3.772	17° 3.516	22° 3.204	27° 2.864	31° 2.524	35° 2.200	39° 1.904	42° 1.644	45° 1.416	48° 1.220	50° 1.052	52° 0.908	54° 0.784	56° 0.684	59° 0.596
5.5	0°0′ 3.304	5°18′ 3.264	10° 3.148	15° 2.968	20° 2.754	24° 2.492	29° 2.236	32° 1.984	36° 1.748	39° 1.532	42° 1.340	45° 1.168	48° 1.020	50° 0.892	52° 0.780	54° 0.684	56° 0.600
6.0	0°0′ 2.776	4°46′ 2.748	9° 2.672	14° 2.536	18° 2.372	23° 2.184	27° 1.988	30° 1.792	34° 1.600	37° 1.424	40° 1.260	43° 1.112	45° 0.984	47° 0.868	49° 0.764	51° 0.676	53° 0.600
6.5	0°0′ 2.378	4°24′ 2.348	9° 2.284	13° 2.188	17° 2.068	21° 1.924	25° 1.788	28° 1.616	32° 1.464	35° 1.316	38° 1.180	40° 1.032	43° 0.940	45° 0.836	47° 0.748	49° 0.664	51° 0.592
7.0	0°0′ 2.040	4° 5′ 2.024	8° 1.980	12° 1.908	16° 1.816	20° 1.704	23° 1.584	27° 1.460	30° 1.336	33° 1.216	36° 1.100	38° 0.992	41° 0.892	43° 0.804	45° 0.720	47° 0.648	49° 0.584
7.5	0°0′ 1.776	3°49′ 1.768	8° 1.732	11° 1.676	15° 1.604	18° 1.520	22° 1.424	25° 1.324	28° 1.200	31° 1.120	34° 1.024	36° 0.932	39° 0.848	41° 0.768	43° 0.696	45° 0.628	47° 0.568
8.0	0°0′ 1.564	3°35′ 1.552	7° 1.528	11° 1.484	14° 1.428	17° 1.356	21° 1.284	24° 1.200	27° 1.120	29° 1.036	32° 0.952	35° 0.876	37° 0.800	39° 0.732	41° 0.668	43° 0.608	45° 0.552
8.5	0°0′ 1.384	3°22′ 1.376	7° 1.356	10° 1.324	13° 1.276	16° 1.224	19° 1.160	22° 1.096	25° 1.024	28° 0.956	30° 0.888	33° 0.820	35° 0.756	37° 0.696	39° 0.636	41° 0.584	43° 0.536
9.0	0°0′ 1.236	3°11′ 1.228	6° 1.212	9° 1.188	13° 1.148	16° 1.104	18° 1.056	21° 1.000	24° 0.944	27° 0.884	29° 0.824	31° 0.768	34° 0.712	36° 0.660	38° 0.608	40° 0.560	42° 0.516
10.0	0°0′ 1.000	2°51′ 0.996	5°43′ 0.984	9° 0.968	11° 0.944	14° 0.912	17° 0.876	19° 0.840	22° 0.800	24° 0.760	27° 0.716	29° 0.672	31° 0.632	33° 0.588	35° 0.548	37° 0.512	39° 0.476
10.5	0°0′ 0.908	2°44′ 0.904	5°26′ 0.896	8° 0.880	11° 0.860	13° 0.840	16° 0.804	18° 0.776	21° 0.740	23° 0.704	25° 0.668	28° 0.632	30° 0.576	32° 0.556	34° 0.524	36° 0.488	37° 0.456

TABLE 25 POSITION FACTOR $\left(\frac{1}{p^{1.6}}\right)$ OF GLARE SOURCE

(*Clause* 6.5.1)

h/d	l/d β / α	0 (o°)	0.2 (11°)	0.4 (22°)	0.6 (31°)	0.8 (39°)	1.0 (45°)	1.2 (50°)	1.4 (54°)	1.6 (58°)	1.8 (61°)	2.0 (63°)	2.5 (68°)	3.0 (72°)
0	(0°)	1.87	1.56	1.20	0.93	0.72	0.57	0.46	0.38	0.33	0.28	0.25	0.20	0.19
0.1	(6°)	1.30	1.24	1.01	0.79	0.62	0.46	0.37	0.31	0.26	0.23	0.20	0.17	0.16
0.2	(11°)	0.95	0.98	0.80	0.63	0.49	0.37	0.30	0.25	0.22	0.19	0.17	0.15	0.14
0.3	(17°)	0.67	0.73	0.64	0.49	0.38	0.31	0.25	0.31	0.19	0.16	0.15	0.13	0.12
0.4	(22°)	0.48	0.53	0.49	0.39	0.31	0.25	0.21	0.18	0.16	0.14	0.13	0.11	0.10
0.5	(27°)	0.35	0.39	0.36	0.31	0.25	0.21	0.18	0.15	0.14	0.12	0.11	0.10	0.09
0.6	(31°)	0.25	0.30	0.28	0.24	0.21	0.18	0.15	0.13	0.11	0.10	0.10	0.09	0.08
0.7	(35°)	0.19	0.22	0.21	0.20	0.17	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.07
0.8	(39°)	0.14	0.16	0.16	0.15	0.14	0.12	0.11	0.09	0.08	0.08	0.07	0.06	0.06
0.9	(42°)	0.11	0.12	0.13	0.12	0.12	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.05
1.0	(45°)	0.08	0.09	0.10	0.10	0.09	0.08	0.08	0.07	0.06	0.06	0.06	0.05	0.05
1.2	(50°)	0.05	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.04	0.04
1.4	(54°)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
1.6	(58°)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

TABLE 26 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

***Light Distribution Classification* — BZ 1**

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension $X \times Y$		Initial Glare Indices														
2*H*	2*H*	12·4	14·6	12·8	14·8	15·0	9·7	11·4	10·6	12·2	13·3	7·0	8·3	8·2	9·5	11·1
	3*H*	12·6	14·6	13·0	14·8	15·2	9·8	11·3	10·7	12·2	13·3	7·1	8·3	8·3	9·6	11·2
	4*H*	12·7	14·5	13·2	14·8	15·3	9·9	11·5	10·9	12·2	13·4	7·1	8·1	8·3	9·4	11·1
	6*H*	12·7	14·4	13·2	14·8	15·2	9·9	11·2	10·9	12·2	13·4	7·0	8·1	8·3	9·3	11·0
	8*H*	12·8	14·3	13·3	14·7	15·0	9·9	11·0	10·9	12·2	13·2	6·9	7·9	8·2	9·2	10·8
	12*H*	12·8	14·2	13·3	14·6	15·0	9·8	10·9	10·9	12·0	13·1	6·8	7·7	8·1	9·0	10·7
4*H*	2*H*	12·7	14·5	13·2	14·8	15·2	9·9	11·2	10·9	12·1	13·3	7·0	8·0	8·2	9·3	11·0
	3*H*	13·0	14·5	13·5	15·0	15·4	10·1	11·2	11·1	12·2	13·5	7·1	8·0	8·5	9·4	11·1
	4*H*	13·1	14·3	13·6	14·8	15·3	10·1	11·0	11·1	12·0	13·3	7·1	7·7	8·4	9·2	10·9
	6*H*	13·1	14·3	13·6	14·8	15·3	10·1	10·9	11·1	12·0	13·2	7·1	7·6	8·4	9·1	10·8
	8*H*	13·2	14·2	13·7	14·6	15·3	10·2	10·8	11·3	11·9	13·1	7·1	7·6	8·4	9·0	10·6
	12*H*	13·2	14·1	13·7	14·6	15·2	10·1	10·7	11·2	11·9	13·0	7·0	7·5	8·3	8·9	10·5
8*H*	4*H*	13·1	14·2	13·7	14·6	15·2	10·1	10·8	11·1	11·9	13·1	7·1	7·6	8·4	9·0	10·6
	6*H*	13·1	14·0	13·7	14·5	15·2	10·1	10·7	11·2	11·8	13·1	7·1	7·6	8·4	8·9	10·6
	8*H*	13·2	13·9	13·8	14·5	15·2	10·0	10·8	11·2	11·8	13·0	7·0	7·5	8·3	8·9	10·5
	12*H*	13·1	13·8	13·7	14·3	15·1	10·0	10·4	11·1	11·6	13·0	6·9	7·3	8·2	8·8	10·4
12*H*	4*H*	13·2	14·1	13·7	14·6	15·2	10·1	10·7	11·2	11·9	13·0	7·0	7·5	8·3	8·9	10·5
	6*H*	13·2	13·9	13·8	14·5	15·2	10·1	10·6	11·2	11·8	13·0	7·0	7·4	8·3	8·8	10·5
	8*H*	13·1	13·8	13·8	14·3	15·1	10·0	10·4	11·1	11·7	13·0	6·9	7·3	8·2	8·8	10·4
	12*H*	13·1	13·7	13·8	14·2	15·1	10·0	10·4	11·1	11·6	12·9	6·9	7·3	8·2	8·7	10·3

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 27 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 2

Flux Fractions of Lighting Fittings

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension $X \times Y$		Initial Glare Indices														
2*H*	2*H*	14·7	16·8	15·1	17·1	17·5	12·1	13·7	13·0	14·6	15·7	9·5	10·8	10·7	12·0	13·6
	3*H*	15·5	17·5	15·9	17·8	18·2	12·9	14·3	13·8	15·2	16·3	10·1	11·1	11·3	12·3	13·9
	4*H*	15·7	17·6	16·2	17·9	18·4	13·1	14·4	14·0	15·4	16·5	10·2	11·2	11·5	12·5	14·1
	6*H*	15·8	17·6	16·3	18·0	18·4	13·1	14·4	14·1	15·4	16·6	10·3	11·2	11·5	12·5	14·2
	8*H*	16·0	17·7	16·5	18·0	18·4	13·2	14·4	14·2	15·4	16·6	10·3	11·2	11·6	12·5	14·2
	12*H*	16·2	17·8	16·7	18·2	18·6	13·4	14·5	14·4	15·5	16·7	10·4	11·2	11·6	12·6	14·3
4*H*	2*H*	15·3	17·2	15·8	17·5	17·9	12·6	14·0	13·6	14·9	16·1	9·8	10·9	11·0	12·1	13·6
	3*H*	16·3	17·8	16·8	18·2	18·6	13·4	14·5	14·5	15·6	16·7	10·4	11·3	11·7	12·7	14·3
	4*H*	16·6	17·9	17·1	18·2	18·7	13·7	14·5	14·7	15·6	16·8	10·7	11·3	12·1	12·8	14·4
	6*H*	16·8	18·0	17·3	18·4	18·9	13·9	14·7	14·9	15·7	18·9	10·9	11·6	12·2	12·9	14·6
	8*H*	17·0	18·1	17·5	18·4	19·1	14·0	14·7	15·0	15·9	17·1	11·1	11·6	12·4	13·1	14·6
	12*H*	17·3	18·4	17·8	18·8	19·4	14·3	15·0	15·3	16·1	17·3	11·2	11·7	12·5	13·2	14·7
8*H*	4*H*	16·7	17·9	17·2	18·2	18·9	13·7	14·5	14·7	15·6	16·8	10·8	11·3	12·1	12·8	14·4
	6*H*	17·1	18·1	17·7	18·5	19·2	14·0	14·7	15·1	15·8	17·1	11·0	11·6	12·3	12·9	14·6
	8*H*	17·4	18·2	18·1	18·7	19·3	14·3	14·9	15·4	16·0	17·2	11·3	11·9	12·7	13·2	14·7
	12*H*	17·7	18·5	18·4	19·0	19·4	14·7	15·2	15·8	16·2	17·3	11·6	12·1	12·9	13·4	14·9
12*H*	4*H*	16·8	17·9	17·4	18·4	19·0	13·8	14·5	14·9	15·6	16·9	10·8	11·3	12 1	12·8	14·4
	6*H*	17·2	18·1	17·9	18·5	19·2	14·2	14·7	15·3	15·9	17·1	11·1	11·7	12·5	13·0	14·6
	8*H*	17·6	18·3	18·2	18·9	19·4	14·5	15·1	15·6	16·2	17·3	11·4	11·9	12·7	13·3	14·8
	12*H*	17·9	18·5	18·6	19·1	19·6	14·8	15·3	15·9	16·3	17·5	11·7	12·1	13·0	13·4	15·1

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 28 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 3

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension $X \times Y$		Initial Glare Indices														
2H	2H	17·0	19·3	17·5	19·5	20·0	14·6	16·3	15·5	17·2	18·3	11·9	13·3	13·2	14·5	16·1
	3H	18·6	20·8	19·0	21·1	21·5	16·1	17·8	17·0	18·7	19·8	13·3	14·7	14·5	15·9	17·6
	4H	19·1	21·1	19·6	21·4	21·8	16·5	18·0	17·5	18·9	20·0	13·7	14·8	15·0	16·0	17·7
	6H	19·3	21·1	19·8	21·4	21·8	16·6	18·0	17·6	18·9	20·0	13·8	14·8	15·0	16·1	17·7
	8H	19·3	21·2	19·8	21·6	21·9	16·7	18·0	17·7	19·0	20·0	13·9	14·8	15·1	16·1	17·7
	12H	19·4	21·2	20·0	21·6	21·9	16·8	18·0	17·8	19·0	20·0	13·9	14·8	15·1	16·1	17·7
4H	2H	17·8	19·8	18·3	20·1	20·5	15·2	16·7	16·2	17·6	18·7	12·4	13·6	13·7	14·8	16·5
	3H	19·6	21·3	20·1	21·7	22·0	16·9	18·1	17·9	19·1	20·2	14·0	14·9	15·2	16·2	17·8
	4H	20·4	21·9	20·9	22·4	22·9	17·7	18·6	18·7	19·7	20·9	14·7	15·5	16·0	16·9	18·5
	6H	20·7	22·1	21·2	22·6	23·1	17·8	18·7	18·7	19·8	21·0	14·9	15·5	16·1	17·0	18·6
	8H	20·8	22·1	21·3	22·6	23·1	17·9	18·7	18·9	19·9	21·0	15·0	15·6	16·3	17·0	18·6
	12H	20·8	22·1	21·4	22·6	23·2	18·0	18·7	19·0	19·9	21·1	15·0	15·6	16·3	17·0	18·6
8H	4H	20·7	21·9	21·2	22·4	22·9	17·8	18·6	18·8	19·8	20·9	14·9	15·5	16·2	16·9	18·5
	6H	21·2	22·1	21·7	22·7	23·3	18·2	18·9	19·3	19·9	21·3	15·2	15·7	16·5	17·0	18·8
	8H	21·3	22·2	22·0	22·8	23·4	18·3	19·0	19·4	20·1	21·4	15·3	15·8	16·6	17·3	18·9
	12H	21·4	22·2	22·1	22·8	23·5	18·4	19·0	19·5	20·2	21·4	15·3	15·8	16·6	17·3	18·9
12H	4H	20·7	21·9	21·3	22·4	22·9	17·8	18·6	18·8	19·8	21·0	14·9	15·5	16·2	17·0	18·5
	6H	21·2	22·1	21·9	22·7	23·3	18·2	18·9	19·3	20·0	21·3	15·2	15·7	16·6	17·2	18·8
	8H	21·3	22·2	22·0	22·8	23·4	18·3	19·0	19·4	20·2	21·5	15·3	15·8	16·6	17·3	18·9
	12H	21·4	22·2	22·1	22·8	23·5	18·4	19·0	19·5	20·2	21·6	15·3	15·8	16·6	17·3	19·0

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height H.
Y = Room dimension parallel to the line of sight in terms of the height H.

TABLE 29 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

***Light Distribution Classification* — BZ 4**

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent					Conversion Terms for Linear Fittings Viewed	
		Reflection Factors of Room Surfaces (Percent)																
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30		
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30		
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		
Room Dimension $X \times Y$		Initial Glare Indices															End-wise	Cross-wise
2*H*	2*H*	17·3	19·8	17·7	20·1	20·5	15·0	16·8	15·8	17·7	18·8	12·4	13·9	13·6	15·1	16·6	+0·5	+0·6
	3*H*	19·4	21·8	19·8	22·1	22·5	17·0	18·8	17·9	19·7	20·8	14·3	15·8	15·5	17·0	18·5	+0·6	+0·1
	4*H*	20·2	22·4	20·7	22·6	23·1	17·8	19·3	18·7	20·2	21·3	15·1	16·3	16·3	17·5	19·1	+0·9	−0·2
	6*H*	20·4	22·6	21·0	22·9	23·3	18·0	19·6	19·0	20·5	21·6	15·4	16·5	16·7	17·8	19·4	+1·3	−0·5
	8*H*	20·7	22·7	21·2	23·1	23·5	18·3	19·6	19·2	20·6	21·7	15·6	16·5	16·9	17·8	19·5	+1·5	−0·6
	12*H*	20·9	22·8	21·5	23·2	23·6	18·4	19·6	19·4	20·6	21·8	15·6	16·6	16·9	18·0	19·6	+1·7	−0·7
4*H*	2*H*	18·2	20·4	18·8	20·7	21·1	15·8	17·4	16·7	18·2	19·4	13·1	14·3	14·4	15·6	17·2	+0·5	+0·6
	3*H*	20·7	22·5	21·2	22·9	23·3	18·2	19·4	19·2	20·4	21·5	15·3	16·4	16·6	17·7	19·4	+0·7	+0·1
	4*H*	22·0	23·6	22·6	24·0	24·5	19·2	20·3	20·2	21·4	22·6	16·4	17·2	17·7	18·7	20·3	+0·9	−0·1
	6*H*	22·1	23·8	22·7	24·2	24·7	19·5	20·5	20·4	21·6	22·8	16·7	17·3	18·0	18·8	20·4	+1·3	−0·4
	8*H*	22·4	23·9	22·9	24·3	25·0	19·7	20·6	20·7	21·7	22·9	17·0	17·5	18·2	18·9	20·5	+1·4	−0·6
	12*H*	22·7	24·0	23·2	24·4	25·1	20·0	20·7	21·0	21·8	23·0	17·0	17·5	18·2	18·9	20·5	+1·7	−0·7
8*H*	4*H*	22·2	23·6	22·7	24·1	24·7	19·4	20·3	20·4	21·4	22·7	16·7	17·3	18·0	18·7	20·3	+0·8	−0·1
	6*H*	22·9	24·3	23·6	24·7	25·4	20·2	21·0	21·3	22·0	23·3	17·2	17·8	18·5	19·1	20·9	+1 2	−0·5
	8*H*	23·3	24·4	23·9	25·0	25·8	20·6	21·1	21·7	22·3	23·7	17·5	18·1	18·8	19·6	21·3	+1·4	−0·7
	12*H*	23·5	24·6	24·2	25·2	26·0	20·7	21·4	21·7	22·6	23·9	17·5	18·1	18·9	19·6	21·3	+1·6	−0·8
12*H*	4*H*	22·5	23·7	23·0	24·2	24·8	19·7	20·4	20·7	21·5	22·7	16·7	17·2	18·0	18·7	20·3	+0·8	−0·1
	6*H*	23·1	24·4	23·8	25·0	25·8	20·5	21·2	21·6	22·4	23·7	17·4	18·1	18·7	19·6	21·2	+1·1	−0·5
	8*H*	23·5	24·6	24·2	25·2	26·0	20·7	21·4	21·8	22·6	23·9	17·6	18·2	18·9	19·7	21·3	+1·3	−0·8
	12*H*	23·7	24·6	24·5	25·2	26·0	20·8	21·4	21·8	22·6	24·1	17·6	18·2	18·9	19·7	21·5	+1·5	−0·8

H = Height of fittings above 1·2·m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 30 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 5

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension *X*×*Y*		Initial Glare Indices														
2*H*	2*H*	18·0	20·4	18·4	20·9	21·3	15·7	17·7	16·5	18·6	19·7	13·2	14·8	14·4	16·0	17·7
	3*H*	20·7	23·0	21·1	23·3	23·7	18·4	20·2	19·2	21·0	22·1	15·7	17·1	16·8	18·3	20·1
	4*H*	21·9	24·1	22·4	24·5	24·8	19·5	21·1	20·5	22·0	23·1	16·9	18·1	18·1	19·3	20·9
	6*H*	22·9	25·1	23·4	25·4	25·8	20·5	22·1	21·4	23·0	24·1	17·7	18·9	18·9	20·2	21·8
	8*H*	23·2	25·3	23·8	25·8	26·2	20·9	22·3	21·8	23·3	24·4	18·2	19·3	19·5	20·6	22·2
	12*H*	23·9	25·9	24·5	26·4	26·7	21·6	22·8	22·5	23·9	25·0	18·6	19·7	19·8	21·0	22·7
4*H*	2*H*	19·2	21·5	19·7	21·8	22·2	16·9	18·4	17·8	19·3	20·4	14·2	15·4	15·4	16·6	18·3
	3*H*	22·2	24·2	22·7	24·6	25·0	19·8	21·1	20·8	22·2	23·3	16·9	18·0	18·1	19·3	21·0
	4*H*	23·8	25·6	24·3	26·0	26·5	21·2	22·3	22·2	23·4	24·6	18·5	19·3	19·8	20·6	22·3
	6*H*	24·7	26·5	25·3	26·9	27·5	22·1	23·3	23·1	24·3	25·5	19·3	20·0	20·5	21·5	23·2
	8*H*	25·5	26·9	26·0	27·4	28·0	22·8	23·7	23·7	24·8	26·0	19·9	20·7	21·2	22·1	23·7
	12*H*	26·0	27·5	26·5	27·9	28·5	23·3	24·2	24·3	25·3	26·5	20·5	21·1	21·7	22·5	24·1
8*H*	4*H*	24·4	25·9	24·9	26·3	26·9	21·7	22·6	22·7	23·7	24·9	18·9	19·6	20·1	21·0	22·6
	6*H*	26·1	27·3	26·7	27·8	28·5	23·4	24·1	24·4	25·1	26·5	20·4	20·9	21·7	22·2	23·9
	8*H*	26·8	28·0	27·5	28·6	29·2	24·0	24·8	25·1	26·0	27·2	21·0	21·6	22·4	23·0	24·6
	12*H*	27·3	28·5	28·0	29·1	29·7	24·6	25·3	25·6	26·5	27·7	21·7	22·2	23·0	23·7	25·3
12*H*	4*H*	24·6	26·1	25·1	26·5	27·1	21·9	22·8	22·9	23·9	25·1	19·1	19·7	20·3	21·1	22·7
	6*H*	26·3	27·5	27·0	28·1	28·7	23·6	24·3	24·7	25·5	26·7	20·6	21·1	21·9	22·6	24·2
	8*H*	27·0	28·2	27·7	28·7	29·4	24·2	25·0	25·3	26·2	27·4	21·3	21·9	22·7	23·4	25·0
	12*H*	27·5	28·8	28·3	29·4	30·0	24·8	25·6	26·0	26·6	28·0	22·0	22·6	23·4	23·9	25·7

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 31 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 6

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent					Conversion Terms for Linear Fittings Viewed	
		Reflection Factors of Room Surfaces (Percent)																
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30		
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30		
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		
Room Dimension $X \times Y$		Initial Glare Indices															End-wise	Cross-wise
2*H*	2*H*	16·5	19·2	16·9	19·5	20·0	14·3	16·4	15·2	17·3	18·4	12·0	13·6	13·2	14·7	16·3	−0·6	+0·4
	3*H*	19·5	22·0	19·9	22·3	22·7	17·3	19·2	18·2	20·1	21·2	14·8	16·3	16·0	17·5	19·1	−0·8	+0·7
	4*H*	20·9	23·4	21·4	23·7	24·0	18·7	20·5	19·6	21·3	22·4	16·2	17·5	17·4	18·7	20·3	−1·0	+1·0
	6*H*	22·3	24·7	22·8	25·0	25·4	20·1	21·8	21·0	22·7	23·8	17·4	18·7	18·6	20·0	21·6	−1·2	+1·5
	8*H*	23·2	25·3	23·7	25·8	26·2	20·9	22·3	21·8	23·3	24·5	18·3	19·4	19·6	20·7	22·4	−1·3	+1·8
	12*H*	24·0	26·2	24·5	26·7	27·1	21·7	23·2	22·6	24·3	25·4	19·1	20·1	20·3	21·5	23·1	−1·5	+2·0
4*H*	2*H*	17·7	20·2	18·2	20·5	20·8	15·5	17·3	16·4	18·1	19·2	13·0	14·3	14·2	15·5	17·1	−0·5	+0·3
	3*H*	21·1	23·3	21·6	23·8	24·2	18·8	20·3	19·7	21·4	22·5	16·2	17·2	17·4	18·6	20·2	−0·7	+0·6
	4*H*	23·2	25·0	23·5	25·4	25·9	20·6	21·8	21·5	22·9	24·0	18·0	18·9	19·3	20·3	21·9	−0·9	+0·9
	6*H*	24·3	26·3	24·8	26·7	27·2	21·9	23·2	22·9	24·3	25·4	19·2	20·0	20·4	21·4	23·0	−1·2	+1·3
	8*H*	25·4	27·2	25·9	27·7	28·2	22·9	24·0	23·8	25·1	26·3	20·2	20·9	21·5	22·4	23·9	−1·5	+1·5
	12*H*	26·3	28·0	26·8	28·5	29·0	23·8	24·8	24·6	25·9	27·1	21·0	21·7	22·2	23·2	24·7	−1·7	+1·9
8*H*	4*H*	23·8	25·6	24·3	26·1	26·6	21·3	22·4	22·2	23·5	24·7	18·6	19·3	19·9	20 8	22·3	−0·8	+0·8
	6*H*	25·8	27·4	26·4	27·9	28·5	23·2	24·3	24·2	25·3	26·6	20·5	21·2	21·7	22·5	24·2	−1·0	+1·1
	8*H*	26·8	28·4	27·5	29·0	29·7	24·3	25·3	25·3	26 4	27·7	21·5	22·2	22·8	23·7	25·3	−1·1	+1·4
	12*H*	27·9	29·3	28·5	29·9	30·6	25·3	26·2	26·3	27·4	28·6	22·5	23·1	23·8	24·6	26·2	−1·3	+1·7
12*H*	4*H*	24·1	25·7	24·5	26·2	26·8	21·6	22·6	22·4	23·7	24·8	18·7	19·5	20·0	20·9	22·5	−0·7	+0·7
	6*H*	26·2	27·7	26·8	28·3	29·0	23·6	24·6	24·6	25·8	27·0	20·8	21·5	22·1	23·0	24·6	−0·9	+1·1
	8*H*	27·3	28·7	27·9	29·3	30·0	24·7	25·6	25·7	26·8	28·0	21·9	22·5	23·2	24·0	25·6	−1·1	+1·4
	12*H*	28·6	29·9	29·3	30·5	31·2	26·0	26·8	27·0	27·8	29·2	23·1	23·6	24·3	24·9	26·7	−1·2	+1·7

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 32 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 7

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent					Conversion Terms for Linear Fittings Viewed	
		Reflection Factors of Room Surfaces (Percent)																
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30		
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30		
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		
Room Dimension *X* × *Y*		Initial Glare Indices															End-wise	Cross-wise
2*H*	2*H*	15·5	18·4	16·0	18·7	19·1	13·5	15·7	14·3	16·5	17·6	11·1	12·7	12·3	13·9	15·4	−1·1	+1·4
	3*H*	18·6	21·3	19·1	21·5	22·0	16·6	18·6	17·4	19·4	20·4	14·0	15·6	15·2	16·7	18·3	−1·5	+2·4
	4*H*	20·2	22·7	20·7	23·0	23·4	18·1	19·8	19·0	20·7	22·3	15·7	17·0	16·9	18·2	19·8	−1·9	+3·1
	6*H*	21·8	24·3	22·3	24·6	25·0	19·7	21·4	20·6	20·3	23·4	17·1	18·4	18·3	19·5	21·2	−2·4	+4·0
	8*H*	22·7	25·0	23·3	25·4	25·8	20·5	22·0	21·4	23·1	24·1	18·1	19·1	19·3	20·5	22·1	−2·7	+4·7
	12*H*	23·6	25·9	24·2	26·4	26·8	21·4	23·0	22·4	24·0	25·1	18·8	20·0	20·0	21·3	22·9	−3·1	+5·5
4*H*	2*H*	16·7	19·2	17·2	19·5	19·9	14·6	16·4	15·5	17·2	18·3	12·2	13·5	13·4	14·8	16·3	−0·8	+1·0
	3*H*	20·3	22·6	20·9	23·0	23·4	18·1	19·6	19·0	20·7	21·7	15·4	16·6	16·7	18·0	19·6	−1·1	+1·9
	4*H*	22·3	24·4	22·8	24·9	25·4	20·0	21·4	20·9	22·4	23·6	17·5	18·4	18·8	19·8	21·4	−1·5	+2·5
	6*H*	23·8	25·9	24·5	26·4	26·9	21·5	22·9	22·5	23·9	25·1	18·8	19·7	20·1	21·1	22·7	−1·9	+3·5
	8*H*	25·0	26·9	25·5	27·4	27·9	22·6	23·8	23·5	24·9	26·0	20·0	20·7	21·2	22·1	23·6	−2·2	+4·1
	12*H*	26·0	27·8	26·5	28·3	28·9	23·6	24·7	24·5	25·8	27·0	20·9	21·6	22·2	23·0	24·5	−2·6	+5·0
8*H*	4*H*	23·2	25·1	23·7	25·6	26·2	20·8	22·0	21·7	23·2	24·3	18·2	18.9	19·4	20·3	21·8	−1·2	+2·0
	6*H*	25·4	27·2	26·0	27·7	28·3	22·9	24·0	23·9	25·0	26·3	20·2	21·0	21·4	22·3	24·1	−1·6	+2·9
	8*H*	26·5	28·1	27·2	28·7	29·4	24·1	25·0	25·1	26·2	27·5	21·3	22·1	22·6	23·6	25·2	−1·8	+3·5
	12*H*	27·8	29·4	28·4	29·9	30·7	25·3	26·3	26·3	27·4	[illegible]	22·5	23·1	23·8	24·6	26·2	−2·2	+4·4
12*H*	4*H*	23·5	25·3	24·0	25·8	26·4	21·1	22·2	22·0	23·3	24·5	18·4	19·1	19·6	20·5	22·0	−1·1	+1·8
	6*H*	25·8	27·5	26·4	28·0	28·8	23·3	24·3	24·3	25·5	26·7	20·6	21·4	21·9	22·8	24·4	−1·4	+2·7
	8*H*	27·1	28·7	27·7	29·2	30·0	24·6	25·6	25·6	26·8	28·0	21·8	22·5	23·1	23·9	25·5	−1·6	+3·2
	12*H*	28·6	30·0	29·2	30·6	31·4	26·0	26·9	27·0	27·9	29·5	23·2	23·6	24·4	24·9	26·8	−1·9	+4·0

H = Height of fittings above 1·2 *m* eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

TABLE 33 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 8

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent					Conversion Terms for Linear Fittings Viewed	
		Reflection Factors of Room Surfaces (Percent)																
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30		
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30		
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		
Room Dimension $X \times Y$		Initial Glare Indices															End-wise	Cross-wise
2H	2H	14·4	17·3	14·9	17·6	18·1	12·3	14·7	13·2	15·5	16·5	10·1	11·7	11·2	12·9	14·4	+0·6	+3·8
	3H	17·8	20·5	18·3	20·7	21·2	15·8	17·8	16·6	18·6	19·6	13·3	14·8	14·5	16·0	17·5	−0·1	+4·6
	4H	19·4	22·0	19·9	22·3	22·6	17·3	19·1	18·2	20·0	21·1	14·9	16·4	16·1	17·6	19·1	−0·6	+5·2
	6H	21·1	23·7	21·7	24·0	24·4	19·1	20·9	20·0	21·8	22·8	16·6	17·9	17·8	19·1	20·6	−1·3	+6·1
	8H	22·1	24·5	22·7	25·1	25·3	20·0	21·6	20·9	22·6	23·7	17·5	18·7	18·7	20·0	21·6	−1·7	+6·6
	12H	23·1	25·4	23·6	25·9	26·3	21·0	22·5	21·9	23·6	24·6	18·4	19·6	19·6	20·9	22·5	−2·1	+7·4
4H	2H	15·7	18·2	16·2	18·5	18·9	13·6	15·4	14·5	16·3	17·4	11·2	12·7	12·3	13·8	15·4	+0·8	+3·1
	3H	19·5	21·8	20·0	22·2	22·6	17·3	18·9	18·2	19·9	21·0	14·7	15·9	15·9	17·2	18·9	+0·4	+3·9
	4H	21·5	23·8	22·1	24·2	24·7	19·3	20·7	20·3	21·8	22·9	16·8	17·8	18·0	19·2	20·8	0·0	+4·5
	6H	23·2	25·4	23·7	25·8	26·3	21·0	22·4	21·9	23·4	24·6	18·4	19·2	19·7	20·7	22·3	−0·6	+5·3
	8H	24·4	26·4	25·0	26·9	27·4	22·1	23·4	23·0	24·5	25·6	19·6	20·4	20·8	21·8	23·3	−0·9	+5·9
	12H	25·5	27·4	26·0	27·9	28·5	23·2	24·4	24·1	25·5	26·6	20·6	21·3	21·8	22·7	24·2	−1·3	+6·6
8H	4H	22·5	24·5	23·0	25·0	25·4	20·2	21·5	21·1	22·5	23·7	17·6	18·4	18·9	19·8	21·4	+0·3	+3.9
	6H	24·9	26·8	25·4	27·3	27·9	22·5	23·7	23·5	24·7	26·0	19·8	20·6	21·0	21·9	23·7	−0·1	+4·6
	3H	26·1	27·9	26·8	28·4	29·1	23·7	24·8	24·7	25·9	27·2	21·0	21·7	22·2	23·2	24·9	−0·4	+5·1
	12H	27·3	29·0	28·0	29·6	30·2	25·0	25·9	26·0	27·1	28·3	22·1	22·9	23·4	24·3	25·9	−0·7	+5·9
12H	4H	22·8	24·7	23·3	25·2	25·8	20·5	21·7	21·4	22·8	23·9	17·9	18·6	19·1	20·0	21·5	+0·4	+3·7
	6H	25·3	27·1	26·0	27·7	28·4	23·0	24·0	24·0	25·2	26·3	20·2	21·0	21·5	22·5	24·0	0·0	+4·4
	8H	26·6	28·2	27·2	28·8	29·5	24·2	25·2	25·2	26·4	27·6	21·5	22·1	22·7	23·6	25·2	−0·2	+4·8
	12H	28·1	29·6	28·7	30·2	30·9	25·6	26·5	26·6	27·7	29·0	22·8	23·5	24·0	24·8	26·7	−0·4	+5·5

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height H.
Y = Room dimension parallel to the line of sight in terms of the height H.

TABLE 34 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 9

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension $X \times Y$		Initial Glare Indices														
2*H*	2*H*	14·8	17·7	15·4	18·1	18·5	12·9	15·1	13·8	16·0	17·0	10·6	12·2	11·8	13·4	14·9
	3*H*	18·2	21·0	18·8	21·2	21·6	16·3	18·3	17·2	19·2	20·2	13·8	15·4	15·0	16·6	18·1
	4*H*	20·0	22·7	20·6	23·0	23·3	18·0	19·9	18·9	20·8	21·8	15·6	17·0	16·8	18·2	19·7
	6*H*	21·7	24·4	22·3	24·6	24·9	19·7	21·6	20·6	22·5	23·5	17·2	18·6	18·4	19·8	21·3
	8*H*	22·7	25·1	23·3	25·7	26·0	20·6	22·4	21·6	23·2	24·3	18·2	19·4	19·4	20·7	22·3
	12*H*	23·7	26·2	24·3	26·7	27·1	21·6	23·4	22·6	24·4	25·4	19·1	20·3	20·3	21·3	23·2
4*H*	2*H*	16·2	18·9	16·7	19·1	19·5	14·2	16·1	15·1	16·9	18·0	11·8	13·2	12·9	14·4	15·9
	3*H*	20·0	22·5	20·5	22·9	23·3	17·9	19·6	18·8	20·6	21·8	15·3	16·6	16·5	17·9	19·5
	4*H*	21·8	24·2	22·3	24·7	25·1	19·8	21·3	20·8	22·4	23·4	17·3	18·3	18·5	19·7	21·3
	6*H*	23·5	25·9	24·0	26·4	26·8	21·5	23·0	22·3	24·1	25·1	19·0	20·0	20·2	21·5	23·0
	8*H*	25·1	27·2	25·5	27·6	28·2	22·8	24·1	23·7	25·2	26·3	20·3	21·1	21·5	22·5	24·0
	12*H*	26·1	28·1	26·5	28·6	29·2	23·8	25·1	24·7	26·2	27·3	21·3	22·1	22·5	23·5	25·0
8*H*	4*H*	23·1	25·2	23·6	25·6	26·2	20·8	22·1	21·7	23·2	24·3	18·3	19·1	19·5	20·5	22·1
	6*H*	25·4	27·4	26·0	27·9	28·6	23·2	24·4	24·2	25·4	26·7	20·6	21·4	21·8	22·8	24·4
	8*H*	26·6	28·6	27·3	29·1	29·8	24·3	25·5	25·3	26·7	27·9	21·7	22·5	22·9	24·0	25·5
	12*H*	28·0	29·7	28·6	30·2	30·8	25·6	26·7	26·7	27·8	29·0	22·9	23·6	24·2	25·1	26·7
12*H*	4*H*	23·3	25·4	23·8	25·8	26·3	21·1	22·4	21·9	23·4	24·6	18·5	19·4	19·7	20·8	22·3
	6*H*	25·8	27·8	26·5	28·4	29·0	23·5	24·7	24·5	25·9	27·1	21·0	21·7	22·3	23·2	24·8
	8*H*	27·2	29·0	27·9	29·6	30·3	24·9	25·9	25·9	27·1	28·3	22·2	22·9	23·4	24·4	25·9
	12*H*	28·6	30·5	29·3	30·8	31·4	26·3	27·3	27·3	28·3	29·7	23·5	24·2	24·7	25·5	27·3

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height H.
Y = Room dimension parallel to the line of sight in terms of the height H.

TABLE 35 INITIAL GLARE INDEX

[*Clause* 6.5.2(c)]

Light Distribution Classification — BZ 10

FLUX FRACTIONS OF LIGHTING FITTINGS

Upper / Lower		0 Percent / 100 Percent					25 Percent / 75 Percent					50 Percent / 50 Percent				
		Reflection Factors of Room Surfaces (Percent)														
Ceiling		70	70	50	50	30	70	70	50	50	30	70	70	50	50	30
Walls		50	30	50	30	30	50	30	50	30	30	50	30	50	30	30
Floor		14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Room Dimension $X \times Y$		Initial Glare Indices														
2*H*	2*H*	19·5	22·5	20·0	22·8	23·2	17·6	19·8	18·4	20·7	21·7	15·3	17·1	16·5	18·3	19·8
	3*H*	24·0	26·8	24·5	27·1	27·5	22·1	24·2	23·0	25·0	26·1	19·8	21·5	20·9	22·6	24·1
	4*H*	26·4	29·2	26·9	29·4	29·8	24·5	26·4	25·4	27·3	28·3	22·1	23·6	23·3	24·8	26·3
	6*H*	29·1	31·8	29·6	32·1	32·5	27·1	29·1	28·0	29·9	30·9	24·8	26·2	25·9	27·4	28·9
	8*H*	30·7	33·2	31·3	33·6	34·0	28·7	30·4	29·6	31·2	32·4	26·2	27·4	27·4	28·7	30·3
	12*H*	32·6	35·1	33·1	35·6	36·0	30·5	32·3	31·4	33·3	34·4	28·1	29·3	29·3	30·6	32·3
4*H*	2*H*	20·2	22·9	20·6	23·2	23·5	18·2	20·1	19·1	21·0	22·0	15·8	17·3	17·0	18·5	20·0
	3*H*	24·9	27·4	25·4	27·8	28·3	22·8	24·6	23·7	25·6	26·6	20·4	21·6	21·5	22·9	24·6
	4*H*	27·5	29·9	28·1	30·4	31·0	25·5	27·0	26·4	28·0	29·2	25·0	24·0	24·2	25·4	26·9
	6*H*	30·1	32·5	30·6	32·9	33·5	28·0	29·5	28·9	30·6	31·7	25·5	26·5	26·7	27·9	29·5
	8*H*	32·0	34·1	32·5	34·6	35·2	29·7	31·1	30·6	32·2	33·3	27·2	28·1	28·4	29·5	31·0
	12*H*	33·9	35·9	34·3	36·4	36·9	31·6	32·9	32·5	34·0	35·1	29·1	29·9	30·3	31·3	32·8
8*H*	4*H*	28·0	30·1	28·5	30·6	31·1	25·8	27·1	26·7	28·1	29·3	23·2	24·1	24·4	25·5	27·0
	6*H*	31·1	32·9	31·6	33·4	34·0	28·8	29·9	29·6	31·0	32·3	26·1	26·8	27·3	28·2	29·9
	8*H*	32·7	34·6	33·3	35·2	35·8	30·4	31·6	31·4	32·7	34·0	27·8	28·5	29·0	30·0	31·6
	12*H*	34·7	36·6	35·3	37·2	37·9	32·4	33·6	33·4	34·6	35·9	29·7	30·5	31·0	31·9	33·5
12*H*	4*H*	28·1	30·2	28·6	30·7	31·2	25·9	27·2	26·8	28·2	29·4	23·3	24·2	24·5	24·6	27·1
	6*H*	31·2	33·0	31·8	33·6	34·3	28·9	30·1	29·9	31·2	32·4	26·3	26·9	27·5	28·5	30·1
	8*H*	32·9	34·8	33·6	35·4	36·1	30·6	31·8	31·8	32·9	34·2	28·0	28·7	29·2	30·2	31·8
	12*H*	35·0	36·8	35·6	37·4	38·2	32·7	33·8	33·8	34·8	36·2	30·0	30·7	31·2	32·1	33·9

H = Height of fittings above 1·2-m eye level.
X = Room dimension at right angles to the line of sight in terms of the height *H*.
Y = Room dimension parallel to the line of sight in terms of the height *H*.

This is above the recommended limit of 19 and so the effect of aligning the fittings parallel to the long walls must be examined. The conversion term for end-wise viewing from Table 31 is − 1.6 and the glare index is then 24.2 − 1.6 − 5.5 = 17.1

This installation is thus acceptable when the fittings are mounted parallel to the long walls and are viewed in the direction of the long walls, for example, end-wise.

It remains to check the glare index when the fittings are viewed crosswise from the alternative viewing position, for example, from the centre of the long walls. For this position of viewing, $X = 10\ H$ and $Y = 4\ H$.

Initial glare index (Table 31)	22.3
Crosswise viewing conversion	+ 0.7
Table 36 conversion	− 5.5
Glare index	17.5

The glare from the installation is thus acceptable from either view point when the fittings are mounted parallel to the long walls of the room.

7. ENERGY CONSERVATION

7.1 Introduction — Energy consumption in lighting of buildings is of the order of 15 percent of the total energy consumption. A substantial portion of the energy consumed on lighting can be saved by utilization of daylight and rational design of supplementary artificial lights. Poor daylight design is one of the major factors responsible for wastage of energy. Inadequate daylight indoors leads to switching of artificial lights for carrying out different visual activities. Major wastage of energy is due to erroneous basis of designing daytime artificial lights irrespective of daylight availability. Low efficiency lamps, poor maintenance of windows and luminaires also results in poor illumination leading to wastage of energy.

7.2 Design of Windows

7.2.1 In tropics, plenty of daylight is available outdoors for most of daylight hours. This can be used for providing satisfactory illumination in buildings. Therefore, daytime use of artificial lights can be minimized by proper design of windows for adequate daylight indoors. Daylighting design should be according to IS : 2440-1975 based on clear design sky. Although IS : 2240-1975 permits windows in any orientation, provided they are adequately shielded against sun, the orientation of a building along E-W axis with windows on longer sides facing North and South provides advantage of solar heat in winter while minimizing it in summer. Further, the North and South facing windows can be suitably shielded from direct sunlight by simple vertical and horizontal louvers, respectively. As heat gain in summer and heat loss in winter through windows is proportional to the glass area, a minimum of glass area need be provided for satisfying the daylight requirement and a good part of this glass area should be openable for allowing in the flow of outdoor breeze. The level of daylight in a room depends upon daylight availability outdoors, room size, interior finish, window size, location of windows, glazing material, dirt collection on glass, obstruction due to window frame, louvres and external obstructions such as opposite buildings and trees, etc. Illumination requirement for performing a task depends upon its angular size, contrast, speed and accuracy involved. The finer the task, the higher is the task illumination. The recommended values of illumination for some tasks are given in Table 1.

7.2.2 Fenestration expressed as percentage of floor area required for satisfactory visual performance of a few tasks for different separation to height (S/H) ratio of external obstructions such as opposite buildings are given in Table 37. The obstructions at a distance of three times their height or more ($S/H \geqslant 3$) from a window facade are not significant and a window facing such an obstruction may be regarded as a case of unobstructed window.

7.2.3 Following assumptions have been made in arriving at the values given in Table 37.

a) An average interior finish with ceiling white, walls off white and floor grey has been assumed.

b) Ceiling height of 3 m and room depths up to 10 m and floor area between 30 and 50 m² have been assumed. For floor area beyond 50 m² and less than 30 m², the values of percent fenestration should be modified by a factor of 0.85 and 1.15 respectively.

c) It is assumed that windows are of metallic sashes and glazed with 3 mm thick plane glass. For wooden sashes, the area of a window should be increased by a factor of about 1.1.

d) Windows are provided with louvres of width up to 60 cm.

7.2.4 Distribution of daylight on the working plane in a room is good, if suitable window height, window width and sill height are chosen in accordance with the following recommendations:

a) In office buildings, windows of height 1.2 m or more in the centre of a bay with sill level at 1.0 to 1.2 m above floor and in residential buildings, windows of height 1.0 m to 1.1 m with sill height as 0.9-1.0 m above floor are recommended for good distribution of daylight indoors. Window width can accor-

TABLE 36 CONVERSION TERMS FOR DOWNWARD FLUX, LUMINOUS AREA HEIGHT ABOVE 1.2 m EYE LEVEL

(*Example* 34)

Downward Flux, F (1) lumens	Conversion Term (2)	Luminous Area, A (3) cm^2	Conversion Term (4)	Height, H Above 1.2 m Eye Level (5) m	Conversion Term (6)
100	− 6.0	65	+ 8.0	0.9	− 1.3
150	− 4.9	97	+ 6.6	1.2	− 1.0
200	− 4.2	129	+ 5.6	1.8	− 0.6
300	− 3.1	194	+ 4.2	2.4	− 0.3
500	− 1.8	323	+ 2.4	3.0	0.0
700	− 0.9	452	+ 1.2	3.7	+ 0.3
1 000	0.0	645	0.0	4.6	+ 0.6
1 500	+ 1.1	968	− 1.4	6.1	+ 1.0
2 000	+ 1.8	1 290	− 2.4	7.6	+ 1.3
3 000	+ 2.9	1 935	− 3.8	9.1	+ 1.6
5 000	+ 4.2	3 225	− 5.6	12.2	+ 2.1
7 000	+ 5.1	4 516	− 6.8		
10 000	+ 6.0	6 450	− 8.0		
15 000	+ 7.1	9 675	− 9.4		
20 000	+ 7.8	12 900	− 10.4		
30 000	+ 8.9	19 350	− 11.8		
50 000	+ 10.2	32 250	− 13.6		

TABLE 37 RECOMMENDED FENESTRATION (PERCENT OF FLOOR AREA) FOR DIFFERENT LEVELS OF WORKPLANE ILLUMINATION IN THE CENTRE AND REAR PART OF A ROOM

(*Clauses* 7.2.2 *and* 7.2.3)

Daylight Level, lux		Separation to Height Ratio of Opposite Obstruction				
Room Centre	Room Rear	1.0	1.5	2.0	2.5	3.0 or More
150	70	13.0	11.0	9.0	8.5	8.0
200	100	16.0	13.0	11.0	10.5	10.0
240	125	19.0	16.0	13.5	12.5	12.0
280	150	22.5	18.5	16.0	14.5	14.0
320	175	25.5	21.5	18.5	16.5	16.0
360	200	29.0	24.0	21.0	19.0	18.0

NOTE — For floor area less than 30 m^2 and greater than 50 m^2, these values of fenestration percentage are to be multiplied by 1.15 and 0.85 respectively.

dingly be adjusted depending upon the required fenestration percentage of the floor area.

b) If the room depth is more than 10 m, window should be provided on opposite sides for bilateral lighting.

c) It is desirable to have a white finish for ceiling and off white (light colour) to white for walls. There is about 7 percent improvement in lighting levels in changing the finish of walls from moderate to white. The reflectances of typical finishers are given in Table 38.

TABLE 38 REFLECTANCES OF COMMON INTERIOR FINISHES

[*Clause* 7.2.4 (c)]

Finish (1)	Reflectances (2)
Whitewash	0.7-0.8
Cream colour	0.6-0.7
Light green	0.5-0.6
Light pink	0.6-0.7
Light blue	0.4-0.5
Cement terrazo	0.25-0.35

7.3 Design of Supplementary Artificial Lights

7.3.1 Daylighting design discussed above is based on IS : 2440-1975 which ensures adequate daylight indoors for about 90 percent of the working hours for the prevalent sky conditions in India. However, for periods of poor daylight availability, such as when: (a) dark cloudy conditions occur, (b) work is expected to be performed beyond design time corresponding to solar altitude below 15° on clear days and (c) daylight entry is restricted due to excessive external obstructions in very deep rooms and adequate artificial lighting is required to supplement daylight. Present practice of artificial lighting design of building takes no account of daylight availability indoors as the design is based on lumen method assuming night conditions. Therefore, to conserve energy on lighting, it is advisable to provide adequate daylight indoors and design supplementary artificial lights for periods of poor daylight availability. A rational basis for the design of supplementary artificial lighting for the duration of poor daylight conditions has been evoloved. Based on this work, power requirements in terms of W/m² for different tasks illumination are given in Table 39.

7.3.2 Luminaires emanating more light in the downward direction (such as reflector with or without diffusing plastics) and mounted at a height of 1.5 to 2.0 m above the workplane have been considered here. Assumptions regarding interior finish and room dimension remain the same as in the case of daylighting design.

TABLE 39 RECOMMENDED SUPPLEMENTARY ARTIFICIAL LIGHTS FOR REQUIRED TOTAL ILLUMINATION DUE TO DAYLIGHT AND ARTIFICIAL LIGHTS

(*Clause* 7.3.2)

Total Illumination (1) lux	Supplementary Artificial Lights (2) W/m²
70	2.0
100	2.8
125	3.6
150	4.4
175	5.2
200	6.0

Note — These values of watts per m² should be multiplied by 1.15 and 0.85 for floor area less than 30 m² and greater than 50 m² respectively.

7.3.3 For good distribution and integration of daylight with artificial lights, the following guidelines are recommended.

a) Employ cool daylight fluorescent tubes for supplementary artificial lighting.

b) Distribute luminaires with a separation of 2 to 3 m in each bay of 3-4 m width.

c) Provide more supplementary lights such as twin tube luminaires in work areas where daylight is expected to be poor, for example, in the rear region of a room having single window and in the central region of a room having windows on opposite walls. In the vicinity of windows, only single tube luminaires should be provided.

7.4 Choice of Light Sources and Luminaires

7.4.1 Luminous efficacy of a light source has considerable bearing on energy conservation. A source of maximum lumen output per watt of electrical energy has the minimum power consumption. In the last few decades, there have been tremendous developments in the field of light sources. Now there are light sources which are almost twenty times as efficient as initially developed incandescent lamps. Use of efficient light sources is one of the important measures for energy conservation in lighting. Luminous efficacy of some of the lamps used in lighting of buildings are given in Table 40. Following recommendations may be used in the choice of sources for different locations:

a) For office buildings, cool daylight fluorescent tubes are recommended for supplementary artificial lighting of work area.

b) Cool daylight fluorescent tubes are also recommended for lighting of residential buildings.

c) For corridors and stair cases, white fluorescent tubes with about 10 percent higher lumen output should be preferred.

d) Incandescent lamps may be used for local lighting, wherever necessary. Also in locations such as toilets and bathrooms, where switching off of light is required for short duration, incandescent lamps should be preferred.

e) For industrial lighting including transit sheds and warehouses, fluorescent tubes because of their high efficiency and low brightness, are preferred for ceiling heights up to 7 metres. For mounting height of above 7 metres, the high pressure mercury vapour lamps, although less efficient than fluorescent tubes, are preferred because of the better optical control and due to their compact size. Where colour is not an important factor, sodium vapour lamps can also be used.

7.4.2 It is clear from Table 40 that, for the same amount of light output, the consumption of electrical energy with cool daylight fluorescent tubes recommended for offices and residential buildings will be only 25 percent of the corresponding consumption with incandescent lamps.

Similarly, with white fluorescent tubes recommended for corridors and stairs cases, the electrical consumption reduces to 22 percent of the energy consumption with incandescent lamps.

TABLE 40 LUMINOUS EFFICIENCY AND LIFE OF LIGHT SOURCES

(*Clauses* 7.4.1 *and* 7.4.2)

Light Source	Efficiency (lm/watt)	Average Life (hours)
Incandescent lamps		
GLS 25-1 000 W	8-18	1 000
Blended light lamps		
MLL 100-500 W	18-26	5 000
Cool daylight		
fluorescent tubes 20-80 W	61	5 000
Warm white fluorescent tubes		
20-80 W	67	5 000
High pressure mercury vapour lamp		
a) 80 W	36.9	5 000
b) 125 W	41	5 000
c) 400 W	52	5 000
High pressure sodium lamp		
a) 70 W	82.8	5 000
b) 250 W	100	5 000
c) 400 W	117.5	5 000
Tungsten halogen incandescent		
lamp 500-2 000 W	22-27	2 000

NOTE — Efficiency quoted includes control gear losses.

7.4.3 Efficient luminaire also plays an important role for energy conservation in lighting. The choice of a luminaire should be such that it is efficient not only initially but also throughout its life. Following luminaires are recommended for different locations.

a) For offices, semi-direct type of luminaires are recommended so that both the work-plane illumination and surround luminance can be effectively enhanced.

b) For corridors and stair cases, direct type of luminaires with wide spread of light distributions are recommended.

c) In residential buildings, bare fluorescent tubes are recommended. Wherever the incandescent lamps are employed, they should be provided with white enamelled conical reflectors at an inclination of about 45° from vertical.

7.5 Cleaning Schedule for Window Panes and Luminaires — Adequate schedule for cleaning of window panes and luminaires will result in significant advantage of enhanced daylight and lumen output from luminaires. This will tend to reduce the duration over which artificial lights will be used and minimize the wastage of energy. A 3 to 6 months interval for periodic cleaning of luminaires and window panes is recommended for maximum utilization of daylight and artificial light.

7.6 Photocontrols for Artificial Lights — There is a considerable wastage of electrical energy in lighting of buildings due to carelessness in switching off lights even when sufficient daylight is available indoors. In offices and commercial buildings, occupants generally switch on lights in the morning and keep them on throughout the day. When sufficient daylight is available inside, suitable photocontrols can be employed to switch off the artificial lights and thus prevent the wastage of energy. Energy saving from adequate daylighting and supplementary artificial lighting design can be made more effecitve by use of photocontrol devices.

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