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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

UNIT – I - BUILDING ENERGY CODES AND STANDARDS – SARA 5132

UNIT 1

INTRODUCTION

National policies on sustainable and energy efficient development, The Energy Conservation (Amendment) Act, 2010, Introduction and Guidelines of ECBC – Energy Efficiency Performance levels, Energy Performance Index, Compliance approaches – prescriptive method, whole building performance method (Energy simulation), Compliance requirements, Building Envelope – Fenestration, opaque construction, Daylighting, building envelope sealing, Roof - Skylights, Building envelope trade off method.

Objective: To understand the need & evolution of energy conservation in building industry and codes and standards for the same.

Methodology:

National policies on sustainable and energy efficient development, The Energy Conservation (Amendment) Act, 2010	Presentation
Introduction and Guidelines of ECBC	Lecture
Energy Efficiency Performance levels, EPI, Compliance approaches – prescriptive method, whole building performance method, Compliance requirements, Building Envelope, Daylighting, building envelope sealing, Roof - Skylights, Building envelope trade off method.	Power point presentation, Reading and Discussion sessions.

1. Purpose

The purpose of the Energy Conservation Building Code (Code) is to provide minimum requirements for the energy-efficient design and construction of buildings. The Code also provides two additional sets of incremental requirements for buildings to achieve enhanced levels of energy efficiency that go beyond the minimum requirements.

2 Scope

2. Scope

The Code is applicable to buildings or building complexes that have a connected load of 100 kW or greater or a contract demand of 120 kVA or greater and are intended to be used for commercial purposes.

Buildings intended for private residential purposes only are not covered by the Code.

2.1 Energy Efficiency Performance Levels

The code prescribes the following three levels of energy efficiency:

(a) Energy Conservation Building Code Compliant Building (ECBC Building)
ECBC Buildings shall demonstrate compliance by adopting the mandatory and prescriptive requirements listed under ECBC Compliant Building requirements in §4 to §7, or by following the provisions of the Whole Building Performance (WBP) Method in §9.

(b) Energy Conservation Building Code Plus Building (ECBC+ Building)
ECBC+ Buildings shall demonstrate compliance by adopting the mandatory and prescriptive requirements listed under ECBC+ Compliant Building requirements in §4 to §7, or by following the provisions of the Whole Building Performance (WBP) Method in §9.

(c) Super Energy Conservation Building Code Building (SuperECBC Building)
SuperECBC Buildings shall demonstrate compliance by adopting the mandatory and prescriptive requirements listed under SuperECBC Compliant Building requirements in §4 to §7, or by following the provisions of the Whole Building Performance (WBP) Method in §9.

2.2 Building Systems

The provisions of this code apply to:

(a) Building envelope,
(b) Mechanical systems and equipment, including heating, ventilating, and air conditioning, service hot water heating,
(c) Interior and exterior lighting, and
(d) Electrical power and motors, and renewable energy systems.

The provisions of this code do not apply to plug loads, and equipment and parts of buildings that use energy for manufacturing processes, unless otherwise specified in the Code.

2.3 Precedence

The following codes, programs, and policies will take precedence over the Code in case of conflict:

(d) Any policy notified as taking precedence over this Code, or any other rules on safety, security, health, or environment by Central, State, or Local Government.

(e) Bureau of Energy Efficiency's Standards and Labelling for appliances and Star Rating Program for buildings, provided both or either are more stringent than the requirements of this Code.

2.4 Reference Standards

The National Building Code of India 2016 (NBC) is the reference standard for lighting levels, heating, ventilating, and air conditioning (HVAC), thermal comfort conditions, natural ventilation, and any other building materials and system design criteria addressed in this Code.

2.5 Building Classification

Any one or more building or part of a building with commercial use is classified as per the functional requirements of its design, construction, and use. The key classification is as below:

(a) **Hospitality**: Any building in which sleeping accommodation is provided for commercial purposes, except any building classified under Health Care. Buildings and structures under Hospitality shall include the following:

    i. No-star Hotels – like Lodging-houses, dormitories, no-star hotels/motels
    ii. Resort
    iii. Star Hotel

(b) **Health Care**: Any building or part thereof, which is used for purposes such as medical or other treatment or care of persons suffering from physical or mental illness, disease, or infirmity; care of infants, convalescents, or aged persons, and for penal or correctional detention in which the liberty of the inmates is restricted. Health Care buildings ordinarily provide sleeping accommodation for the occupants. Buildings and structures like hospitals, sanatoria, out-patient healthcare, laboratories, research establishments, and test houses are included under this type.

(c) **Assembly**: Any building or part of a building, where number of persons congregate or gather for amusement, recreation, social, religious, patriotic, civil, travel and similar purposes. Buildings like theatres or motion picture halls, gathering halls, and transport buildings like airports, railway stations, bus stations, and underground and elevated mass rapid transit system are included in this group.

(d) **Business**: Any building or part thereof which is used for transaction of business, for keeping of accounts and records and similar purposes, professional establishments, and service facilities. There are two subcategories under Business – Daytime Business and 24-hour Business. Unless otherwise mentioned, Business buildings shall include both Daytime and 24-hour subcategories.

(e) **Educational**: Any building used for schools, colleges, universities, and other training institutions for day-care purposes involving assembly for instruction, education, or recreation for students. If residential accommodation is provided in the schools, colleges, or universities or coaching/ training institution, that portion of occupancy shall be classified as a No-star Hotel. Buildings and structures under Educational shall include following types-

i. Schools
ii. Colleges
iii. Universities
iv. Training Institutions

(f) **Shopping Complex**: Any building or part thereof, which is used as shops, stores, market, for display and sale of merchandise, either wholesale or retail. Buildings like shopping malls, stand-alone retails, open gallery malls, super markets, or hyper markets are included in this type.

(g) **Mixed-use Building**: In a mixed-use building, each commercial part of a building must be classified separately, and –

i. If a part of the mixed-use building has different classification and is less than 10% of the total above grade floor area, the mixed-use building shall show compliance based on the building sub-classification having higher percentage of above grade floor area.

ii. If a part of the mixed-use building has different classification and one or more sub-classification is more than 10% of the total above grade floor area, the compliance requirements for each sub-classification, having area more than 10% of above grade floor area of a mixed-use building shall be determined by the requirements for the respective building classification in §4 to §7.

Any building which does not fall under any of the categories defined above shall be classified in a category mentioned above that best describes the function of the building.

Note 2-1 Building Typologies for ECBC 2017

Energy efficiency requirements for the Code were derived after analysing 16 different non-residential building typologies (shown below), that in turn are broadly based on building classification in the National Building Code of India. Spatial layouts, material specifications, façade characteristics, and occupancy patterns have an impact on energy efficiency of a building and differ for these typologies. Potential for reducing energy use with technology and materials thus varies from building type to type. By analysing this potential, ECBC energy efficiency requirements are now sensitive to building typologies and, to the extent possible, only requirements that are feasible have been included.

Hospitality

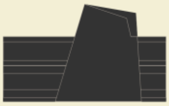
1. Star Hotel
2. No Star Hotel
3. Resort

Educational

1. College
2. University
3. Institution
4. School

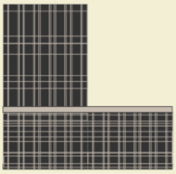
Health Care

1. Hospital
2. Out-patient Healthcare



Shopping Complex

1. Shopping Mall
2. Stand-alone Retails
3. Open Gallery Malls
4. Super Markets



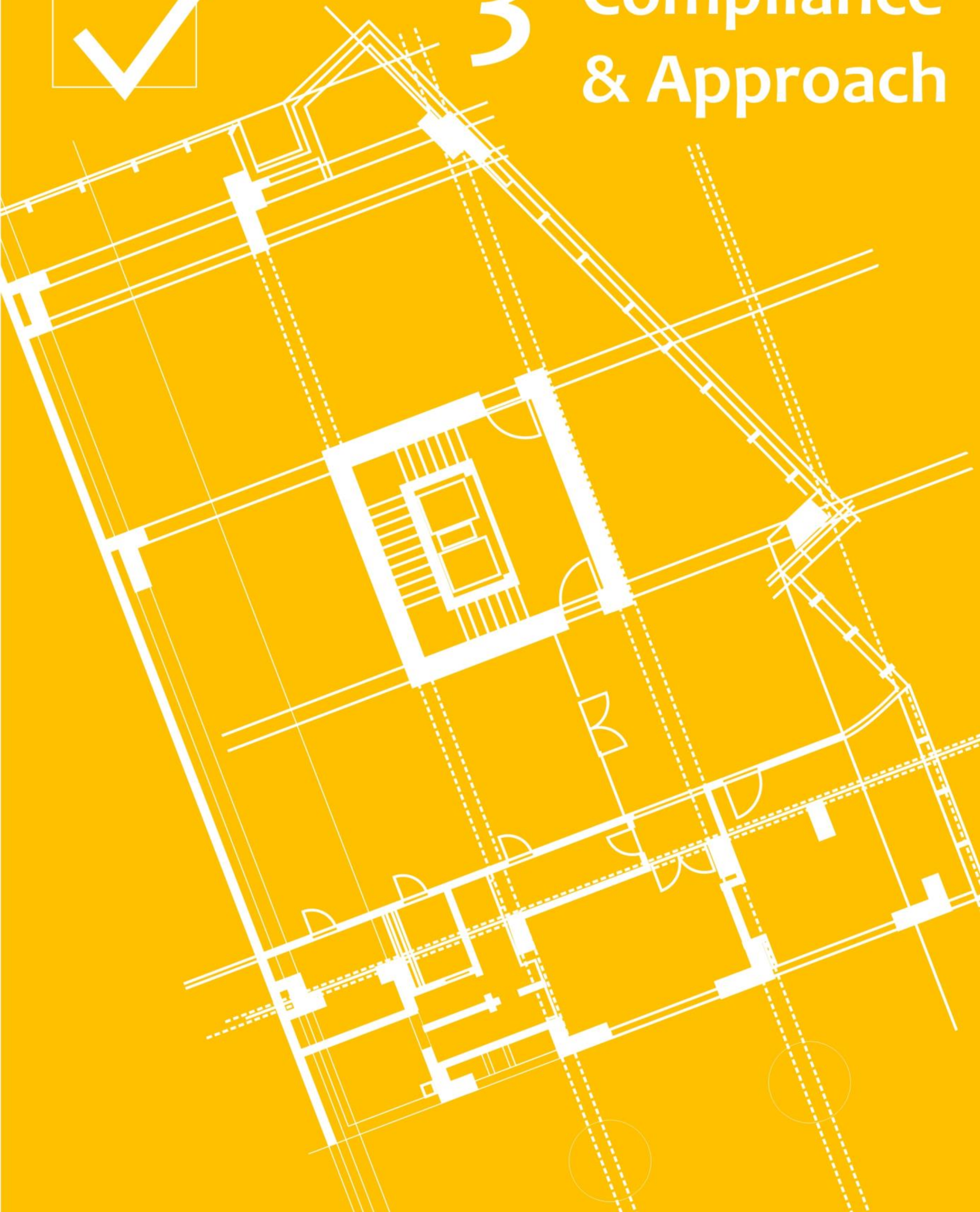
Business

1. Large Office (>30,000 m^2)
2. Medium Office (10,000m^2-30,000 m^2)
3. Small Office (<10,000 m^2)

Assembly

1. Multiplex
2. Theatre
3. Building used for Transport Services

3 Compliance & Approach



3. Compliance and Approach

3.1 General

To comply with the Code, buildings shall

(a) have an Energy Performance Index Ratio (EPI Ratio) as defined in §3.1.1 that is less than or equal to 1

and,

(b) meet all mandatory requirements mentioned under §4.2, §5.2 , §6.2, and §7.2.

3.1.1 Energy Performance Index

The Energy Performance Index (EPI) of a building is its annual energy consumption in kilowatt-hours per square meter of the building. While calculating the EPI of a building, the area of unconditioned basements shall not be included. EPI can be determined by:

$$EPI = \frac{annual\ energy\ consumption\ in\ kWh}{total\ built - up\ area\ (excluding\ unconditioned\ basements)}$$

To comply with the Code, EPI shall be calculated based on one of the following:

(a) Prescriptive Method including Building Envelope Trade-off Method (see §3.2.2)
(b) Whole Building Performance Method (see §3.2.3)

3.1.2 Determining EPI Ratio

The EPI Ratio of a building is the ratio of the EPI of the Proposed Building to the EPI of the Standard Building:

$$EPI\ Ratio = \frac{EPI\ of\ Proposed\ Building}{EPI\ of\ Standard\ Building}$$

where,

Proposed Building is consistent with the actual design of the building, and complies with all the mandatory requirements of ECBC.

Standard Building is a standardized building that has the same building floor area, gross wall area and gross roof area as the Proposed Building, complies with the mandatory requirements §4.2, §5.2 , §6.2, and §7.2, and minimally complies with prescriptive requirements of §4.3, §5.3, and §6.3 for ECBC Buildings.

The EPI of the Proposed Building shall be established through any one of the following two methods described in §3.2 –

(a) Prescriptive Method (see §3.2.2)
(b) Whole Building Performance Method (see §3.2.3)

3.1.2.1 EPI Ratio through Prescriptive Method

ECBC Buildings that demonstrate compliance through Prescriptive Method (§3.2.2) shall be deemed to have an EPI equal to the Standard Building EPI, and therefore an EPI Ratio of 1. ECBC+ Buildings and SuperECBC Buildings that demonstrate compliance through Prescriptive Method shall be deemed to have an EPI Ratio equal to the EPI Ratios listed in §9.5 under the applicable building type and climate zone.

3.1.2.2 EPI Ratio through Whole Building Performance Method

The EPI of buildings that demonstrate compliance through Whole Building Performance Method (§3.2.3) shall be calculated using the compliance path defined in §3.1.1 and detailed in §9. The EPI Ratio of a building that uses the Whole Building Performance Method to show compliance, should be less than or equal to the EPI Ratio listed in §9.5 for the applicable building type and climate zone.

3.1.2.3 EPI Ratio for Core and Shell Buildings

EPI for core and shell buildings shall be calculated for the entire building based on the final design of the common areas and the relevant mandatory undertaking(s) in the tenant lease agreement for the leased areas, as per §3.1.2.1 or §3.1.2.2.

3.1.2.4 EPI Ratio for Mixed-use Development

In a mixed-use building, each commercial part of a building must be classified separately, and EPI Ratio shall be calculated separately for each sub-classification, as per §3.1.2.1 or §3.1.2.2 . The EPI Ratio of a mixed-use Proposed Building shall be calculated based on area-weighted average method. To calculate the reference maximum design EPI Ratio, listed in Table 9-5 through Table 9-7, applicable for the mixed-use building, each commercial part of mixed-use building shall be classified separately, and,

(a) If a part of the mixed-use building has different classification and is less than 10% of the total above grade area (AGA), the EPI Ratio of the mixed-use Proposed Building shall be less than or equal to Maximum Allowed EPI listed in Table 9-5 through Table 9-7, for the building sub-classification having highest percentage of above grade floor area.

(b) If a part of the mixed-use building has different classification and is more than 10% of the total above grade floor area, the EPI of the mixed-use Proposed Building shall be less than or equal to Maximum Allowed EPI for compliance calculated based on area weighted average method for all building sub-classifications listed in Table 9-5 through Table 9-7.

Exceptions to the above: Any portion of a mixed-use building classified in a category which does not fall under the scope of ECBC is exempted from demonstrating compliance.

3.2 Compliance Approaches

Buildings that fall within the scope of the Code as mentioned in §2, shall comply with the Code by meeting all the mandatory requirements (see §3.2.1) and any of the compliance paths mentioned in §3.2.2, §3.2.2.1, or §3.2.3.

3.2.1 Mandatory Requirements

Buildings shall comply with all mandatory requirements mentioned under §4.2, §5.2 , §6.2, and §7.2, irrespective of the compliance path.

3.2.2 Prescriptive Method

A building complies with the Code using the Prescriptive Method if it meets the prescribed minimum (or maximum) values for envelope components (§4.3), comfort systems and controls (§5.3, §5.4, §5.5), and lighting and controls (§6.3), in addition to meeting all the mandatory requirements.

3.2.2.1 Building Envelope Trade-off Method

Building Envelope Trade-off Method may be used in place of the prescriptive criteria of §4.3.1, §4.3.2 and §4.3.3. A building complies with the Code using the Building Envelope Trade-off Method if the Envelope Performance Factor (EPF) of the Proposed Building is less than or equal to the EPF of the Standard Building, calculated as per §4.3.5, in addition to meeting the prescriptive requirements for comfort systems and controls (§5.3, §5.4), and lighting and controls (§6.3), and all the mandatory requirements (§4.2, §5.2, §6.2 and §7.2).

3.2.3 Whole Building Performance Method

A building complies with the Code using the Whole Building Performance (WBP) Method when the estimated annual energy use of the Proposed Design is less than that of the Standard Design, even though it may not comply with the specific provisions of the prescriptive requirements in §4 trough §7. The mandatory requirements of §4 through §7 (§4.2, §5.2, §6.2, and §7.2) shall be met when using the WBP Method.

3.3 Compliance Requirements

3.3.1 New Building Compliance

3.3.1.1 Full building Compliance

New buildings with completed fit-outs shall comply with either the provisions of §4 through §7 of this Code or the Whole Building Performance Method of §9.

3.3.1.2 Core and Shell building Compliance

New core and shell building shall demonstrate compliance with ECBC requirements for the following base building systems in the common areas:

(a) Building envelope
(b) Thermal comfort systems and controls (only those installed by developer/ owner)
(c) Lighting systems and controls (only those installed by developer/ owner)
(d) Electrical systems (installed by developer/ owner)
(e) Renewable energy systems

Additionally, the tenant lease agreement shall have a legal undertaking clause to ensure interior fit-outs made by tenant shall be Code compliant. The legal undertaking shall mandate the relevant energy efficiency compliance requirements for all interior fit-outs within the tenant leased area, including, but not limited to, §5.2.1, §5.2.2.2, §5.2.2.3, §5.2.3, §6, and §7.2.4.

3.3.2 Additions to Existing Buildings

Where the new connected load demand of the addition plus the existing building exceeds 100 kW or 120 kVA, the additions shall comply with the provisions of §4 through §7. Compliance may be demonstrated in either of the following ways:

(a) The addition shall comply with the applicable requirements, or
(b) The addition, together with the entire existing building, shall comply with the requirements of this Code that shall apply to the entire building, as if it were a new building.

Exceptions to §3.3.2: When space conditioning is provided by existing systems and equipment, the existing systems and equipment need not comply with this code. However, any new equipment installed must comply with specific requirements applicable to that equipment.

3.3.3 Alterations to Existing Buildings

Where the connected load or contract demand of the existing building exceeds 100 kW or 120 kVA respectively, part of a building and its systems that are being altered shall meet the provisions of §4 through §7.

Exception to §3.3.3: When the entire building complies with all of the provisions of §4 through §7, as if it were a new building.

3.4 Approved Analytical Tools

A building following the whole building performance approach shall show compliance through a whole building energy simulation software that has been approved by BEE. Compliance to the daylight requirements of §4.2.3, if calculated through software tools, shall be shown through a daylighting software approved by BEE. The list of BEE approved software for whole building energy simulation and daylighting analysis is given in Appendix E.

3.5 Administrative Requirements

Administrative requirements, including but not limited to, permit requirements, enforcement, interpretations, claims of exemption, approved calculation methods, and rights of appeal are specified by the authority having jurisdiction.

3.6 Compliance Documents

3.6.1 Compliance Documents

Construction drawings and specifications shall show all pertinent data and features of the building, equipment, and systems in sufficient detail to permit the authority having jurisdiction to verify that the building complies with the requirements of this code. Details shall include, but are not limited to:

(a) Building Envelope: opaque construction materials and their thermal properties including thermal conductivity, specific heat, density along with thickness; fenestration U-factors, solar heat gain coefficients (SHGC), visible light transmittance (VLT) and building envelope sealing documentation; overhangs and side fins, building envelope sealing details;

(b) Heating, Ventilation, and Air Conditioning: system and equipment types, sizes, efficiencies, and controls; economizers; variable speed drives; piping insulation; duct sealing, insulation and location; solar water heating system; requirement for balance report;

(c) Lighting: lighting schedule showing type, number, and wattage of lamps and ballasts; automatic lighting shutoff, occupancy sensors, and other lighting controls; lamp efficacy for exterior lamps;

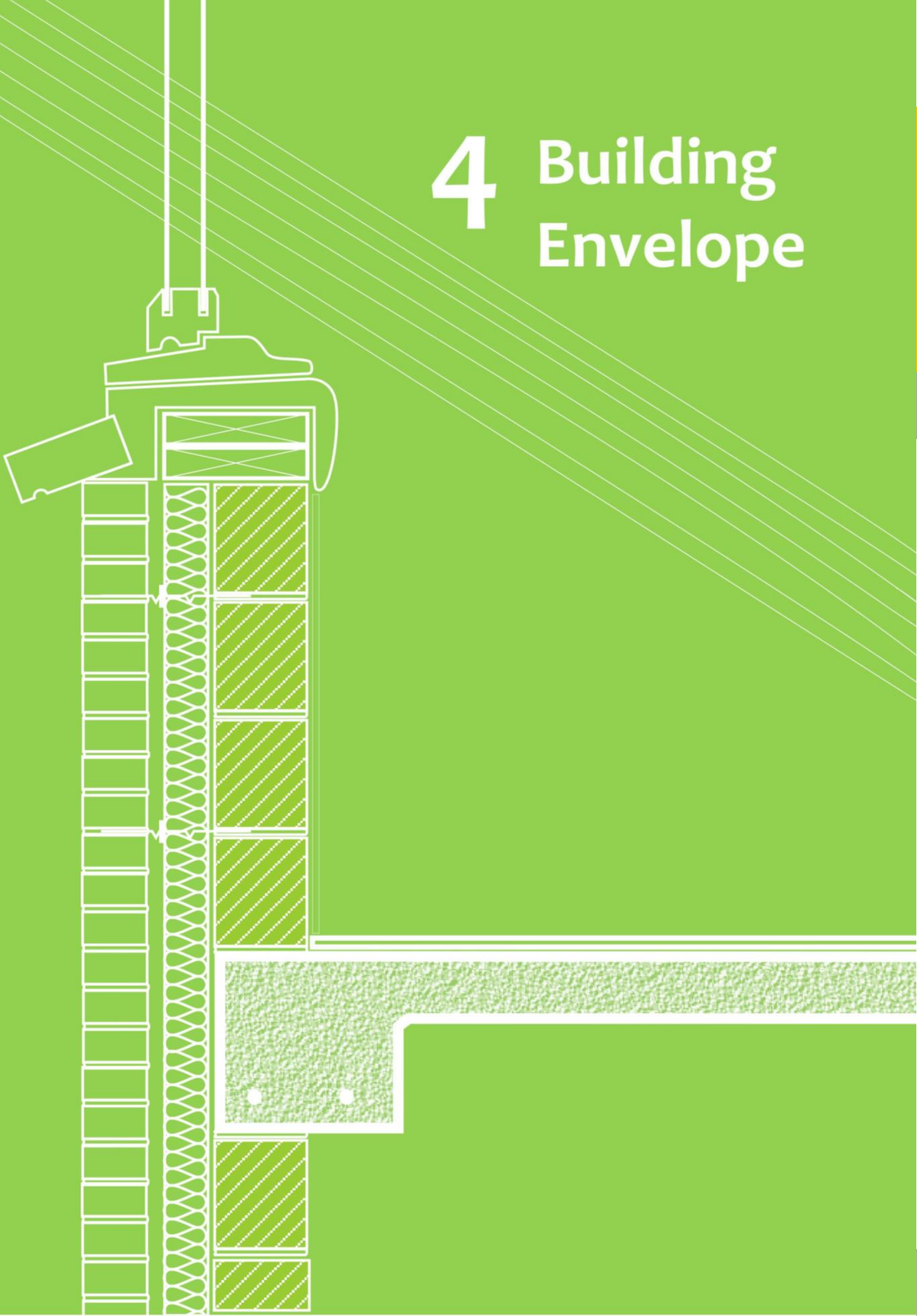
(d) Electrical Power: electric schedule showing transformer losses, motor efficiencies, and power factor correction devices; electric check metering and monitoring system.

(e) Renewable energy systems: system peak generation capacity, technical specifications, solar zone area

3.6.2 Supplemental Information

The authority having jurisdiction may require supplemental information necessary to verify compliance with this code, such as calculations, worksheets, compliance forms, manufacturer’s literature, or other data.

4 Building Envelope



4. Building Envelope

4.1 General

The building envelope shall comply with the mandatory provisions of §4.2, and the prescriptive criteria of §4.3.

4.2 Mandatory Requirements

4.2.1 Fenestration

4.2.1.1 U-Factor

U-factors shall be determined for the overall fenestration product (including the sash and frame) in accordance with ISO-15099 by an accredited independent laboratory, and labeled or certified by the manufacturer. U-factors for sloped glazing and skylights shall be determined at a slope of 20 degrees above the horizontal. For unrated products, use the default table in Appendix A.

4.2.1.2 Solar Heat Gain Coefficient

SHGC shall be determined for the overall single or multi glazed fenestration product (including the sash and frame) in accordance with ISO-15099 by an accredited independent laboratory, and labeled or certified by the manufacturer.

Exceptions to §4.2.1.2:

(a) Shading coefficient (SC) of the center of glass alone multiplied by 0.86 is an acceptable alternate for compliance with the SHGC requirements for the overall fenestration area.
(b) Solar heat gain coefficient (SHGC) of the glass alone is an acceptable alternate for compliance with the SHGC requirements for the overall fenestration product.

4.2.1.3 Visual Light Transmittance

Visual light transmittance (VLT) shall be determined for the fenestration product in accordance with ISO-15099 by an accredited independent laboratory, and labeled or certified by the manufacturer. For unrated products, use the default table in Appendix A.

4.2.2 Opaque Construction

U-factors shall be calculated for the opaque construction in accordance with ISO-6946. Testing shall be done in accordance with approved ISO Standard for respective insulation type by an accredited independent laboratory, and labeled or certified by the manufacturer. For unrated products, use the default tables in Appendix A.

4.2.3 Daylighting

Above grade floor areas shall meet or exceed the useful daylight illuminance (UDI) area requirements listed in Table 4-1 for 90% of the potential daylit time in a year. Mixed-use buildings shall show compliance as per the criteria prescribed in §2.5. Compliance shall be demonstrated either through daylighting simulation method in §4.2.3.1 or the manual method in §4.2.3.2 . Assembly buildings and other buildings where daylighting will interfere with the functions or processes of 50% (or more) of the building floor area, are exempted from meeting the requirements listed in Table 4-1.

Table 4-1 Daylight Requirement

Building Category	*Percentage of above grade floor area meeting the UDI requirement*		
	ECBC	ECBC+	SuperECBC
Business, Educational	40%	50%	60%
No Star Hotel Star Hotel Healthcare	30%	40%	50%
Resort	45%	55%	65%
Shopping Complex	10%	15%	20%
Assembly*	Exempted		
*and other buildings where daylighting will interfere with the functions or processes of 50% (or more) of the building floor area			

4.2.3.1 Daylighting Simulation Method

Only BEE approved software shall be used to demonstrate compliance through the daylighting simulation method. Buildings shall achieve illuminance level between 100 lux and 2,000 lux for the minimum percentage of floor area prescribed in Table 4-1 for at least 90% of the potential daylit time. Illuminance levels for all spaces enclosed by permanent internal partitions (opaque, translucent, or transparent) with height greater or equal to 2 m from the finished floor, shall be measured as follows:

(a) Measurements shall be taken at a work plane height of 0.8 m above the finished floor.

(b) The period of analysis shall be fixed for 8 hours per day, anytime between 8:00 AM IST to 5:00 PM IST, resulting in 2,920 hours in total for all building types except for Schools. Schools shall be analyzed for 7 hours per day, anytime between 7:00 AM IST to 3:00 PM IST.

(c) Available useful daylight across a space shall be measured based on point-by-point grid values. UDI shall be calculated for at least one point for each square meter of floor area.

(d) Fenestration shall be modeled with actual visible light transmission (VLT) as per the details provided in the material specification sheet.

(e) All surrounding natural or man-made daylight obstructions shall be modeled if the distance between the façade of the building (for which compliance is shown) and surrounding natural or man-made daylight obstructions is less than or equal to twice the height of the man-made or natural sunlight obstructers. If the reflectance of the surfaces is not known, default reflectance of 30% and 0% shall be used for all vertical surfaces of man-made and natural obstructers respectively.

(f) Interior surface reflectance shall be modeled based on the actual material specification. If material specification is not available, following default values shall be used:

Table 4-2 Default Values for Surface Reflectance

Surface Type	*Reflectance*
Wall or Vertical Internal Surfaces	50%
Ceiling	70%
Floor	20%
Furniture (permanent)	50%

4.2.3.2 Manual Daylighting Compliance Method

This method can be used for demonstrating compliance with daylighting requirements without simulation. Daylight extent factors (DEF) mentioned in Table 4-3 shall be used for manually calculating percentage of above grade floor area meeting the UDI requirement for 90% of the potential daylit time in a year.

Table 4-3 Daylight Extent Factors (DEF) for Manually Calculating Daylight Area

Shading	*Latitude*	*Window Type*	*VLT < 0.3*				*VLT ≥0.3*			
			North	South	East	West	North	South	East	West
No shading or PF < 0.4	≥15°N	All window types	2.5	2.0	0.7	0.5	2.8	2.2	1.1	0.7
	< 15°N		2.4	2.0	1.3	0.6	1.7	2.2	1.5	0.8
Shading with PF ≥ 0.4	All latitudes	All window types without light shelf	2.8	2.3	1.5	1.1	3.0	2.5	1.8	1.5
		Window with light shelf	3.0	2.5	1.8	1.6	3.5	3.0	2.1	1.8

(a) To calculate the daylit area:
    i. In a direction perpendicular to the fenestration, multiply daylight extent factor (DEF) by the head height of the fenestration or till an opaque partition higher than head height of the fenestration, whichever is less.
    ii. In the direction parallel to the fenestration, daylit area extends a horizontal dimension equal to the width of the fenestration plus either 1 meter on each side of the aperture, or the distance to an opaque partition, or one-half the distance to an adjacent fenestration, whichever is least.
    iii. For skylights, calculate the horizontal dimension in each direction equal to the top aperture dimension in that direction plus either the floor-to-ceiling height (H) for skylights, or 1.5 H for monitors, or H or 2H for the sawtooth configuration, or the distance to the nearest 1 meter or higher opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is least.
(b) A separate architectural plan shall be prepared with all daylit areas marked on the floor plans. A summary shall be provided showing compliance as per Table 4-1.
(c) Glazed façades, with non-cardinal orientation, shall be categorized under a particular cardinal direction if its orientation is within ± 45 degrees of that cardinal direction.
(d) Any surrounding natural or man-made daylight obstructions shall not be considered in this method.

4.2.4 Building Envelope Sealing

Following areas of the building envelope, of all except naturally ventilated buildings or spaces, shall be sealed, caulked, gasketed, or weather-stripped:

(a) Joints around fenestration, skylights, and door frames
(b) Openings between walls and foundations, and between walls and roof, and wall panels
(c) Openings at penetrations of utility services through roofs, walls, and floors
(d) Site-built fenestration and doors
(e) Building assemblies used as ducts or plenums
(f) All other openings in the building envelope
(g) Exhaust fans shall be fitted with a sealing device such as a self-closing damper
(h) Operable fenestration should be constructed to eliminate air leakages from fenestration frame and shutter frame

Note 4-1 Daylight Extent Factor and Useful Daylight Illuminance

Useful Daylight Illuminance (UDI) is defined as the annual occurrence of daylight between 100 lux to 2,000 lux on a work plane. This daylight is most useful to occupants, glare free and when available, eliminates the need for artificial lighting.

Application of UDI and Daylight Extent Factor

A 7,200 m^2 four story office building in Delhi is trying to achieve ECBC level compliance. Building is oriented along east west axis. It has a rectangular layout (60 m x 30 m). Total built up area is distributed evenly across all floors above grade. VLT of glazing in all orientations is 0.39. Windows have light shelves and external shading devices with PF ≥ 0.4. Head height of fenestrations is 3.0 m. Length of glazing on the north and south facing façade is 45 meter and on the east façade, 25 meter.

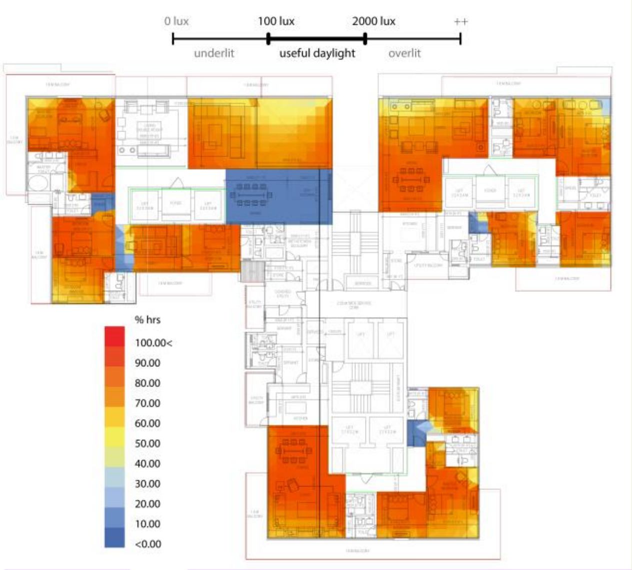
Table 4-1 lists the minimum daylight area requirements for ECBC Buildings. Row 2 of the table specifies that all ECBC Buildings other than resorts and shopping malls and, more than 3 stories above the ground shall have a minimum of 40% of its floor area exposed to daylight in range of 100 – 2,000 lux for at least 90% of the year.

This office building must then have at least 2,880 m^2 (40% of 7,200 m^2) of floor area fulfilling the UDI requirements. Across each floor plate, this area should be then 2,880/ 4 = 720 m^2.

Compliance with § 4.2.3 Daylight Requirements can be checked for through two approaches.

(a) Analysis through software

If the whole building performance approach is used, compliance for daylighting requirements can be checked by analysing the façade and floor plate design in an analytical software approved by BEE (§ 3.4). The image below, developed through an approved software, specifies the lux levels and time period of a year during which lighting levels would be available. With this information, designers can check if the required minimum area as per § 4.2.3 has the required daylight levels.



UDI Analysis with a Daylighting Analysis Software

(b) Manual method

This approach will be suitable for projects adopting the prescriptive compliance approach. From Table 4-3 determine the daylight extent factor (DEF) for the building. For a building located in Delhi (latitude > 15 degrees), with glazing of VLT ≥ 0.3, shading PF ≥0.4 shading and light shelves in windows, DEFs for windows in North = 3.5, in South = 3.0, in East = 2.1, and in West = 1.8. Head height is 3.0 m. There are no opaque partitions adjacent to the external walls and windows are arranged in a continuous strip.

Area complying with requirements of should be calculated as follows:

In a direction perpendicular to the fenestration, multiply daylight extent factor (DEF) by the head height of the fenestration or till an opaque partition higher than head height of the fenestration, whichever is less. Head height will be considered because there are no opaque partitions near the external walls.

In the direction parallel to the fenestration, daylit area extends a horizontal dimension equal to the width of the fenestration plus either 1 meter on each side of the aperture, or the distance to an opaque partition, or one-half the distance to an adjacent fenestration, whichever is least. In this case, 1 meter on each side of the windows at extreme ends of the window strip in each façade will be considered since there are no opaque partitions adjacent to wall and no opaque area between the windows.

Table 4-1-1 Calculation for Daylight Area Meeting UDI Requirement

Orientation	*DEF*	*Window/ Fenestration Width*	*X m (distance perpendicular to fenestration)*	*Y m (distance parallel to fenestration)*	*(X x Y m²) Above grade area meeting the UDI requirement for 90% of the time in an year*
North	3.5	45 m	3.5 x 3 = 10.5 m	(45+2) =47 m	(47 x 10.5) = 493.5 m^2
South	3.0	45 m	3.0 x 3= 9.0 m	(45+2) =47 m	(47 x 9.0) = 423 m^2
East	2.1	25 m	2.1 x 3 = 6.3 m	(25+2) = 27 m	(27 x 6.3) = 170 m^2
West	1.8	0 m (service zone)	0	0	0
Total daylight area per floor meeting UDI requirement during 90% of the year					1086.5 m^2
Total daylight area in building meeting UDI requirement during 90% of the year					1086.5 x 4 = 4,346 m^2

4,346 m2 of area will meet the UDI requirements. This is 60.3 % of the total above grade floor area of 7,200 m2. Thus, the building will comply with UDI requirement.

Daylight area should be indicated in floor plans submitted to code enforcement authorities. Design guidelines on daylighting stated in NBC (Part 8: Building Services, Section 1: Lighting and Natural Ventilation, Subsection 4.2: Daylighting) should also be referred to achieve the ECBC, ECBC+, or SuperECBC requirement.

4.3 Prescriptive Requirements

4.3.1 Roof

Roofs shall comply with the maximum assembly U-factors in Table 4-4 through Table 4-6. The roof insulation shall be applied externally as part of structural slab and not as a part of false ceiling.

Table 4-4 Roof Assembly U-factor (W/m².K) Requirements for ECBC Compliant Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
All building types, except below	0.33	0.33	0.33	0.33	0.28
School <10,000 m² AGA	0.47	0.47	0.47	0.47	0.33
Hospitality > 10,000 m² AGA	0.20	0.20	0.20	0.20	0.20

Table 4-5 Roof Assembly U-factor (W/m².K) Requirements for ECBC+ Compliant Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
Hospitality, Healthcare Assembly	0.20	0.20	0.20	0.20	0.20
Business Educational Shopping Complex	0.26	0.26	0.26	0.26	0.20

Table 4-6 Roof Assembly U-factor (W/m².K) Requirements for SuperECBC Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
All buildings types	0.20	0.20	0.20	0.20	0.20

4.3.1.1 Vegetated and Cool Roof

All roofs that are not covered by solar photovoltaics, or solar hot water, or any other renewable energy system, or utilities and services that render it unsuitable for the purpose, shall be either cool roofs or vegetated roofs.

(a) For qualifying as a cool roof, roofs with slopes less than 20° shall have an initial solar reflectance of no less than 0.60 and an initial emittance no less than 0.90. Solar reflectance shall be determined in accordance with ASTM E903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996).

(b) For qualifying as a vegetated roof, roof areas shall be covered by living vegetation

4.3.2 Opaque External Wall

Opaque above grade external walls shall comply with the maximum assembly U-factors in Table 4-7 through Table 4-9.

Table 4-7 Opaque Assembly Maximum U-factor (W/m².K) Requirements for a ECBC compliant Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
All building types, except below	0.40	0.40	0.40	0.55	0.34
No Star Hotel < 10,000 m^2 AGA	0.63	0.63	0.63	0.63	0.40
Business < 10,000 m^2 AGA	0.63	0.63	0.63	0.63	0.40
School <10,000 m^2 AGA	0.85	0.85	0.85	1.00	0.40

Table 4-8 Opaque Assembly Maximum U-factor (W/m².K) Requirements for ECBC+ Compliant Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
All building types, except below	0.34	0.34	0.34	0.55	0.22
No Star Hotel < 10,000 m^2 AGA	0.44	0.44	0.44	0.44	0.34
Business < 10,000 m^2 AGA	0.44	0.44	0.44	0.55	0.34
School <10,000 m^2 AGA	0.63	0.63	0.63	0.75	0.44

Table 4-9 Opaque Assembly Maximum U-factor (W/m².K) Requirements for SuperECBC Building

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
All building types	0.22	0.22	0.22	0.22	0.22

Exceptions to §4.3.1.1: Opaque external walls of an unconditioned building of No Star Hotel, Healthcare, and School categories in all climatic zones, except for cold climatic zone, shall have a maximum assembly U-factor of 0.8 W/m^2.K.

4.3.3 Vertical Fenestration

For all climatic zones, vertical fenestration compliance requirements for all three incremental energy efficiency levels, i.e. ECBC, ECBC+, and SuperECBC, shall comply with the following:

(a) Maximum allowable Window Wall Ratio (WWR) is 40% (applicable to buildings showing compliance using the Prescriptive Method, including Building Envelope Trade-off Method)

(b) Minimum allowable Visual Light Transmittance (VLT) is 0.27

(c) Assembly U-factor includes both frame and glass area weighted U-factors
(d) Assembly SHGC includes both frame and glass area weighted SHGC

Vertical fenestration shall comply with the maximum Solar Heat Gain Coefficient (SHGC) and U-factor requirements of Table 4-10. Vertical fenestration on non-cardinal direction, shall be categorized under a particular cardinal direction if its orientation is within ± 22.5° of that cardinal direction.

Table 4-10 Vertical Fenestration Assembly U-factor and SHGC Requirements for ECBC Buildings

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
Maximum U-factor (W/m².K)	3.00	3.00	3.00	3.00	3.00
Maximum SHGC Non-North	0.27	0.27	0.27	0.27	0.62
Maximum SHGC North for latitude ≥ 15°N	0.50	0.50	0.50	0.50	0.62
Maximum SHGC North for latitude < 15°N	0.27	0.27	0.27	0.27	0.62
See Appendix A for default values of unrated fenestration.					

Table 4-11 Vertical Fenestration U-factor and SHGC Requirements for ECBC+ buildings and SuperECBC buildings

	Composite	*Hot and dry*	*Warm and humid*	*Temperate*	*Cold*
Maximum U-factor (W/m².K)	2.20	2.20	2.20	3.00	1.80
Maximum SHGC Non-North	0.25	0.25	0.25	0.25	0.62
Maximum SHGC North for latitude ≥ 15°N	0.50	0.50	0.50	0.50	0.62
Maximum SHGC North for latitude < 15°N	0.25	0.25	0.25	0.25	0.62

Exceptions to SHGC requirements in Table 4-10 above:

For fenestration with a permanent external projection, including but not limited to overhangs, side fins, box frame, verandah, balcony, and fixed canopies that provide permanent shading to the fenestration, the equivalent SHGC for the proposed shaded fenestration may be determined as less than or equal to the SHGC requirements of Table 4-10. Equivalent SHGC shall be calculated by following the steps listed below:

(a) Projection factor (PF) for the external permanent projection, shall be calculated as per the applicable shading type listed in §8.2. The range of projection factor for using the SEF is $0.25 \leq PF \geq 1.0$. Other shading devices shall be modeled through the Whole Building Performance Method in §9.
(b) A shaded vertical fenestration on a non-cardinal direction, shall be categorized either under a particular cardinal direction or a primary inter-cardinal direction if its orientation is within the range of ±22.5 degrees of the cardinal or primary inter-cardinal direction.
(c) An equivalent SHGC is calculated by dividing the SHGC of the unshaded fenestration product with a Shading Equivalent Factor (SEF). SEF shall be determined for each orientation and shading device type as per Equation 4.1.
(d) The maximum allowable SHGC is calculated by multiplying the prescriptive SHGC requirement from Table 4-10 with the SEF.

Equation 4.1: $\boldsymbol{SEF} = (C_3 \times PF^3) + (C_2 \times PF^2) + (C_1 \times PF) + C_0$

Where,

$0.25 \leq PF \geq 1.0$, and,

C_3, C_2, C_1 and C_0 are the coefficient of shading equivalent factor (SEF), listed inTable 4-12 and Table 4-13.

Table 4-12 Coefficients of Shading Equivalent Factors for Latitudes greater than or equal to 15 °N

	Overhang + Fin				*Overhang*				*Fin**			
Coefficients	C3	C2	C1	C0	C3	C2	C1	C0	C3	C2	C1	C0
North	-0.03	-0.23	1.09	0.99	-0.02	-0.10	0.43	0.99	0.14	-0.39	0.62	0.99
East	4.49	-6.35	4.70	0.52	-0.05	0.42	0.66	1.02	0.12	-0.35	0.57	0.99
South	-4.09	8.14	-0.73	1.32	-1.01	1.91	0.24	1.12	0.53	-1.35	1.48	0.88
West	-1.21	3.92	-0.56	1.28	1.52	-2.51	2.30	0.76	0.02	-0.15	0.46	1.01
North-East	-0.95	1.50	0.84	1.18	2.19	-3.78	2.62	0.72	-1.64	3.07	-1.05	1.30
South-East	2.67	-4.99	5.68	0.32	-0.93	1.37	0.76	0.99	0.68	-1.47	1.35	0.88
South-West	-0.50	1.36	2.45	0.73	-3.23	5.61	-1.56	1.32	1.86	-3.81	2.71	0.69
North-West	-6.85	11.7	-3.92	1.89	-0.22	0.19	0.74	1.01	-2.02	2.63	-0.18	1.14

* Coefficients are for side fins on both sides of fenestration. For side fins on only one side, divide the coefficients mentioned in this table by 2.

Table 4-13 Coefficients of Shading Equivalent Factors for Latitudes less than 15 °N

	Overhang + Fin				*Overhang*				*Fin**			
Coefficients	C3	C2	C1	C0	C3	C2	C1	C0	C3	C2	C1	C0
North	-0.09	-0.29	1.41	1.05	-0.05	-0.10	0.54	1.02	0.10	-0.40	0.77	1.01
East	-0.55	0.89	1.28	0.97	-0.62	0.88	0.51	1.02	0.15	-0.41	0.56	0.98
South	-4.09	6.98	-1.92	1.41	-2.49	4.89	-2.45	1.43	1.57	-3.35	2.62	0.59
West	-1.99	3.82	-0.19	1.18	-0.16	0.10	0.89	0.97	0.06	-0.22	0.48	0.99
North-East	-1.73	3.45	-0.02	1.23	0.10	-0.55	1.15	0.92	-0.26	0.30	0.48	1.02
South-East	-2.06	4.32	-0.96	1.41	-0.60	0.90	0.37	0.94	0.83	-1.42	1.22	0.92
South-West	-2.06	4.48	-1.13	1.40	-0.39	0.50	0.60	0.87	1.56	-3.17	2.41	0.73
North-West	-0.53	0.72	1.79	0.93	0.10	-0.38	0.96	0.96	0.24	-0.57	0.90	0.97

* Coefficients are for side fins on both sides of fenestration. For side fins on only one side, divide the coefficients mentioned in this table by 2.

(e) The maximum allowable SHGC of glazing shall be 0.9.

(f) Any surrounding man-made or natural sunlight obstructers shall be considered as a permanent shading of PF equal to 0.4 if

  i. the distance between the vertical fenestration of the building, for which compliance is shown, and surrounding man-made or natural sunlight obstructers is less than or equal to twice the height of the surrounding man-made or natural sunlight obstructers; and

  ii. the surrounding man-made or natural sunlight obstructers shade the façade for at least 80% of the total time that the façade is exposed to direct sun light on a summer solstice. Compliance shall be shown using a sun path diagram for summer solstice super-imposed on the building plan.

(g) Vertical fenestration, located such that its bottom is more than 2.2 m above the level of the floor, is exempt from the SHGC requirements in Table 4-10, if the following conditions are complied with:

  i. The Total Effective Aperture for the elevation is less than 0.25, including all fenestration areas more than 1.0 meter above the floor level; and,

  ii. An interior light shelf is provided at the bottom of this fenestration area, with a projection factor on interior side not less than:

    a. for E-W, SE, SW, NE, and NW orientations

    b. 0.5 for S orientation, and

    c. 0.35 for N orientation when latitude is less than 15°N.

Note 4-2 Equivalent SHGC and Projection Factor

A 5,400 m^2 two story office building in Delhi is trying to achieve ECBC level compliance. It has a rectangular layout (90 m x 30 m) with floor to floor height of 4.0 m and floor area is evenly distributed over the two floors. Windows are either east or west facing and equally distributed on the two floors. The windows are all 1.85m in length and 2.165m in height with an overhang of 0.85 m. Cill level is 1.385 m above floor level. The overall glazing area is 384 m^2. SHGC of the glazing in the East/West Fenestration is 0.30; area wighted U-Factor is 3.0 W/m^2.K. VLT of the glazing in all orientation is 0.5. Will the vertical fenestration comply with the ECBC from the prescriptive approach?

Solution:

Table 4-10 and §4.3.3 lists the U-factor, SHGC and VLT requirements for vertical fenestration for ECBC compliant buildings. The building is located in Delhi (Latitude: $28^0$70' N, Longitude: $77^0$10'E), which falls under the composite climate, as per Appendix B, Table 12.1. To fulfil prescriptive requirements, Window to Wall ratio ≤ 40%, SHGC ≤ 0.27, U-factor ≤ 3.0 W/m^2.K, and VLT ≥ 0.27.

Total Floor area = 5400 m^2

Total wall area = 2 x (2x ((90m x 4m) + (30m x 4m))) = 1,920 m^2

Total Fenestration area = 384 m^2

Window to Wall Ratio (WWR) = 384/1,920 = 20%

As per the calculations, the building has a WWR of 20%, thus complying with the requirement for WWR. The U-factor is also less than 3.0 W/m^2.K. Similarly the VLT is 0.45, which is greater than the minimum specified value of 0.27, thus complying with the u-factor and VLT requirement.

Equivalent SHGC Calculation

As the windows have an overhang, this case will fall under the exception, and the *equivalent SHGC* value will be calculated as per *Equation 4.1, i.e.*

$$SEF = (C_3 \times PF^3) + (C_2 \times PF^2) + (C_1 \times PF) + C_0$$

Where,

PF= Projection Factor, and,
C_0, C_1, C_2, C_3 are coefficients of Shading Equivalent Factors (SEF), listed in Table 4-12 and Table 4-13.

First, calculate Projection Factor (PF) for each orientation. Shading Equivalent Factor coefficients should be from Table 4-12, as the latitude is greater than 15^0N.

$$SEF_{East} = (C_3 \times PF^3) + (C_2 \times PF^2) + (C_1 \times PF) + C_0$$

$$SEF_{East} = (-0.05 \times (0.345)^3) + (0.42 \times (0.345)^2) + (0.66 \times 0.345) + 1.02$$

$$SEF_{East} = 1.296$$

Therefore, equivalent $SHGC_{East}$ = 0.3 ÷ 1.296 = 0.23 Hence the vertical fenestration on the east façade will comply as per prescriptive approach, as the equivalent SHGC is less than maximum allowed.

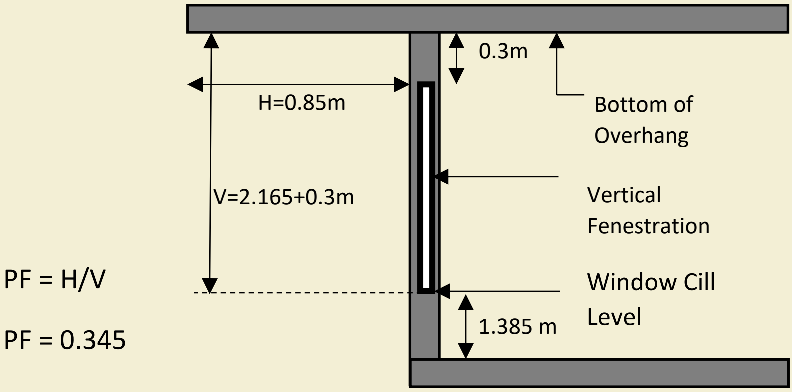
Similarly, for the west façade:

$SEF_{West} = (C_3 \times PF^3) + (C_2 \times PF^2) + (C_1 \times PF) + C_0$

$SEF_{West} = (1.52 \times 0.345^3) + (-2.51 \times 0.345^2) + (2.30 \times 0.345) + 0.76$

$SEF_{West} = 1.317$

Therefore equivalent $SHGC_{West} = 0.3 \div 1.317 = 0.23$, hence the vertical fenestration on the west façade will comply using the prescriptive approach, as the equivalent SHGC is less than maximum allowed.



4.3.3.1 U-factor Exception

Vertical fenestration on all unconditioned buildings or unconditioned spaces may have a maximum U-factor of 5 W/m^2.K provided they comply with all conditions mentioned in Table 4-14.

Table 4-14 U-factor (W/m².K) Exemption Requirements for Shaded Building

Building Type	*Climate zone*	*Orientation*	*Maximum Effective SHGC*	*Minimum VLT*	*PF*
Unconditioned buildings or unconditioned spaces	All except cold	Non-North for all latitudes and North for latitude < 15°N	0.27	0.27	≥0.40
		North for latitude > 15°N	0.27	0.27	0.0

4.3.4 Skylights

Skylights shall comply with the maximum U-factor and maximum SHGC requirements of Table 4-15. Skylight roof ratio (SRR), defined as the ratio of the total skylight area of the roof, measured to the outside of the frame, to the gross exterior roof area, is limited to a maximum of 5% for ECBC Building, ECBC+ Building, and SuperECBC Building, when using the Prescriptive Method for compliance.

Table 4-15 Skylight U-factor and SHGC Requirements (U-factor in W/m².K)

Climate	*Maximum U-factor*	*Maximum SHGC*
All climatic zones	4.25	0.35

Exception to §4.3.4 Skylights in temporary roof coverings or awnings over unconditioned spaces.

4.3.5 Building Envelope Trade-Off Method

The building envelope complies with the code if the Envelope Performance Factor (EPF) of the Proposed Building is less than the EPF of the Standard Building, where the Standard Building exactly complies with the prescriptive requirements of building envelope. This method shall not be used for buildings with WWR>40%. Trade-off is not permitted for skylights. Skylights shall meet requirements of 4.3.4. The envelope performance factor shall be calculated using the following equations.

Equation 4.2: $\boldsymbol{EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest}}$

$$EPF_{Roof} = c_{Roof} \sum_{s=1}^{n} U_s A_s$$

$$EPF_{Wall} = c_{Wall,Mass} \sum_{s=1}^{n} U_s A_s + c_{Wall,Other} \sum_{s=1}^{n} U_s A_s$$

$$\begin{aligned} EPF_{Fenest} = {} & c_{1Fenest,North} \sum_{w=1}^{n} U_w A_w + c_{2Fenest,North} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + c_{1Fenest,South} \sum_{w=1}^{n} U_w A_w + c_{2Fenest,South} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + c_{1Fenest,East} \sum_{w=1}^{n} U_w A_w + c_{2Fenest,East} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + c_{1Fenest,West} \sum_{w=1}^{n} U_w A_w + c_{2Fenest,West} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \end{aligned}$$

EPF_{Roof}	Envelope performance factor for roofs. Other subscripts include walls and fenestration.
A_s, A_w	The area of a specific envelope component referenced by the subscript "s" or for windows the subscript "w".
$SHGC_w$	The solar heat gain coefficient for windows (w).
SEF_w	A multiplier for the window SHGC that depends on the projection factor of an overhang or side fin.
U_s	The U-factor for the envelope component referenced by the subscript "s".
c_{Roof}	A coefficient for the "Roof" class of construction.
C_{wall}	A coefficient for the "Wall"
$C_{1\,Fenes}$	A coefficient for the "Fenestration U-factor"
$C_{2\,Fenes}$	A coefficient for the "Fenestration SHGC"

Values of "c" are taken from Table 4-16 through Table 4-20 for each class of construction.

Table 4-16 Envelope Performance Factor Coefficients – Composite Climate

	Daytime Business, Educational, Shopping Complex		*24-hour Business, Hospitality, Health Care, Assembly*	
	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$
Mass Walls	5.39	-	7.91	-
Curtain Walls, Other	7.83	-	10.32	-
Roofs	14.93	-	17.88	-
North Windows	0.33	81.08	-2.83	119.14
South Windows	-2.30	221.07	-3.54	294.00
East Windows	-1.17	182.64	-3.23	255.91
West Windows	-0.74	182.11	-2.85	252.61

Table 4-17 Envelope Performance Factor Coefficients – Hot and Dry Climate

	Daytime Business, Educational, Shopping Complex		*24-hour Business, Hospitality, Health Care, Assembly*	
	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$
Mass Walls	6.4	-	12.09	-
Curtain Walls, Other	9.58	-	12.30	-
Roofs	14.82	-	21.12	-
North Windows	-0.37	101.66	0.13	136.80
South Windows	-1.35	252.90	-0.21	327.51
East Windows	-0.85	219.91	-0.16	293.19
West Windows	-0.80	226.57	0.15	300.80

Table 4-18 Envelope Performance Factor Coefficients – Hot Humid Climate

	Daytime Business, Educational, Shopping Complex		*24-hour Business, Hospitality, Health Care, Assembly*	
	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$	C factor $_{\text{U-factor}}$	C factor $_{\text{SHGC}}$
Mass Walls	4.91	-	9.66	-
Curtain Walls, Other	7.98	-	13.32	-
Roofs	13.15	-	19.38	-
North Windows	-1.87	102.83	-3.26	135.84
South Windows	-2.62	218.31	-3.54	277.61
East Windows	-2.07	182.40	-3.37	238.68
West Windows	-2.22	184.75	-3.16	235.95

Table 4-19 Envelope Performance Factor Coefficients – Temperate Climate

	Daytime Business, Educational, Shopping Complex		*24-hour Business, Hospitality, Health Care, Assembly*	
	C factor U-factor	C factor SHGC	C factor U-factor	C factor SHGC
Mass Walls	2.35	-	5.06	-
Curtain Walls, Other	4.50	-	7.29	-
Roofs	11.78	-	15.15	-
North Windows	-4.17	106.23	-5.58	123.43
South Windows	-4.66	193.63	-5.90	233.84
East Windows	-4.46	211.50	-5.87	267.49
West Windows	-4.67	215.20	-5.33	262.27

Table 4-20 Envelope Performance Factor Coefficients – Cold Climate

	Daytime Business, Educational, Shopping Complex		*24-hour Business, Hospitality, Health Care, Assembly*	
	C factor U-factor	C factor SHGC	C factor U-factor	C factor SHGC
Mass Walls	17.65	-	12.10	-
Curtain Walls, Other	14.36	-	17.65	-
Roofs	5.79	-	16.02	-
North Windows	-2.40	0.32	8.23	50.36
South Windows	-2.65	-18.75	0.08	172.87
East Windows	-2.78	-16.67	3.83	168.83
West Windows	-2.84	-15.53	5.60	159.43

4.3.6 Standard Building EPF Calculation

EPF of the Standard Building shall be calculated as follows:

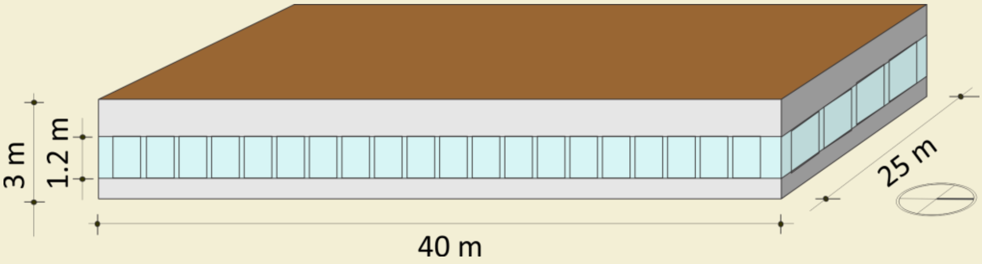
(a) The Standard Building shall have the same building floor area, gross wall area and gross roof area as the Proposed Building. If the building has both 24-hour and daytime occupancies, the distribution between these shall be the same as the Proposed Design.

(b) The U-factor of each envelope component shall be equal to the criteria from §4 for each class of construction.

(c) The SHGC of each window shall be equal to the criteria from §4.3.3.

Application of Building Envelope Trade-off method

A 1,000 m^2 single story daytime use office building in Ahmedabad is trying to achieve ECBC level compliance. Each side has a band of windows, without shading. The materials for the envelope have already been selected, prior to opting for ECBC compliance. Their thermal properties are: roof assembly U-value= .4 W/m².K, external wall assembly U-value = .25 W/m².K, glazing SHGC = .25, VLT = 0.27, area weighted U-value for glazing = 1.8 W/m².K. External walls are mass wall construction type. Dimensions of the building envelope are as follows:



According to Table 11-1, Appendix B, Ahmedabad falls under the hot and dry climate zone. To prove compliance through the prescriptive approach, U values, and SHGC must comply with requirements listed in Table 4-4, Table 4-7, Table 4-10 and VLT and window to wall ratio with requirements in § 4.3.3 for a 24-hour use building in the hot and dry climate zone. The table below lists thermal properties of the building envelope components and the corresponding prescriptive requirements for ECBC complaint buildings.

Table 4-3-1 Prescriptive Requirements and Proposed Thermal Properties

			Prescriptive U-factor (W/m²·K)			*Proposed U-factor (W/m²·K)*	*Area (m²)*
Wall 1– North, South			=<0.63			0.25	90
Wall 2– East, West			=<0.63			0.25	144
Roof			=<0.33			0.4	1000
	U-factor	*SHGC*	*VLT*	*U-factor*	*SHGC*	*VLT*	
Window – South	=<3.0	=<0.27	=<0.27	1.8	0.25	0.27	30
Window – North	=<3.0	=<0.5	=<0.27	1.8	0.25	0.27	30
Window-East	=<3.0	=<0.27	=<0.27	1.8	0.25	0.27	48
Window-West	=<3.3	=<0.27	=<0.27	1.8	0.25	0.27	48

U-value of the roof of the proposed building, at 0.4 W/m².K does not fulfil prescriptive requirements. Similarly, §4.3.3 requires the WWR to be less than 40%. This condition is fulfilled in the proposed buildings as can be seen in the calculations below.

Total Fenestration Area$_{\text{North, South}}$ = 2 x (25m x 1.2m) = 60 m^2

Wall Area$_{\text{North, South}}$ = 2 x (25m x 3m) = 150 m^2

Total Fenestration Area$_{\text{East, West}}$ = 2 x (40m x 1.2m) = 96 m^2

Total Wall Area $_{\text{East, West}}$ = 2 x (40m x 3m) = 240 m^2

Total Fenestration Area = 156 m^2, Total Wall Area = 390 m^2

WWR = 156/390= 0.4.

Hence, this building will not be compliant if the prescriptive approach is followed.

Compliance through Building Envelope Trade-off method

Envelope performance factor (EPF) for the Standard Building and Proposed Building must be compared. As per the Building Envelope Trade-off method, the envelope performance factor (EPF) shall be calculated using the following equations:

Equation 11.1 EPF$_{\text{Total}}$ = EPF$_{\text{Roof}}$ + EPF$_{\text{Wall}}$ + EPF$_{\text{Fenest}}$

Where,

$$EPF_{Roof} = C_{Roof} \sum_{s=1}^{n} U_s A_s$$

$$EPF_{Wall} = C_{Wall,Mass} \sum_{s=1}^{n} U_s A_s + C_{Wall,Other} \sum_{s=1}^{n} U_s A_s$$

$$\begin{aligned} EPF_{Fenest} = {} & C_{1Fenest,North} \sum_{w=1}^{n} U_w A_w + C_{2Fenest,North} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + C_{1Fenest,South} \sum_{w=1}^{n} U_w A_w + C_{2Fenest,South} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + C_{1Fenest,East} \sum_{w=1}^{n} U_w A_w + C_{2Fenest,East} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \\ & + C_{1Fenest,West} \sum_{w=1}^{n} U_w A_w + C_{2Fenest,West} \sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w \end{aligned}$$

Standard Building EPF will be derived from U-factors, SHGCs and VLTs of walls, roofs and fenestration from Table 4-4, Table 4-7, Table 4-10 and § 4.3.3 for a 24-hour use building in the hot and dry climate zone. Values of C are from 24-hour Office building in hot and dry climatic zone for each class of construction from Table 4-16. Since There is no shading for the windows, M_w will not be considered.

Step 1: Calculation of EPF $_{\textit{Proposed Building}}$ from actual envelope properties

$$EPF_{Roof,Actual} = C_{Roof} \sum_{s=1}^{n} U_s \, A_s$$

= 14.82 x 0.40 x 1,000 = 5,928

$$EPF_{Wall,Actual} = C_{Wall,Mass} \sum_{s=1}^{n} U_s \, A_s \; + \; C_{Wall,Other} \sum_{s=1}^{n} U_s \, A_s$$

= (6.4 x 0.25 x 90) + (6.4 x 0.25 x 144) = 374.4

$$EPF_{Fenest} = EPF_{Fenest}, North + \; EPF_{Fenest}, South + \; EPF_{Fenest}, East + \; EPF_{Fenest}, West$$

$$EPF_{Fenest} = C_{1Fenest,} \textstyle\sum_{w=1}^{n} U_w \, A_w \; + \; C_{2Fenest,} \displaystyle\sum_{w=1}^{n} \frac{SHGC_w}{SEF_w} A_w$$

Hence,

$EPF_{Fenest}, North$ = -0.37 x 1.8 x 30 + 101.66 x 0.25 x 30 = -19.98 + 762.45= 742.47

$EPF_{Fenest}, South$ = -1.35 x 1.8 x 30 + 252.90 x 0.25 x 30 = -72.9 + 1,896.75 = 1,823.85

$EPF_{Fenest}, East$ = -0.85 x 1.8 x 48 + 219.91 x 0.25 x 48 = - 73.44 + 2,638.9 = 2, 565.46

$EPF_{Fenest}, West$ = -0.80 x 1.8 x 48 + 226.57 x 0.25 x 48 = -69.12 + 2,718.8 = 2,649.7

Therefore,

$EPF_{Fenest} = 7{,}781.5$

$EPF_{Proposed}$ = 5,928 + 374.4 + 7,781.5 = 14,083.9

Step 2: Calculating EPF $_{\textit{Standard Building}}$ from prescriptive envelope requirements

$$EPF_{Roof,Actual} = C_{Roof} \sum_{s=1}^{n} U_s \, A_s$$

= 14.82 x 0.33 x 1000 = 4,890.6

$$EPF_{Wall,Actual} = C_{Wall,Mass} \sum_{s=1}^{n} U_s \, A_s \; + \; C_{Wall,Other} \sum_{s=1}^{n} U_s \, A_s$$

= (6.4 x 0.63 x 90) + (6.4 x 0.63 x 144) = 362.88 + 580.6 = 943.5

$$EPF_{Fenest} = EP\mathrm{F}_{Fenest}, North + \ EPF_{Fenest}, South + \ EPF_{Fenest}, East + \ EPF_{Fenest}, West$$

Now,

$EPF_{Fenest}, North$ = -0.37 x 3.3 x 30 + 101.66 x 0.5 x 30 = - 36.63 + 1,524.9 = 1,488.3

$EPF_{Fenest}, South$ = -1.35 x 3.3 x 30 + 252.9 x 0.27 x 30 = -133.7 + 2.048.5 = 1,914.8

$EPF_{Fenest}, East$ = -0.85 x 3.3 x 48 + 219.91 x 0.27 x 48 = -134.64 + 2,850 = 2,715.4

$EPF_{Fenest}, West$ = -0.8 x 3.3 x 48 + 226.57 x 0.27 x 48 = -126.7 + 2,936 = 2,809.6

Therefore, $EPF_{Fenest} = 8{,}928$

$EPF_{Baseline}$ = 4,890.6 + 943.5 + 8,928= 14,762.2

Since $EPF_{Baseline}$ > $EPF_{Proposed}$, therefore the building is compliant with ECBC building envelope requirements.

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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

UNIT – II - BUILDING ENERGY CODES AND STANDARDS – SARA 5132

UNIT 2

ECBC – COMFORT SYSTEMS AND CONTROLS

Ventilation - Minimum Space Conditioning Equipment Efficiencies -Unitary, Split, Packaged Air-Conditioners, Variable Refrigerant Flow, Air Conditioning and Condensing Units Serving Computer Rooms. Controls – Temperature control, air conditioning control, occupancy control, fan controls. Piping and duct work. System Balancing. Condensers, Service water heating, cooling towers, Economizers, Variable Flow Hydronic Systems, Energy recovery. Low-energy Comfort Systems. Lighting and controls, electrical and renewable energy systems. Calculation of energy requirements of a proposed and standard design.

Objective: To devise the applicability of the methodologies prescribed in the codes, To comprehend the compliance approaches

Methodology:

Ventilation & Controls	Presentation & Lecture Discussion sessions.
Lighting and controls, electrical and renewable energy systems	Presentation & Lecture Reading and Discussion sessions.
Calculation of energy requirements of a proposed and standard design.	Power point presentation and Lecture

5. Comfort Systems and Controls

5.1 General

All heating, ventilation, air conditioning equipment and systems, and their controls shall comply with the mandatory provisions of §5.2 and the prescriptive criteria of §5.3 for the respective building energy efficiency level.

All service water heating equipment and systems shall comply with the mandatory provisions of §5.2.

5.2 Mandatory Requirements

5.2.1 Ventilation

(a) All habitable spaces shall be ventilated with outdoor air in accordance with the requirements of §5.2.1 and guidelines specified in the National Building Code 2016 (Part 8: Building Services, Section 1: Lighting and Natural Ventilation, Subsection 5: Ventilation).

(b) Ventilated spaces shall be provided with outdoor air using one of the following:

  i. Natural ventilation
  ii. Mechanical ventilation
  iii. Mixed mode ventilation

5.2.1.1 Natural Ventilation Design Requirements

Naturally ventilated buildings or spaces in a mixed-mode ventilated buildings shall:

(a) Comply with guidelines provided for natural ventilation in NBC.

(b) Have minimum BEE 3-star rated ceiling fans, if provided with ceiling fans.

(c) Have exhaust fans complying with minimum efficiency requirements of fans in §5.3, if provided.

5.2.1.2 Mechanical Ventilation Air Quantity Design Requirements

Buildings that are ventilated using a mechanical ventilation system or spaces in mixed-mode ventilated buildings that are ventilated with a mechanical system, either completely or in conjunction with natural ventilation systems, shall:

(a) Install mechanical systems that provide outdoor air change rate as per NBC.

(b) Have a ventilation system controlled by CO sensors for basement carpark spaces with total car park space greater than or equal to 600 m^2.

Note 5-1 Adaptive Thermal Comfort

Human body has the ability to adapt to environmental conditions and become accustomed to them over time. People accustomed to the variability of environmental parameters in non-air-conditioned buildings can live and work through a larger temperature range without experiencing thermal discomfort. This logic informs the adaptive thermal comfort model for buildings. Adaptive comfort models offer an opportunity to reduce energy use as buildings can be operated at more moderate temperatures. Energy used to maintain stringent comfort conditions through mechanical equipment can thus be avoided. Operative temperatures for the model can be calculated using the formulae below.

Naturally Ventilated Buildings

Indoor Operative Temperature = (0.54 x outdoor temperature) + 12.83

Where, indoor operative temperature (°C) is neutral temperature, & outdoor temperature is the 30-day outdoor running mean air temperature (°C).

The 90 % acceptability range for the India specific adaptive models for naturally ventilated buildings is ± 2.38°C.

For example, Indoor Operative Temperature for a naturally ventilated building in Delhi

= (0.54 x 33.0) + 12.83 = 30.68 °C

Mixed Mode Buildings

Indoor Operative Temperature = (0.28 x outdoor temperature) + 17.87

Where indoor operative temperature (°C) is neutral temperature & outdoor temperature is the 30-day outdoor running mean air temperature (°C).

The 90% acceptability range for the India specific adaptive models for mixed-mode buildings is ± 3.46°C.

For example, Indoor Operative Temperature for a mixed mode building in Delhi

= (0.28 x 33.0) + 17.87 = 27.1 °C

Air Conditioned Buildings

Indoor Operative Temperature = (0.078 x outdoor temperature) + 23.25

Where indoor operative temperature (°C) is neutral temperature & outdoor temperature is the 30-day outdoor running mean air temperature (°C).

The 90% acceptability range for the adaptive models for conditioned buildings is ±1.5°C.

For example, Indoor Operative Temperature for an air-conditioned building in Delhi

= (0.078 x 33.0) + 23.25

= 25.8 °C

5.2.1.3 Demand Control Ventilation

Mechanical ventilation systems shall have demand control ventilation if they provide outdoor air greater than 1,500 liters per second, to a space greater than 50 m^2, with occupant density exceeding 40 people per 100 m^2 of the space, and are served by one or more of the following systems:

(a) An air side economizer
(b) Automatic outdoor modulating control of the outdoor air damper

Exceptions to § 5.2.1.3: Following shall be exempt from installing demand control ventilation systems:

(a) Classrooms in Schools, call centers category under Business
(b) Spaces that have processes or operations that generate dust, fumes, mists, vapors, or gases and are provided with exhaust ventilation, such as indoor operation of internal combustion engines or areas designated for unvented food service preparation, or beauty salons
(c) Systems with exhaust air energy recovering system

5.2.2 Minimum Space Conditioning Equipment Efficiencies

5.2.2.1 Chillers

(a) Chillers shall meet or exceed the minimum efficiency requirements presented in Table 5-1 through Table 5-2 under ANSI/ AHRI 550/ 590 conditions.
(b) The application of air-cooled chiller is allowed in all buildings with cooling load less than 530 kW. For buildings with cooling load equal to or greater than 530 kW, the number of air-cooled chiller shall be restricted to 33% of the total installed chilled water capacity unless the authority having jurisdiction mandates the application of air cooled chillers.
(c) Minimum efficiency requirements under BEE Standards and Labeling Program for chillers shall take precedence over the minimum requirements presented in Table 5-1 through Table 5-2.
(d) To show compliance to ECBC, minimum requirement of both COP and IPLV requirement of ECBC Building shall be met. To show compliance with ECBC+ Building and SuperECBC Building, minimum requirement of either COP or IPLV of respective efficiency level shall be met.

Table 5-1 Minimum Energy Efficiency Requirements for water cooled Chillers

	ECBC Building		*ECBC+ Building*		*SuperECBC Building*	
Chiller Capacity (kWr)	COP	IPLV	COP	IPLV	COP	IPLV
<260	4.7	5.8	5.2	6.9	5.8	7.1
≥260 & <530	4.9	5.9	5.8	7.1	6.0	7.9
≥530 &<1,050	5.4	6.5	5.8	7.5	6.3	8.4
≥1,050 &<1,580	5.8	6.8	6.2	8.1	6.5	8.8
≥1,580	6.3	7.0	6.5	8.9	6.7	9.1

Table 5-2 Minimum Energy Efficiency Requirements for air cooled Chillers

	ECBC Building		*ECBC+ Building*		*SuperECBC Building*
Chiller Capacity (kWr)	COP	IPLV	COP	IPLV	COP/ IPLV
<260	2.8	*3.5*	3.0	*4.0*	NA
≥260	3.0	*3.7*	3.2	*5.0*	NA

5.2.2.2 Unitary, Split, Packaged Air-Conditioners

Unitary air-conditioners shall meet or exceed the efficiency requirements given in

Table 5-3 through Table 5-5. Window and split air conditioners shall be certified under BEE's Star Labeling Program. EER shall be as per IS 8148 for all unitary, split, packaged air conditioners greater than 10 kWr.

Table 5-3 Minimum Requirements for Unitary, Split, Packaged Air Conditioners in ECBC Building

Cooling Capacity (kWr)	Water Cooled	Air Cooled
≤ 10.5	NA	BEE 3 Star
> 10.5	3.3 EER	2.8 EER

Table 5-4 Minimum Requirements for Unitary, Split, Packaged Air Conditioners in ECBC+ Building

Cooling Capacity (kWr)	Water Cooled	Air Cooled
≤ 10.5	NA	BEE 4 Star
> 10.5	3.7 EER	3.2 EER

Table 5-5 Minimum Requirements for Unitary, Split, Packaged Air Conditioners in SuperECBC Building

Cooling Capacity (kWr)	Water Cooled	Air Cooled
≤ 10.5	NA	BEE 5 Star
>10.5	3.9 EER	3.4 EER

5.2.2.3 Variable Refrigerant Flow

Variable Refrigerant Flow (VRF) systems shall meet or exceed the efficiency requirements specified in Table 5-6 as per the ANSI/AHRI Standard 1230 while the Indian Standard on VRF is being developed. BEE Standards and Labeling requirements for VRF shall take precedence over the current minimum requirement.

*Table 5-6 Minimum Efficiency Requirements for VRF Air conditioners for ECBC Building**

		For Heating or cooling or both	
Type	Size category (kWr)	EER	IEER
VRF Air Conditioners, Air cooled	< 40	3.28	4.36
	>= 40 and < 70	3.26	4.34
	>= 70	3.02	4.07

* The revised EER and IEER values as per Indian Standard for VRF corresponding to values in this table will supersede as and when the revised standards are published.

5.2.2.4 Air Conditioning and Condensing Units Serving Computer Rooms

Air conditioning and condensing units serving computer rooms shall meet or exceed the energy efficiency requirements listed in Table 5-7.

Table 5-7 Minimum Efficiency Requirements for Computer Room Air Conditioners

Equipment type	Net Sensible Cooling Capacity[a]	Minimum SCOP-127[b]	
		Downflow	Upflow
All types of computer room ACs Air/ Water/ Glycol	All capacity	2.5	2.5

a. Net Sensible cooling capacity = Total gross cooling capacity - latent cooling capacity – Fan power
b. Sensible Coefficient of Performance (SCOP-127): A ratio calculated by dividing the net sensible cooling capacity in watts by the total power input in watts (excluding reheater and dehumidifier) at conditions defined in ASHRAE Standard 127-2012 Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners)

5.2.3 Controls

To comply with the Code, buildings shall meet the requirements of §5.2.3.1 through §5.2.3.5.

5.2.3.1 Timeclock

Mechanical cooling and heating systems in Universities and Training Institutions of all sizes and all Shopping Complexes with built up area greater than 20,000 m^2 shall be controlled by timeclocks that:

(a) Can start and stop the system under different schedules for three different day-types per week,

(b) Are capable of retaining programming and time setting during loss of power for a period of at least 10 hours, and

(c) Include an accessible manual override that allows temporary operation of the system for up to 2 hours.

Exceptions to §5.2.3.1:

(a) Cooling systems less than 17.5 kWr

(b) Heating systems less than 5.0 kWr

(c) Unitary systems of all capacities

5.2.3.2 Temperature Controls

Mechanical heating and cooling equipment in all buildings shall be installed with controls to manage the temperature inside the conditioned zones. Each floor or a building block shall be installed with at least one control to manage the temperature. These controls should meet the following requirements:

(a) Where a unit provides both heating and cooling, controls shall be capable of providing a temperature dead band of 3.0°C within which the supply of heating and cooling energy to the zone is shut off or reduced to a minimum.

(b) Where separate heating and cooling equipment serve the same temperature zone, temperature controls shall be interlocked to prevent simultaneous heating and cooling.

(c) Separate thermostat control shall be installed in each
   i. guest room of Resort and Star Hotel,
   ii. room less than 30 m^2 in Business,
   iii. air-conditioned class room, lecture room, and computer room of Educational,
   iv. in-patient and out-patient room of Healthcare

5.2.3.3 Occupancy Controls

Occupancy controls shall be installed to de-energize or to throttle to minimum the ventilation and/or air conditioning systems when there are no occupants in:

(a) Each guest room in a Resort and Star Hotel

(b) Each public toilet in a Star Hotel or Business with built up area more than 20,000 m^2

(c) Each conference and meeting room in a Star Hotel or Business

(d) Each room of size more than 30 m^2 in Educational buildings

5.2.3.4 Fan Controls

Cooling towers in buildings with built up area greater than 20,000 m^2, shall have fan controls based on wet bulb logic, with either:

(a) Two speed motors, pony motors, or variable speed drives controlling the fans, or
(b) Controls capable of reducing the fan speed to at least two third of installed fan power

5.2.3.5 Dampers

All air supply and exhaust equipment, having a Variable Frequency Drive (VFD), shall have dampers that automatically close upon:

(a) Fan shutdown, or,
(b) When spaces served are not in use
(c) Backdraft gravity damper is acceptable in the system with design outdoor air of the system is less than 150 liters per second in all climatic zones except cold climate, provided backdraft dampers for ventilation air intakes are protected from direct exposure to wind.
(d) Dampers are not required in ventilation or exhaust systems serving naturally conditioned spaces.
(e) Dampers are not required in exhaust systems serving kitchen exhaust hoods.

5.2.4 Additional Controls for ECBC+ and SuperECBC Buildings

ECBC+ building shall comply with requirements of § 5.2.4 in addition to complying with requirements of §5.2.3.

5.2.4.1 Centralized Demand Shed Controls

ECBC+ and SuperECBC Buildings with built up area greater than 20,000 m^2 shall have a building management system. All mechanical cooling and heating systems in ECBC+ and SuperECBC Buildings with any programmable logic controller (PLC) to the zone level shall have the following control capabilities to manage centralized demand shed in noncritical zones:

(a) Automatic demand shed controls that can implement a centralized demand shed in non-critical zones during the demand response period on a demand response signal.
(b) Controls that can remotely decrease or increase the operating temperature set points by four degrees or more in all noncritical zones on signal from a centralized control point
(c) Controls that can provide an adjustable rate of change for the temperature setup and reset

The centralized demand shed controls shall have additional capabilities to

(a) Be disabled by facility operators
(b) Be manually controlled from a central point by facility operators to manage heating and cooling set points

5.2.4.2 Supply Air Temperature Reset

Multi zone mechanical cooling and heating systems in ECBC+ and SuperECBC Buildings shall have controls that automatically reset the supply-air temperature in response to building loads or to outdoor air temperature. Controls shall reset the supply air temperature to at least 25% of the difference between the design supply air temperature and the design room air temperature.

Exception to § 5.2.4.2 : ECBC+ and SuperECBC Buildings in warm humid climate zone.

5.2.4.3 Chilled Water Temperature Reset

Chilled water systems with a design capacity exceeding 350 kWr supplying chilled water to comfort conditioning systems in ECBC+ and SuperECBC Buildings shall have controls that automatically reset supply water temperatures by representative building loads (including return water temperature) or by outdoor air temperature.

Exceptions to § 5.2.4.3: Controls to automatically reset chilled water temperature shall not be required where the supply temperature reset controls causes improper operation of equipment.

5.2.5 Additional Controls for SuperECBC Buildings

SuperECBC Buildings shall comply with requirements of § 5.2.5 in addition to complying with requirements of § 5.2.3 and § 5.2.4.

5.2.5.1 Variable Air Volume Fan Control

Fans in Variable Air Volume (VAV) systems in SuperECBC Buildings shall have controls or devices that will result in fan motor demand of no more than 30% of their design wattage at 50% of design airflow based on manufacturer's certified fan data.

5.2.6 Piping and Ductwork

5.2.6.1 Piping Insulation

Piping for heating, space conditioning, and service hot water systems shall meet the insulation requirements listed in Table 5-8 through Table 5-10. Insulation exposed to weather shall be protected by aluminum sheet metal, painted canvas, or plastic cover. Cellular foam insulation shall be protected as above, or be painted with water retardant paint.

Exceptions to § 5.2.6.1:

(a) Reduction in insulation R value by 0.2 (compared to values in Table 5-8, Table 5-9 and Table 5-10) to a minimum insulation level of R-0.4 shall be permitted for any pipe located in partition within a conditioned space or buried.

(b) Insulation R value shall be increased by 0.2 over and above the requirement stated in Table 5-8 through Table 5-10 for any pipe located in a partition outside a building with direct exposure to weather.

(c) Reduction in insulation R value by 0.2 (compared to values in Table 5-8, Table 5-9 and Table 5-10) to a minimum insulation level of R-0.4 shall be permitted for buildings in Temperate climate zone.

Table 5-8 Insulation Requirements for Pipes in ECBC Building

Operating Temperature (ºC)	Pipe size (mm)	
	<25	>=40
	Insulation R value (m^2.K/W)	
Heating System		
94°C to 121°C	0.9	1.2
60°C to 94°C	0.7	0.7
40°C to 60°C	0.4	0.7
Cooling System		
4.5°C to 15°C	0.4	0.7
< 4.5°C	0.9	1.2
Refrigerant Piping (Split systems)		
4.5°C to 15°C	0.4	0.7
< 4.5°C	0.9	1.2

Table 5-9 Insulation Requirements for Pipes in ECBC+ Building

Operating Temperature (ºC)	Pipe size (mm)	
	< 40	>=40
	Insulation R value (m^2.K/W)	
Heating System		
94°C to 121°C	1.1	1.3
60°C to 94°C	0.8	0.8
40°C to 60°C	0.5	0.9
Cooling System		
4.5°C to 15°C	0.5	0.9
< 4.5°C	1.1	1.3
Refrigerant Piping (Split Systems)		
4.5°C to 15°C	0.5	0.9
< 4.5°C	1.1	1.3

Table 5-10 Insulation Requirements for Pipes in SuperECBC Buildings

Operating Temperature (ºC)	Pipe size (mm)	
	< 40	>=40
	Insulation R value (m².K/W)	
Heating System		
94°C to 121°C	1.5	1.5
60°C to 94°C	1.0	1.3
40°C to 60°C	0.7	1.1
Cooling System		
4.5°C to 15°C	0.7	1.2
< 4.5°C	1.5	1.5
Refrigerant Piping (Split Systems)		
4.5°C to 15°C	0.4	0.7
< 4.5°C	1.5	1.5

5.2.6.2 Ductwork and Plenum Insulation

Ductwork and plenum shall be insulated in accordance with Table 5-11.

Table 5-11 Ductwork Insulation (R value in m^2 . K/W) Requirements

Duct Location	Supply ducts	Return ducts
Exterior	R -1.4	R -0.6
Unconditioned Space	R -0.6	None
Buried	R -0.6	None

5.2.7 System Balancing

5.2.7.1 General

System balancing shall be done for systems serving zones with a total conditioned area exceeding 500 m^2.

5.2.7.2 Air System Balancing

Air systems shall be balanced in a manner to first minimize throttling losses; then, for fans with fan system power greater than 0.75 kW, fan speed shall be adjusted to meet design flow conditions.

5.2.7.3 Hydronic System Balancing

Hydronic systems shall be proportionately balanced in a manner to first minimize throttling losses; then the pump impeller shall be trimmed or pump speed shall be adjusted to meet design flow conditions.

5.2.8 Condensers

5.2.8.1 Condenser Locations

Condensers shall be located such that the heat sink is free of interference from heat discharge by devices located in adjoining spaces, and do not interfere with other such systems installed nearby.

5.2.9 Service Water Heating

5.2.9.1 Solar Water Heating

To comply with the Code, Hotels and Hospitals in all climatic zones and all buildings in cold climate zone with a hot water system, shall have solar water heating equipment installed to provide for:

(a) at least 20% of the total hot water design capacity if above grade floor area of the building is less than 20,000 m^2

(b) at least 40% of the total hot water design capacity if above grade floor area of the building is greater than or equal to 20,000 m^2

For compliance with ECBC+ and SuperECBC, Hotels and Hospitals in all climatic zones and all buildings in cold climate zone with a hot water system, shall have solar water heating equipment installed to provide at least 40% and 60% respectively of the total hot water design capacity.

Exception to § 5.2.9.1: Systems that use heat recovery to provide the hot water capacity required as per the efficiency level or building size.

5.2.9.2 Heating Equipment Efficiency

Service water heating equipment shall meet or exceed the performance and minimum efficiency requirements presented in available Indian Standards

(a) Solar water heater shall meet the performance/ minimum efficiency level mentioned in IS 13129 Part (1&2)

(b) Gas Instantaneous water heaters shall meet the performance/minimum efficiency level mentioned in IS 15558 with above 80% Fuel utilization efficiency.

(f) Electric water heater shall meet the performance/ minimum efficiency level mentioned in IS 2082.

5.2.9.3 Other Water Heating System

Supplementary heating system shall be designed to maximize the energy efficiency of the system and shall incorporate the following design features in cascade:

(a) Maximum heat recovery from hot discharge system like condensers of air conditioning units,
(b) Use of gas fired heaters wherever gas is available, and
(c) Electric heater as last resort.

5.2.9.4 Piping Insulation

Piping insulation shall comply with § 5.2.6.1. The entire hot water system including the storage tanks, pipelines shall be insulated conforming to the relevant IS standards on materials and applications.

5.2.9.5 Heat Traps

Vertical pipe risers serving storage water heaters and storage tanks not having integral heat traps and serving a non-recirculating system shall have heat traps on both the inlet and outlet piping.

5.2.9.6 Swimming Pools

All heated pools shall be provided with a vapor retardant pool cover on or at the water surface. Pools heated to more than 32˚C shall have a pool cover with a minimum insulation value of R-4.1.

Exception to § 5.2.9.6: Pools deriving over 60% of their energy from site-recovered energy or solar energy source.

5.3 Prescriptive Requirements

Compliance shall be demonstrated with the prescriptive requirements in this section. Supply, exhaust, and return or relief fans with motor power exceeding 0.37 kW shall meet or exceed the minimum energy efficiency requirements specified in Table 5-12 through Table 5-14 except the following need not comply with the requirement

(a) Fans in un-ducted air conditioning unit where fan efficiency has already been taken in account to calculate the efficiency standard of the comfort system.
(b) Fans in Health Care buildings having HEPA filters.
(c) Fans inbuilt in energy recovery systems that pre-conditions the outdoor air.

Table 5-12 Mechanical and Motor Efficiency Requirements for Fans in ECBC Buildings

System type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	60%	IE 2

Table 5-13 Mechanical and Motor Efficiency Requirements for Fans in ECBC+ Buildings

System type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	65%	IE 3

Table 5-14 Mechanical and Motor Efficiency Requirements for Fans in SuperECBC Buildings

System Type	*Fan Type*	*Mechanical Efficiency*	*Motor Efficiency (As per IS 12615)*
Air-handling unit	Supply, return and exhaust	70%	IE 4

5.3.1 Pumps

Chilled and condenser water pumps shall meet or exceed the minimum energy efficiency requirements specified in Table 5-15 through Table 5-17. Requirements for pumps in district chiller systems and hot water pumps for space heating are limited to the installed efficiency requirement of individual pump equipment only. To show compliance, calculate the total installed pump capacity in kilo watt and achieve the prescribed limits per kilo watt of refrigeration installed in the building.

Exceptions to § 5.3.1: Pumps used in processes e.g. service hot water, chilled water used for refrigeration etc.

Table 5-15 Pump Efficiency Requirements for ECBC Building

Equipment	*ECBC*
Chilled Water Pump (Primary and Secondary)	18.2 W/ kW_r with VFD on secondary pump
Condenser Water Pump	17.7 W/ kW_r
Pump Efficiency (minimum)	70%

Table 5-16 Pump Efficiency Requirements for ECBC+ Building

Equipment	*ECBC+ Building*
Chilled Water Pump (Primary and Secondary)	16.9 W/ kW_r with VFD on secondary pump
Condenser Water Pump	16.5 W/ kW_r
Pump Efficiency (minimum)	75%

Table 5-17 Pump Efficiency Requirements for SuperECBC Building

Equipment	*SuperECBC Building*
Chilled Water Pump (Primary and Secondary)	14.9 W/ kW_r with VFD on secondary pump
Condenser Water Pump	14.6 W/ kW_r
Pump Efficiency (minimum)	85%

5.3.2 Cooling Towers

Cooling towers shall meet or exceed the minimum efficiency requirements specified in Table 5-18. ECBC+ and SuperECBC Buildings shall have additional VFD installed in the cooling towers.

Table 5-18 Cooling Tower Efficiency Requirements for ECBC, ECBC+, and SuperECBC Buildings

Equipment type	*Rating Condition*	*Efficiency*
Open circuit cooling tower Fans	35°C entering water 29°C leaving water 24°C WB outdoor air	0.017 kW/kW_r *0.31 kW/ L/s*

5.3.3 Economizers

5.3.3.1 Economizer for ECBC, ECBC+, and SuperECBC Building

Each cooling fan system in buildings with built up area greater than 20,000 m^2, shall include at least one of the following:

(a) An air economizer capable of modulating outside-air and return-air dampers to supply 50% of the design supply air quantity as outside-air.

(b) A water economizer capable of providing 50% of the expected system cooling load at outside air temperatures of 10°C dry-bulb/7.2°C wet-bulb and below.

Exception to §5.3.3.1:

(a) Projects in warm-humid climate zones are exempt.

(b) Projects with only daytime occupancy in the hot-dry are exempt.

(c) Individual ceiling mounted fan systems is less than 3,200 liters per second exempt.

5.3.3.2 Partial Cooling

Where required by §5.3.3.1 economizers shall be capable of providing partial cooling even when additional mechanical cooling is required to meet the cooling load.

5.3.3.3 Economizer Controls

Air economizer shall be equipped with controls

(a) That allow dampers to be sequenced with the mechanical cooling equipment and not be controlled by only mixed air temperature.
(b) capable of automatically reducing outdoor air intake to the design minimum outdoor air quantity when outdoor air intake will no longer reduce cooling energy usage.
(c) Capable of high-limit shutoff at 24 °C dry bulb temperature.

5.3.3.4 Testing

Air-side economizers shall be tested in the field following the requirements in §12 Appendix C to ensure proper operation.

Exception to §5.3.3.4: Air economizers installed by the HVAC system equipment manufacturer and certified to the building department as being factory calibrated and tested per the procedures in §12.

5.3.4 Variable Flow Hydronic Systems

5.3.4.1 Variable Fluid Flow

HVAC pumping systems having a total pump system power exceeding 7.5 kW shall be designed for variable fluid flow and shall be capable of reducing pump flow rates to an extent which is lesser or equal to the limit, where the limit is set by the larger of:

(a) 50% of the design flow rate, or
(b) the minimum flow required by the equipment manufacturer for proper operation of the chillers or boilers.

5.3.4.2 Isolation Valves

Water cooled air-conditioning or heat pump units with a circulation pump motor greater than or equal to 3.7 kW shall have two-way automatic isolation valves on each water cooled air-conditioning or heat pump unit that are interlocked with the compressor to shut off condenser water flow when the compressor is not operating.

5.3.4.3 Variable Speed Drives

Chilled water or condenser water systems that must comply with either §5.3.4.1 or §5.3.4.2 and that have pump motors greater than or equal to 3.7 kW shall be controlled by variable speed drives.

5.3.5 Boilers

Gas and oil fired boilers shall meet or exceed the minimum efficiency requirements specified in Table 5-19 and Table 5-20.

Table 5-19 Minimum Efficiency Requirements for Oil and Gas Fired Boilers for ECBC building

Equipment Type	*Sub Category*	*Size Category*	*Minimum FUE*
Boilers, Hot Water	Gas or oil fired	All capacity	80%
FUE - fuel utilization efficiency			

Table 5-20 Minimum Efficiency Requirements for Oil and Gas Fired Boilers for ECBC+ and SuperECBC building

Equipment Type	*Sub Category*	*Size Category*	*Minimum FUE*
Boilers, Hot Water	Gas or oil fired	All capacity	85%
FUE - fuel utilization efficiency			

5.3.6 Energy Recovery

All Hospitality and Healthcare, with systems of capacity greater than 2,100 liters per second and minimum outdoor air supply of 70% shall have air-to-air heat recovery equipment with minimum 50% recovery effectiveness

At least 50% of heat shall be recovered from diesel and gas fired generator sets installed in Hospitality, Healthcare, and Business buildings with built up area greater than 20,000 m^2.

5.4 Total System Efficiency – Alternate Compliance Approach

Buildings may show compliance by optimizing the total system efficiency for the plant side comfort system instead of the individual equipment mentioned under the prescriptive requirement. This alternate compliance approach is applicable for central chilled water plant side system in all building types. The total installed capacity per kilo-watt refrigeration load shall be less than or equal to maximum threshold requirements as specified in Table 5-21. Equipment that can be included in central chilled water plant side system for this alternate approach are chillers, chilled water pumps, condenser water pumps, and cooling tower fan. Compliance check will be based on annual hourly simulation.

Table 5-21 Minimum System Efficiency Requirement for ECBC, ECBC+, and SuperECBC Buildings*

Water Cooled Chilled Water Plant	*Maximum Threshold (kW/kWr)*
ECBC	0.26
ECBC+	0.23
SuperECBC	0.20

5.5 Low-energy Comfort Systems

Alternative HVAC systems which have low energy use may be installed in place of (or in conjunction with) refrigerant-based cooling systems. Such systems shall be deemed to meet the minimum space conditioning equipment efficiency levels of §5.2.2, but shall comply with all other applicable mandatory provisions of §5.2 as applicable. The approved list of low energy comfort systems[1] is given below:

(a) Evaporative cooling
(b) Desiccant cooling system
(c) Solar air conditioning
(d) Tri-generation (waste-to-heat)
(e) Radiant cooling system
(f) Ground source heat pump
(g) Adiabatic cooling system

Buildings with an approved low-energy comfort system installed for more than 50% of the cooling and heating requirement of the building shall be deemed equivalent to the ECBC+ building standard prescribed in § 5.2.2.

Buildings having an approved low energy comfort system installed for more than 90% of the cooling and heating requirement of the building shall be deemed equivalent to the SuperECBC building standard prescribed in §5.2.2.

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[1] This is not an all-inclusive list. The updated list of low energy comfort systems is available at BEE website (https://www.beeindia.gov.in/).

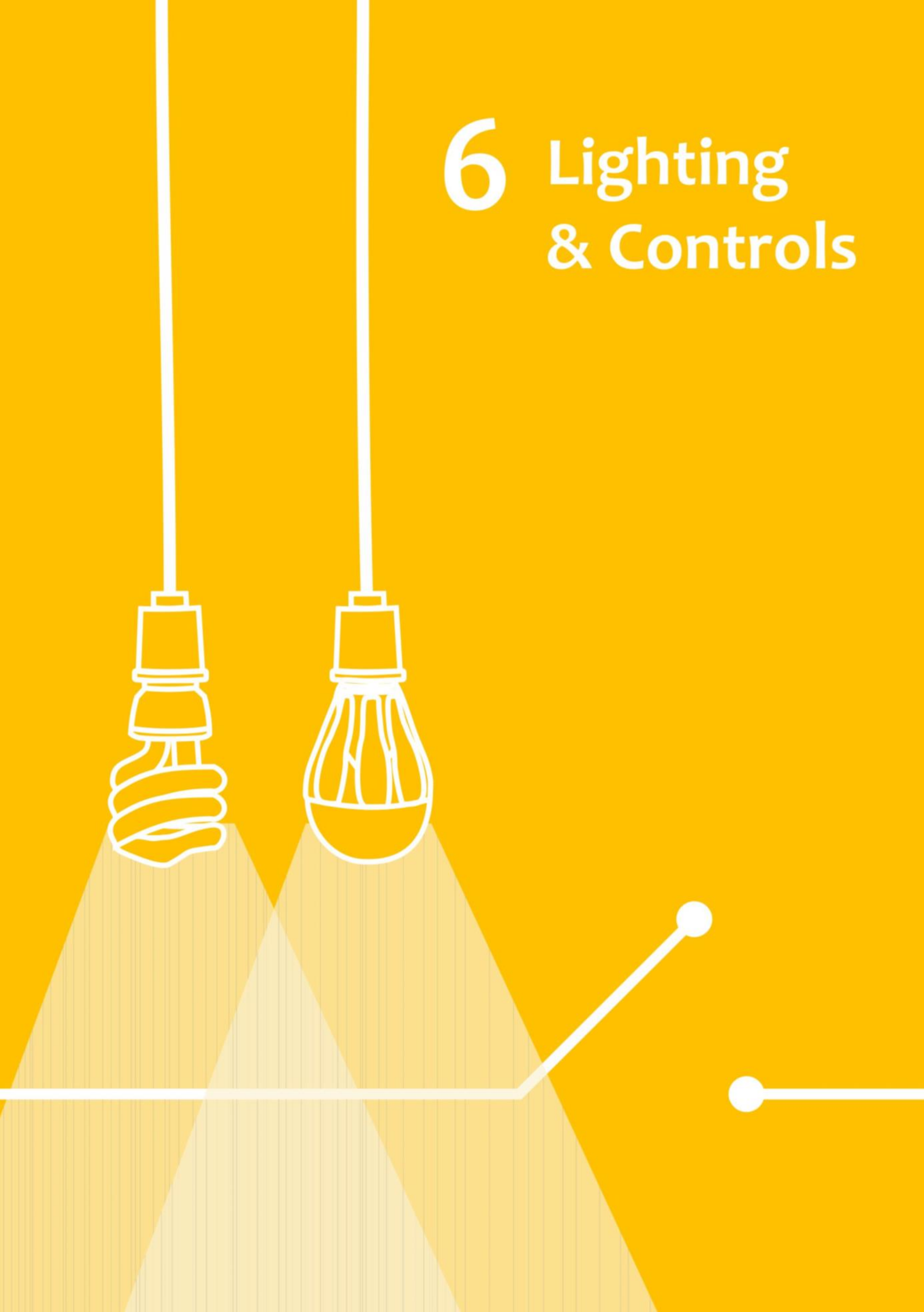
Note 5-2 Thermal Energy Storage

Thermal Energy Storage

Thermal storage may be used for limiting maximum demand, by controlling peak electricity load through reduction of chiller capacity, and by taking advantage of high system efficiency during low ambient conditions. Thermal storage would also help in reducing operating cost by using differential time-of-the day power tariff, where applicable.

The storage media can be ice or water. Water need stratified storage tanks and is mostly viable with large storage capacity and has an advantage of plant operation at higher efficiencies but requires larger storage volumes. In case of central plant, designed with thermal energy storage, its location shall be decided in consultation with the air conditioning engineer. For roof top installations, structural provision shall take into account load coming on the building/structure due to the same. For open area surface installation, horizontal or vertical system options shall be considered and approach ladders for manholes provided. Buried installation shall take into account loads due to movement of vehicles above the area.

6 Lighting & Controls



6. Lighting and Controls

6.1 General

Lighting systems and equipment shall comply with the mandatory provisions of § 6.2 and the prescriptive criteria of § 6.3. The lighting requirements in this section shall apply to:

(a) Interior spaces of buildings,
(b) Exterior building features, including facades, illuminated roofs, architectural features, entrances, exits, loading docks, and illuminated canopies, and,
(c) Exterior building grounds lighting that is provided through the building's electrical service.

Exceptions to §6.1:

(a) Emergency or security lighting that is automatically off during normal building operations.

6.2 Mandatory Requirements

6.2.1 Lighting Control

6.2.1.1 Automatic Lighting Shutoff

(a) 90% of interior lighting fittings in building or space of building larger than 300 m^2 shall be equipped with automatic control device.
(b) Additionally, occupancy sensors shall be provided in
    i. All building types greater than 20,000 m^2 BUA, in
        a. All habitable spaces less than 30 m^2, enclosed by walls or ceiling height partitions.
        b. All storage or utility spaces more than 15 m^2 in all building types with BUA greater than 20,000 m^2.
        c. Public toilets more than 25 m^2, controlling at least 80 % of lighting fitted in the toilet. The lighting fixtures, not controlled by automatic lighting shutoff, shall be uniformly spread in the area.
    ii. In corridors of all Hospitality greater than 20,000 m^2 BUA, controlling minimum 70% and maximum 80% of lighting fitted in the public corridor. The lighting fixtures, not controlled by automatic lighting shut off, shall be uniformly spread in the area.
    iii. In all Business and all conference or meeting rooms.
(c) Automatic control device shall function on either:

   i. A scheduled basis at specific programmed times. An independent program schedule shall be provided for areas of no more than 2,500 m^2 and not more than one floor, or,
   ii. Occupancy sensors that shall turn off the lighting fixtures within 15 minutes of an occupant leaving the space. Light fixtures controlled by occupancy sensors shall have a wall-mounted, manual switch capable of turning off lights when the space is occupied.

Exception to § 6.2.1.1: Lighting systems designed for emergency and firefighting purposes.

6.2.1.2 Space Control

Each space enclosed by ceiling-height partitions shall have at least one control device to independently control the general lighting within the space. Each control device shall be activated either manually by an occupant or automatically by sensing an occupant. Each control device shall

(a) control a maximum of 250 m^2 for a space less than or equal to 1,000 m^2, and a maximum of 1,000 m^2 for a space greater than 1,000 m^2.
(b) have the capability to override the shutoff control required in § 6.2.1.1 for no more than 2 hours, and
(c) be readily accessible and located so the occupants can see the control.

Exception to § 6.2.1.2 (c): The required control device may be remotely installed if required for reasons of safety or security. A remotely located device shall have a pilot light indicator as part of or next to the control device and shall be clearly labeled to identify the controlled lighting.

6.2.1.3 Control in Daylight Areas

(a) Luminaires, installed within day lighting extent from the window as calculated in § 4.2.3, shall be equipped with either a manual control device to shut off luminaires, installed within day lit area, during potential daylit time of a day or automatic control device that:
   i. Has a delay of minimum 5 minutes, or,
   ii. Can dim or step down to 50% of total power.
(b) Overrides to the daylight controls shall not be allowed.
(c) For SuperECBC Buildings, Lighting Power Density adjustment factor of 20% shall be allowed to all spaces with more than 70% of their area under daylight controls.

6.2.1.4 Centralized Controls for ECBC+ and SuperECBC Buildings

ECBC+ and SuperECBC building shall have centralized control system for schedule based automatic lighting shutoff switches.

6.2.1.5 Exterior Lighting Control

(a) Lighting for all exterior applications not exempted in §6.3.5 shall be controlled by a photo sensor or astronomical time switch that is capable of automatically turning off the exterior lighting when daylight is available or the lighting is not required.

(b) Lighting for all exterior applications, of Schools and Business with built up area greater than 20,000 m^2, shall have lamp efficacy not less than 80 lumens per watt, 90 lumens per watt, and 100 lumens per watt, for ECBC, ECBC+, and SuperECBC Buildings respectively, unless the luminaire is controlled by a motion sensor or exempt under §6.1.

(c) Façade lighting and façade non-emergency signage of Shopping Complexes shall have separate time switches.

Exemption to §6.2.1.5: Exterior emergency lighting.

6.2.1.6 Additional Control

The following lighting applications shall be equipped with a control device to control such lighting independently of general lighting:

(a) Display/ Accent Lighting. Display or accent lighting greater than 300 m^2 area shall have a separate control device.

(b) Hotel Guest Room Lighting. Guest rooms and guest suites in a hotel shall have a master control device at the main room entry that controls all permanently installed luminaires and switched receptacles.

(c) Task Lighting. Supplemental task lighting including permanently installed under shelf or under cabinet lighting shall have a control device integral to the luminaires or be controlled by a wall-mounted control device provided the control device complies with §6.2.1.2.

(d) Nonvisual Lighting. Lighting for nonvisual applications, such as plant growth and food-warming, shall be equipped with a separate control device.

(e) Demonstration Lighting. Lighting equipment that is for sale or for demonstrations in lighting education shall be equipped with a separate control device accessible only to authorized personnel.

6.2.2 Exit Signs

Internally-illuminated exit signs shall not exceed 5 Watts per face.

6.3 Prescriptive Requirements

6.3.1 Interior Lighting Power

The installed interior lighting power for a building or a separately metered or permitted portion of a building shall be calculated in accordance with §6.3.4 and shall not exceed the interior lighting power allowance determined in accordance with either §6.3.2 or §6.3.3. Tradeoffs of interior lighting power allowance among portions of the building for which a different method of calculation has been used are not permitted.

Exception to §6.3: The following lighting equipment and applications shall not be considered when determining the interior lighting power allowance, nor shall the wattage for such lighting be included in the installed interior lighting power. However, any such lighting shall not be exempt unless it is an addition to general lighting and is controlled by an independent control device.

(a) Display or accent lighting that is an essential element for the function performed in galleries, museums, and monuments,
(b) Lighting that is integral to equipment or instrumentation and is installed by its manufacturer,
(c) Lighting specifically designed for medical or dental procedures and lighting integral to medical equipment,
(d) Lighting integral to food warming and food preparation equipment,
(e) Lighting for plant growth or maintenance,
(f) Lighting in spaces specifically designed for use by the visually impaired,
(g) Lighting in retail display windows, provided the display area is enclosed by ceiling-height partitions,
(h) Lighting in interior spaces that have been specifically designated as a registered interior historic landmark,
(i) Lighting that is an integral part of advertising or directional signage,
(j) Exit signs,
(k) Lighting that is for sale or lighting educational demonstration systems,
(l) Lighting for theatrical purposes, including performance, stage, and film or video production, and
(m) Athletic playing areas with permanent facilities for television broadcasting.

6.3.2 Building Area Method

Determination of interior lighting power allowance (watts) by the building area method shall be in accordance with the following:

Determine the allowed lighting power density for each appropriate building area type from Table 6-1 for ECBC Buildings, from Table 6-2 for ECBC+ Buildings and from Table 6-3 for SuperECBC Buildings.

(a) Calculate the gross lighted carpet area for each building area type.

(b) The interior lighting power allowance is the sum of the products of the gross lighted floor area of each building area times the allowed lighting power density for that building area type.

Table 6-1 Interior Lighting Power for ECBC Buildings – Building Area Method

Building Type	*LPD (W/m²)*	*Building Area Type*	*LPD (W/m²)*
Office Building	9.50	Motion picture theater	9.43
Hospitals	9.70	Museum	10.2
Hotels	9.50	Post office	10.5
Shopping Mall	14.1	Religious building	12.0
University and Schools	11.2	Sports arena	9.70
Library	12.2	Transportation	9.20
Dining: bar lounge/leisure	12.2	Warehouse	7.08
Dining: cafeteria/fast food	11.5	Performing arts theater	16.3
Dining: family	10.9	Police station	9.90
Dormitory	9.10	Workshop	14.1
Fire station	9.70	Automotive facility	9.00
Gymnasium	10.0	Convention center	12.5
Manufacturing facility	12.0	Parking garage	3.00

In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.

Table 6-2 Interior Lighting Power for ECBC+ Buildings – Building Area Method

Building Area Type	*LPD (W/m²)*	*Building Area Type*	*LPD (W/m²)*
Office Building	7.60	Motion picture theater	7.50
Hospitals	7.80	Museum	8.20
Hotels	7.60	Post office	8.40
Shopping Mall	11.3	Religious building	9.60
University and Schools	9.00	Sports arena	7.80
Library	9.80	Transportation	7.40
Dining: bar lounge/leisure	9.80	Warehouse	5.70
Dining: cafeteria/fast food	9.20	Performing arts theater	13.0
Dining: family	8.70	Police station	7.90
Dormitory	7.30	Workshop	11.3
Fire station	7.80	Automotive facility	7.20
Gymnasium	8.00	Convention center	10.0
Manufacturing facility	9.60	Parking garage	2.40
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

Table 6-3 Interior Lighting Power for SuperECBC Buildings – Building Area Method

Building Area Type	*LPD (W/m²)*	*Building Area Type*	*LPD (W/m²)*
Office Building	5.0	Motion picture theater	4.7
Hospitals	4.9	Museum	5.1
Hotels	4.8	Post office	5.3
Shopping Mall	7.0	Religious building	6.0
University and Schools	6.0	Sports arena	4.9
Library	6.1	Transportation	4.6
Dining: bar lounge/leisure	6.1	Warehouse	3.5
Dining: cafeteria/fast food	5.8	Performing arts theater	8.2
Dining: family	5.5	Police station	5.0
Dormitory	4.6	Workshop	7.1
Fire station	4.9	Automotive facility	4.5
Gymnasium	5.0	Convention center	6.3
Manufacturing facility	6.0	Parking garage	1.5
In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.			

6.3.3 Space Function Method

Determination of interior lighting power allowance (watts) by the space function method shall be in accordance with the following:

(a) Determine the appropriate building type and the allowed lighting power density from Table 6-4 for ECBC Buildings, Table 6-5 for ECBC+ Buildings and, Table 6-6 for SuperECBC Buildings. In cases where both a common space type and building specific space type are listed, building specific space type LPD shall apply.

(b) For each space, enclosed by partitions 80% or greater than ceiling height, determine the gross carpet area by measuring to the face of the partition wall. Include the area of balconies or other projections. Retail spaces do not have to comply with the 80% partition height requirements.

(c) The interior lighting power allowance is the sum of the lighting power allowances for all spaces. The lighting power allowance for a space is the product of the gross lighted carpet area of the space times the allowed lighting power density for that space.

Table 6-4 Interior Lighting Power for ECBC Buildings – Space Function Method

Category	*LPD (W/m²)*	*Lamp category*	*LPD (W/m²)*
Common Space Types			
Restroom	7.70	Stairway	5.50
Storage	6.80	Corridor/Transition	7.10
Conference/ Meeting	11.5	Lobby	9.10
Parking Bays (covered/ basement)	2.20	Parking Driveways (covered/ basement)	3.00
Electrical/Mechanical	7.10	Workshop	17.1
Business			
Enclosed	10.0	Open Plan	10.0
Banking Activity Area	12.6	Service/Repair	6.80
Healthcare			
Emergency	22.8	Recovery	8.60
Exam/Treatment	13.7	Storage	5.50
Nurses' Station	9.40	Laundry/Washing	7.50
Operating Room	21.8	Lounge/Recreation	8.00
Patient Room	7.70	Medical Supply	13.7
Pharmacy	10.7	Nursery	5.70
Physical Therapy	9.70	Corridor/Transition	9.10
Radiology/Imaging	9.10		

Category	*LPD (W/m²)*	*Lamp category*	*LPD (W/m²)*
Hospitality			
Hotel Dining	9.10	Hotel Lobby	10.9
For Bar Lounge/ Dining	14.1	Motel Dining	9.10
For food preparation	12.1	Motel Guest Rooms	7.70
Hotel Guest Rooms	9.10		
Shopping Complex			
Mall Concourse	12.8	For Family Dining	10.9
Sales Area	18.3	For food preparation	12.1
Motion Picture Theatre	9.60	Bar Lounge/ Dining	14.1
Educational			
Classroom/Lecture	13.7	Card File and Cataloguing	9.10
For Classrooms	13.8	Stacks (Lib)	18.3
Laboratory	15.1	Reading Area (Library)	10.0
Assembly			
Dressing Room	9.10	Seating Area - Performing Arts Theatre	22.6
Exhibit Space - Convention Centre	14.0	Lobby - Performing Arts Theatre	21.5
Seating Area - Gymnasium	4.60	Seating Area - Convention Centre	6.40
Fitness Area - Gymnasium	13.70	Seating Religious Building	16.4
Museum - General Exhibition	16.40	Playing Area - Gymnasium	18.8
Museum - Restoration	18.3		

Table 6-5 Interior Lighting Power for ECBC+ Buildings – Space Function Method

Category	*LPD (W/m^2)*	*Lamp category*	*LPD (W/m^2)*
Common Space Types			
Restroom	6.10	Stairway	4.40
Storage	5.40	Corridor/Transition	3.60
Conference/ Meeting	9.20	Lobby	7.30
Parking Bay (covered/ basement)	1.75	Parking Driveways (covered/ basement)	2.50
Electrical/Mechanical	5.70	Workshop	13.7
Business			
Enclosed	8.60	Open Plan	8.60
Banking Activity Area	9.30	Service/Repair	5.50
Healthcare			
Emergency	18.2	Recovery	7.00
Exam/Treatment	10.9	Storage	4.40
Nurses' Station	7.50	Laundry/Washing	6.00
Operating Room	17.5	Lounge/Recreation	6.40
Patient Room	6.10	Medical Supply	10.9
Pharmacy	8.50	Nursery	4.60
Physical Therapy	7.80	Corridor/Transition	7.30
Radiology/Imaging	7.30		
Hospitality			
Hotel Dining	7.30	Hotel Lobby	8.80
For Bar Lounge/ Dining	11.3	Motel Dining	7.30
For food preparation	12.1	Motel Guest Rooms	6.10
Hotel Guest Rooms	7.30		
Shopping Complex			
Mall Concourse	10.2	For Family Dining	8.80
Sales Area	14.6	For food preparation	12.1
Motion Picture Theatre	10.3	Bar Lounge/ Dining	11.3
Educational			
Classroom/Lecture	10.9	Card File and Cataloguing	7.30
For Classrooms	11.0	Stacks (Library)	14.6
Laboratory	12.1	Reading Area (Library)	9.20
Assembly			
Dressing Room	7.30	Seating Area - Performing Arts Theatre	18.1

Category	LPD (W/m²)	Lamp category	LPD (W/m²)
Exhibit Space - Convention Centre	11.2	Lobby - Performing Arts Theatre	17.2
Seating Area - Gymnasium	3.60	Seating Area – Convention Centre	5.10
Fitness Area - Gymnasium	7.85	Seating Religious Building	13.1
Museum - General Exhibition	11.3	Playing Area - Gymnasium	12.9
Museum - Restoration	11.0		

Table 6-6 Interior Lighting Power for SuperECBC Buildings – Space Function Method

Category	LPD (W/m²)	Lamp category	LPD (W/m²)
Common Space Types			
Restrooms	3.80	Stairway	2.70
Storage	3.40	Corridor/Transition	2.30
Conference/ Meeting	5.70	Lobby	4.60
Parking Bays (covered/ basement)	1.10	Driveways (covered/ basement)	1.50
Electrical/Mechanical	3.50	Workshop	8.60
Business			
Enclosed	5.40	Open Plan	5.40
Banking Activity Area	5.80	Service/Repair	3.40
Healthcare			
Emergency	11.4	Recovery	4.40
Exam/Treatment	6.80	Storage	2.70
Nurses' Station	5.00	Laundry/Washing	3.80
Operating Room	10.9	Lounge/Recreation	4.60
Patient Room	3.80	Medical Supply	6.80
Pharmacy	5.30	Nursery	2.90
Physical Therapy	4.90	Corridor/Transition	4.60
Radiology/Imaging	4.60		
Hospitality			
Hotel Dining	4.60	Hotel Lobby	5.50
For Bar Lounge/ Dining	7.00	Motel Dining	4.60
For food preparation	7.50	Motel Guest Rooms	3.80
Hotel Guest Rooms	4.60		
Shopping Complex			
Mall Concourse	6.40	For Family Dining	5.50

Category	*LPD (W/m²)*	*Lamp category*	*LPD (W/m²)*
Sales Area	9.20	For food preparation	7.50
Motion Picture Theatre	6.50	Bar Lounge/ Dining	7.00
Educational			
Classroom/Lecture	6.80	Card File and Cataloguing	4.60
For Classrooms	6.90	Stacks (Library)	9.20
Laboratory	7.50	Reading Area (Library)	5.70
Assembly			
Dressing Room	4.60	Seating Area - Performing Arts Theatre	11.3
Exhibit Space – Convention Centre	7.00	Lobby - Performing Arts Theatre	10.8
Seating Area - Gymnasium	3.40	Seating Area – Convention Centre	3.20
Fitness Area - Gymnasium	3.92	Seating Religious Building	8.20
Museum – General Exhibition	5.65	Playing Area - Gymnasium	6.50
Museum – Restoration	5.50		

Note 6-1 Calculating Interior Lighting Power – Space Function Method

A four-story building has retail on the ground floor and offices on the top three floors. Area is 3,600 m². Space types and their respective areas are mentioned below. Steps for calculating interior lighting power allowance using the space function method for a ECBC building is described below.

For each of the space type, corresponding Lighting Power Density (LPD) values for Business and Shopping complex building type from Table 6-4 are used. Area is multiplied with the LPD values to estimate the lighting power allowance for the whole building. It is 40,055.5 W.

Table 6-1-1 Space Types, Areas and Corresponding LPDs

Space Function	*LPD (W/ m²)*	*Area (m²)*	*Lighting Power Allowance (W)*
Office			
Office - enclosed	10.0	720	7,200
Office – open plan	10.0	1,485	14,850
Meeting Rooms	11.5	120	1,380
Lobbies	7.1	93	660
Restrooms	7.7	51	393
Corridors	7.1	125	887.5
Electrical/ Mechanical	7.1	14	99
Staircase	5.5	84	462
Total			*25,931.5*
Retail			
General sales area	18.3	669	12,243
Offices - enclosed	10.0	28	280
Restrooms	7.7	9	69
Corridors	7.1	79	561
Active Storage	6.8	93	632
Food preparation	12.1	28	339
Total			*14,124*
Building Total			*40,055.5 W*

6.3.4 Installed Interior Lighting Power

The installed interior lighting power calculated for compliance with §6.3 shall include all power used by the luminaires, including lamps, ballasts, current regulators, and control devices except as specifically exempted in §6.1.

Exception to §6.3.4: If two or more independently operating lighting systems in a space are controlled to prevent simultaneous user operation, the installed interior lighting power shall be based solely on the lighting system with the highest power.

6.3.4.1 Luminaire Wattage

Luminaire efficacy shall be 0.7 or above. Luminaire wattage incorporated into the installed interior lighting power shall be determined in accordance with the following:

(a) The wattage of incandescent luminaires with medium base sockets and not containing permanently installed ballasts shall be the maximum labeled wattage of the luminaires.

(b) The wattage of luminaires containing permanently installed ballasts shall be the operating input wattage of the specified lamp/ballast combination. Operating input wattage can be either values from manufacturers' catalogs or values from independent testing laboratory reports.

(c) The wattage of all other miscellaneous luminaire types not described in (a) or (b) shall be the specified wattage of the luminaires.

(d) The wattage of lighting track, plug-in busway, and flexible-lighting systems that allow the addition and/ or relocation of luminaires without altering the wiring of the system shall be the larger of the specified wattage of the luminaires included in the system or 135 Watt per meter (45 W/ft.). Systems with integral overload protection, such as fuses or circuit breakers, shall be rated at 100% of the maximum rated load of the limiting device.

6.3.5 Exterior Lighting Power

Connected lighting power of exterior lighting applications shall not exceed the lighting power limits specified in Table 6-7 for ECBC Buildings, Table 6-8 for ECBC+ Buildings and Table 6-9 for SuperECBC Buildings. Trade-offs between applications are not permitted.

Table 6-7 Exterior Building Lighting Power for ECBC Buildings

Exterior lighting application	*Power limits*
Building entrance (with canopy)	10 W/m^2 of canopied area
Building entrance (w/o canopy)	90 W/ linear m of door width
Building exit	60 W/lin m of door width
Building façade	5.0 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	1.0 W/m^2
Driveways and parking (open/ external)	1.6 W/m^2
Pedestrian walkways	2.0 W/m^2
Stairways	10.0 W/m^2
Landscaping	0.5 W/m^2
Outdoor sales area	9.0 W/m^2

Table 6-8 Exterior Building Lighting Power for ECBC+ Buildings

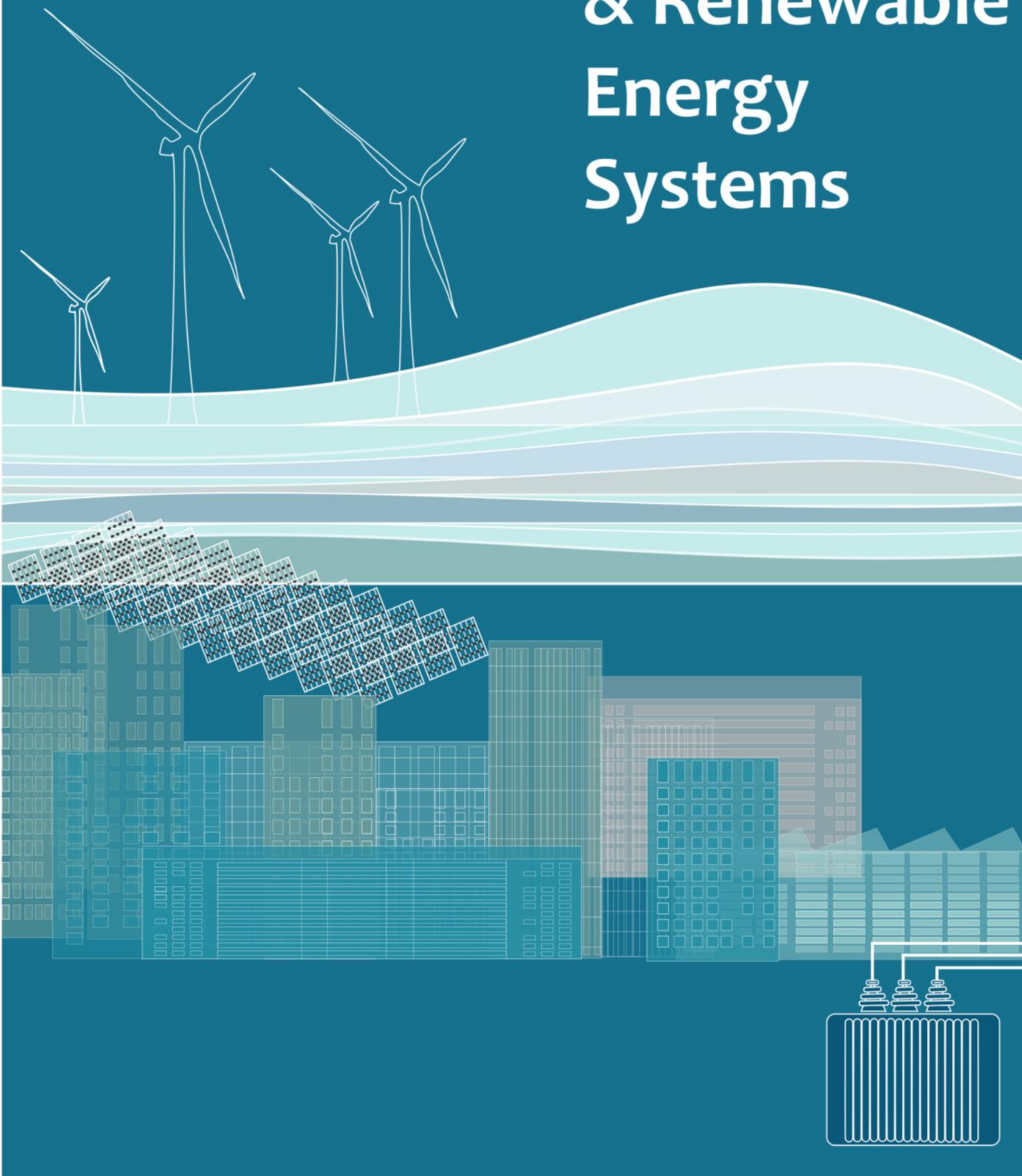
Exterior lighting application	*Power limits*
Building entrance (with canopy)	8.0 W/m^2 of canopied area
Building entrance (w/o canopy)	72 W/ linear m of door width
Building exit	48 W/lin m of door width
Building façade	4.0 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	0.8 W/m^2
Driveways and parking (open/ external)	1.3 W/m^2
Pedestrian walkways	1.6 W/m^2
Stairways	8.0 W/m^2
Landscaping	0.4 W/m^2
Outdoor sales area	7.2 W/m^2

Table 6-9 Exterior Building Lighting Power for SuperECBC Buildings

Exterior lighting application	*Power limits*
Building entrance (with canopy)	5.0 W/m^2 of canopied area
Building entrance (w/o canopy)	45 W/ linear m of door width
Building exit	30 W/lin m of door width
Building façade	2.5 W/m^2 of vertical façade area
Emergency signs, ATM kiosks, Security areas façade	0.5 W/m^2
Driveways and parking (open/ external)	0.8 W/m^2
Pedestrian walkways	1.0 W/m^2
Stairways	5.0 W/m^2
Landscaping	0.25 W/m^2
Outdoor sales area	4.5 W/m^2

7

Electrical & Renewable Energy Systems



7. Electrical and Renewable Energy Systems

7.1 General

All electric and renewable energy equipment and systems shall comply with the mandatory requirements of §7.2.

7.2 Mandatory Requirements

7.2.1 Transformers

7.2.1.1 Maximum Allowable Power Transformer Losses

Power transformers of the proper ratings and design must be selected to satisfy the minimum acceptable efficiency at 50% and full load rating.

Permissible total loss values shall not exceed

(a) 5% of the maximum total loss values mentioned in IS 1180 for oil type transformers in voltage class above 11 kV but not more than 22 kV

(b) 7.5% of the maximum total loss values mentioned in above IS 1180 for oil type transformers in voltage class above 22 kV and up to and including 33 kV

(c) values listed in Table 7.1 for dry type transformers

Table 7-1 Dry Type Transformers

Rating (kVA)	*Impedance (%)*	*Max. Total Loss (W)*					
		ECBC Building		ECBC+ Building		SuperECBC Building	
		50 % Load	100% Load	50 % Load	100% Load	50 % Load	100% Load
16	4.5	150	480	135	440	120	400
25	4.5	210	695	190	635	175	595
63	4.5	380	1,250	340	1,140	300	1,050
100	4.5	520	1,800	475	1,650	435	1,500
160	4.5	770	2,200	670	1,950	570	1,700
200	4.5	890	2,700	780	2,300	670	2,100
250	4.5	1,050	3,150	980	2,930	920	2,700
315	4.5	1,100	3,275	1,025	3,100	955	2,750
400	4.5	1,300	3,875	1,225	3,450	1,150	3,330
500	4.5	1,600	4,750	1,510	4,300	1,430	4,100
630	4.5	2,000	5,855	1,860	5,300	1,745	4,850
1000	5	3,000	9,000	2,790	7,700	2,620	7,000
1250	5	3,600	1,0750	3,300	9,200	3,220	8,400
1600	6.25	4,500	13,500	4,200	11,800	3,970	11,300
2000	6.25	5,400	17,000	5,050	15,000	4,790	14,100
2500	6.25	6,500	20,000	6,150	18,500	5,900	17,500

Total loss values given in above table are applicable for thermal classes E, B and F and have component of load loss at reference temperature according to Clause 17 of IS. An increase of 7% on total for thermal class H is allowed.

Table 7-2 Permissible Losses for Oil Type Transformers. Total losses for oil type transformers shall confirm with Indian Standard IS 1180.

Rating (kVA)	Impedance (%)	Max. Total Loss (W)					
		ECBC Building		ECBC+ Building		SuperECBC Building	
		50 % Load	100% Load	50 % Load	100% Load	50 % Load	100% Load
16	4.5	150	480	135	440	120	400
25	4.5	210	695	190	635	175	595
63	4.5	380	1250	340	1140	300	1050
100	4.5	520	1800	475	1650	435	1500
160	4.5	770	2200	670	1950	570	1700
200	4.5	890	2700	780	2300	670	2100
250	4.5	1050	3150	980	2930	920	2700
315	4.5	1100	3275	1025	3100	955	2750
400	4.5	1300	3875	1225	3450	1150	3330
500	4.5	1600	4750	1510	4300	1430	4100
630	4.5	2000	5855	1860	5300	1745	4850
1000	5	3000	9000	2790	7700	2620	7000
1250	5	3600	10750	3300	9200	3220	8400
1600	6.25	4500	13500	4200	11800	3970	11300
2000	6.25	5400	17000	5050	15000	4790	14100
2500	6.25	6500	20000	6150	18500	5900	17500

Total loss values given in above table are applicable for thermal classes E, B and F and have component of load loss at reference temperature according to Clause 17 of IS 1180 i.e., average winding temperature rise as given in Column 2 of Table 8.2 plus 300C. An increase of 7% on total for thermal class H is allowed.

7.2.1.2 Measurement and Reporting of Transformer Losses

All measurement of losses shall be carried out by using calibrated digital meters of class 0.5 or better accuracy and certified by the manufacturer. All transformers of capacity of 500 kVA and above would be equipped with additional metering class current transformers (CTs) and potential transformers (PTs) additional to requirements of Utilities so that periodic loss monitoring study may be carried out.

7.2.1.3 Voltage Drop

Voltage drop for feeders shall not exceed 2% at design load. Voltage drop for branch circuit shall not exceed 3% at design load.

7.2.2 Energy Efficient Motors

Motors shall comply with the following:

(a) Three phase induction motors shall conform to Indian Standard (IS) 12615 and shall fulfil the following efficiency requirements:
    i. ECBC Buildings shall have motors of IE 2 (high efficiency) class or a higher class
    ii. ECBC+ Buildings shall have IE 3 (premium efficiency) class motors or higher class
    iii. SuperECBC Buildings shall have IE 4 (super premium efficiency) class motors

(b) All permanently wired polyphase motors of 0.375 kW or more serving the building and expected to operate more than 1,500 hours per year and all permanently wired polyphase motors of 50kW or more serving the building and expected to operate more than 500 hour per year, shall have a minimum acceptable nominal full load motor efficiency not less than levels specified in the latest version of IS 12615.

(c) Motors of horsepower differing from those listed in the table shall have efficiency greater than that of the next listed kW motor.

(d) Motor horsepower ratings shall not exceed 20% of the calculated maximum load being served.

(e) Motor nameplates shall list the nominal full-load motor efficiencies and the full-load power factor.

(f) Motor users should insist on proper rewinding practices for any rewound motors. If the proper rewinding practices cannot be assured, the damaged motor should be replaced with a new, efficient one rather than suffer the significant efficiency penalty associated with typical rewind practices. Rewinding practices from BEE guideline for energy efficient motors shall be followed.

(g) Certificates shall be obtained and kept on record indicating the motor efficiency. Whenever a motor is rewound, appropriate measures shall be taken so that the core characteristics of the motor is not lost due to thermal and mechanical stress during removal of damaged parts. After rewinding, a new efficiency test shall be performed and a similar record shall be maintained.

7.2.3 Diesel Generator (DG) Sets

BEE star rated DG sets shall be used in all compliant buildings. DG sets in buildings greater than 20,000 m^2 BUA shall have:

(a) minimum 3 stars rating in ECBC Buildings
(b) minimum 4 stars rating in ECBC+ Buildings
(c) minimum 5 stars rating in SuperECBC Buildings

7.2.4 Check-Metering and Monitoring

(a) Services exceeding 1000 kVA shall have permanently installed electrical metering to record demand (kVA), energy (kWh), and total power factor. The metering shall also display current (in each phase and the neutral), voltage (between phases and between each phase and neutral), and total harmonic distortion (THD) as a percentage of total current.

(b) Services not exceeding 1000 kVA but over 65 kVA shall have permanently installed electric metering to record demand (kW), energy (kWh), and total power factor (or kVARh).

(c) Services not exceeding 65 kVA shall have permanently installed electrical metering to record energy (kWh).

(d) In case of tenant based building, metering should be provided at a location from where each tenant could attach the services.

Table 7-3 Sub Metering Requirements

	120 kVA to 250 kVA	*Greater than 250 kVA*
Minimum requirement for metering of electrical load		
Energy kWh	Required	Required
Demand kVA	Required	Required
Total power factor	Required	Required
Minimum requirement for separation of electrical load		
HVAC system and components	Required	Required
Interior and Exterior Lighting *	Not required	Required
Domestic hot water	Not required	Required
Plug loads	Not required	Required
Renewable power source	Required	Required
Mandatory requirement for building type over the requirement stated above		
Shopping Complex	Façade lighting	Elevator, escalators, moving walks
Business	Data centers	
Hospitality	Commercial kitchens	
* Hotel guestrooms and hospital in patient areas are exempted from the lighting sub-metering requirements.		

7.2.5 Power Factor Correction

All 3 phase shall maintain their power factor at the point of connection as follows:

(a) 0.97 for ECBC Building
(b) 0.98 for ECBC+ building
(c) 0.99 for SuperECBC building

7.2.6 Power Distribution Systems

The power cabling shall be sized so that the distribution losses do not exceed

(a) 3% of the total power usage in ECBC Buildings
(b) 2% of the total power usage in ECBC+ Buildings
(c) 1% of total power usage in SuperECBC Buildings

Record of design calculation for the losses shall be maintained. Load calculation shall be calculated up to the panel level.

7.2.7 Uninterruptible Power Supply (UPS)

In all buildings, UPS shall meet or exceed the energy efficiency requirements listed in Table 7-4. Any Standards and Labeling program by BEE shall take precedence over requirements listed in this section.

Table 7-4 Energy Efficiency Requirements for UPS for ECBC, ECBC+, SuperECBC building

UPS Size	*Energy Efficiency Requirements at 100% Load*
kVA< 20	90.2%
20<=kVA <= 100	91.9%
kVA > 100	93.8%

7.2.8 Renewable Energy Systems

All buildings shall have provisions for installation of renewable energy systems in the future on rooftops or the site.

7.2.8.1 Renewable Energy Generating Zone (REGZ)

(a) A dedicated REGZ equivalent to at least 25 % of roof area or area required for generation of energy equivalent to 1% of total peak demand or connected load of the building, whichever is less, shall be provided in all buildings.
(b) The REGZ shall be free of any obstructions within its boundaries and from shadows cast by objects adjacent to the zone
(c) ECBC+ and SuperECBC building shall fulfil the additional requirements listed in Table 7-5 and Table 7-6 respectively.

Exception to § 7.2.8.1: Projects with solar hot water and/ or solar power generation systems.

Table 7-5 Minimum Solar Zone Area/Renewable Energy Generating Zone Requirement for ECBC+ Building

Building Type	*Minimum Electricity to be Generated in REGZ*
All building types except below	Minimum 2% of total electrical load
Star Hotel > 20,000 m² Resort > 12,500 m² University > 20,000 m² Business >20,000 m²	Minimum 3% of total electricity load

Table 7-6 Minimum Solar Zone Area/Renewable Energy Generating Zone Requirement for SuperECBC Building

Building Type	*Minimum Electricity to be Generated in REGZ*
All Building types except below	Minimum 4% of total electrical load
Star Hotel > 20,000 m² Resort > 12,500 m² University > 20,000 m² Business >20,000 m²	Minimum 6% of total electrical load

7.2.8.2 Main Electrical Service Panel

Minimum rating shall be displayed on the main electrical service panel. Space shall be reserved for the installation of a double pole circuit breaker for a future solar electric installation.

7.2.8.3 Demarcation on Documents

The following shall be indicated in design and construction documents:

(a) Location for inverters and metering equipment,
(b) Pathway for routing of conduit from the REGZ to the point of interconnection with the electrical service,
(c) Routing of plumbing from the REGZ to the water-heating system and,
(d) Structural design loads for roof dead and live load.

8

Definitions, Abbreviations & Acronyms

8. Definitions, Abbreviations, and Acronyms

8.1 General

Certain terms, abbreviations, and acronyms are defined in this section for the purposes of this code. These definitions are applicable to all sections of this code. Terms that are not defined shall have their ordinarily accepted meanings within the context in which they are used.

8.2 Definitions

A

Above grade area (AGA): AGA is the cumulative floor area of all the floor levels of a building that are above the ground level. Ground level shall be as defined in building site plan. A floor level is above grade if one-third of the total external surface area of only the said floor level is above the ground level.

Accredited independent laboratory: testing laboratory not affiliated with producer or consumer of goods or products tested at the laboratory and accredited by national or international organizations for technical competence

Addition: an extension or increase in floor area or height of a building outside of the existing building envelope.

Air conditioning and condensing units serving computer rooms: air conditioning equipment that provides cooling by maintaining space temperature and humidity within a narrow range. Major application is in data centers where dissipating heat generated by equipment takes precedence over comfort cooling for occupants.

Alteration: any change, rearrangement, replacement, or addition to a building or its systems and equipment; any modification in construction or building equipment.

Area weighted average (AWA) method: AWA method is based on the concept of weighted arithmetic mean where instead of each data point contributing equally to the final mean; each data point contributes more “weight” than others based on the size of the area the said data point is applicable to. To calculate the area weighted average mean, a summation of each data point multiplied with its respective area is divided with the total area.

$$AWA = \sum \frac{(\boldsymbol{Data\ point\ X\ area})}{\boldsymbol{Total\ area}}$$

Astronomical time switch: an automatic time switch that makes an adjustment for the length of the day as it varies over the year.

Authority having jurisdiction: the agency or agent responsible for enforcing this Standard.

B

Balancing, air system: adjusting airflow rates through air distribution system devices, such as fans and diffusers, by manually adjusting the position of dampers, splitters vanes, extractors, etc., or by using automatic control devices, such as constant air volume or variable air volume boxes.

Balancing, hydronic system: adjusting water flow rates through hydronic distribution system devices, such as pumps and coils, by manually adjusting the position valves, or by using automatic control devices, such as automatic flow control valves.

Ballast: a device used in conjunction with an electric-discharge lamp to cause the lamp to start and operate under proper circuit conditions of voltage, current, waveform, electrode heat, etc.

Standard Design: a computer model of a hypothetical building, based on actual building design, that fulfils all the mandatory requirements and minimally complies with the prescriptive requirements of ECBC.

Boiler: a self-contained low-pressure appliance for supplying steam or hot water

Building or building complex or complex: a structure wholly or partially enclosed within exterior walls, or within exterior and party walls, and a roof, affording shelter to persons, animals, or property. Building complex means a building or group of buildings constructed in a contiguous area for business, commercial, institutional, healthcare, hospitality purposes or assembly buildings under the single ownership of individuals or group of individuals or under the name of a co-operative group society or on lease and sold as shops or office space or space for other commercial purposes, having a connected load of 100 kW or contract demand of 120 kVA and above.

Building, base: includes building structure, building envelope, common areas, circulation areas, parking, basements, services area, plant room and its supporting areas and, open project site area.

Building, core and shell: buildings where the developer or owner will only provide the base building and its services.

Building, existing: a building or portion thereof that was previously occupied or approved for occupancy by the authority having jurisdiction.

Building envelope: the exterior plus the semi-exterior portions of a building. For the purposes of determining building envelope requirements, the classifications are defined as follows:

(a) Building envelope, exterior: the elements of a building that separate conditioned spaces from the exterior

(b) Building envelope, semi-exterior: the elements of a building that separate conditioned space from unconditioned space or that enclose semi-heated spaces through which thermal energy may be transferred to or from the exterior, or to or from unconditioned spaces, or to or from conditioned spaces

Building grounds lighting: lighting provided through a building's electrical service for parking lot, site, roadway, pedestrian pathway, loading dock, and security applications

Building material: any element of the building envelope through which heat flows and that heat is included in the component U-factor calculations other than air films and insulation

Built up area (BUA): sum of the covered areas of all floors of a building, other than the roof, and areas covered by external walls and parapet on these floors.

24-hour Business Building: Business building operated and occupied for more than 12 hours on each weekday. Intensity of occupancy may vary.

C

Cardinal direction: cardinal directions or cardinal points are the four main directional points of a compass: north, south, east, and west which are also known by the first letters: N,S,E, and W.

Carpet area: net area measured between external walls, from the inner faces of walls. Thickness of internal or partition walls is excluded.

Centralized control: single hardware/ software for observing and controlling operations of a group of equipment and devices with similar or different functions

Circuit breaker: a safety device that automatically stops flow of current in electrical circuits. It protects the circuit from current surge.

Class of construction: classification that determines the construction materials for the building envelope, roof, wall, floor, slab-on-grade floor, opaque door, vertical fenestration, skylight

Daylight window: fenestration 2.2 meter above floor level, with an interior light shelf at bottom of this fenestration

Coefficient of Performance (COP) – cooling: the ratio of the rate of heat removal to the rate of energy input, in consistent units, for a complete refrigerating system or some specific portion of that system under designated operating conditions

Coefficient of Performance (COP) – heating: the ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete heat pump system, including the compressor and, if applicable, auxiliary heat, under designated operating conditions

Common area: areas within a building that are available for use by all tenants in a building (i.e. lobbies, corridors, restrooms, etc.)

Commercial building: a building or a part of building or building complex which are used or intended to be used for commercial purposes and classified as per the time of the day the building is operational and sub classified, as per the functional requirements of its design, construction, and use as per following details:

a) Group I – 24 hours building covering Type A Hospitality, Type B Health Care and Type C Assembly and,
b) Group II – Regular building covering Type D Business, Type E Educational and Type F Shopping Complexes.

Compliance documents: the forms specified in ECBC Rules and Regulations to record and check compliance with these rules. These include but are not limited to EPI Ratio Compliance Report, Building Envelope Compliance Form, Mechanical Systems Compliance Form and Permit Checklist, Lighting System Compliance Form and Permit Checklist and certificates from Certified Energy Auditor for existing or proposed buildings.

Connected load: the sum of the rated wattage of all equipment, appliances and devices to be installed in the building or part of building or building complexes, in terms of kilowatt (kW) that will be allocated to all applicants for electric power consumption in respect of the proposed building or building complexes on their completion.

Contract demand: the maximum demand in kilowatt (kW) or kilo Volt Ampere (kVA) (within a consumer's sanctioned load) agreed to be supplied by the electricity provider or utility in the agreement executed between the user and the utility or electricity provider.

Construction documents: drawings or documents, containing information pertaining to building construction processes and approvals, building materials and equipment specification, architectural details etc. required by the authority having jurisdiction.

Controls or control device: manually operated or automatic device or software to regulate the operation of building equipment

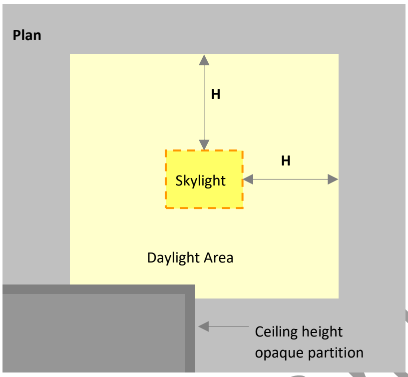
Cool roof: roof with top layer of material that has high solar reflectance and high thermal emittance properties. Cool roof surfaces are characterized by light colors so that heat can be rejected back to the environment.

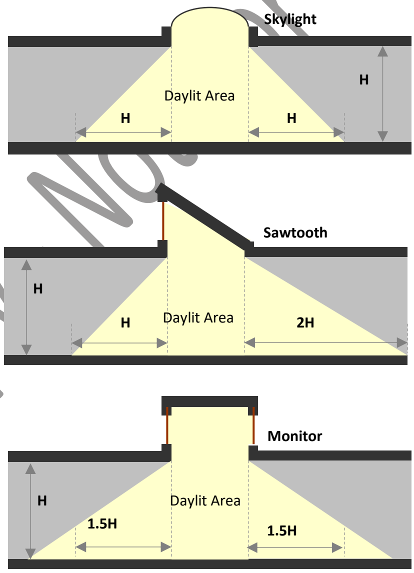
Cumulative design EPI: energy performance index for a building having two or more different functional uses and calculated based on the area weighted average (AWA) method

D

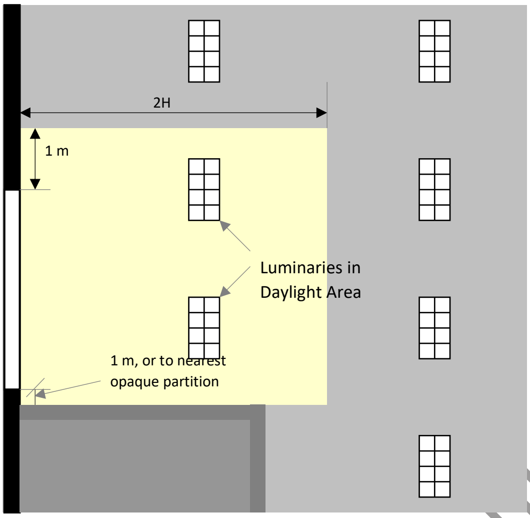
Daylight area: the daylight illuminated floor area under horizontal fenestration (skylight) or adjacent to vertical fenestration (window), described as follows:

(a) Horizontal Fenestration: the area under a skylight, monitor, or sawtooth configuration with an effective aperture greater than 0.001 (0.1%). The daylight area is calculated as the horizontal dimension in each direction equal to the top aperture dimension in that direction plus either the floor-to-ceiling height (H) for skylights, or 1.5 H for monitors, or H or 2H for the sawtooth configuration, or the distance to the nearest 1 meter or higher opaque partition, or one-half the distance to an adjacent skylight or vertical glazing, whichever is least, as shown in the plan and section figures below.





(b) Vertical Fenestration: the floor area adjacent to side apertures (vertical fenestration in walls) with an effective aperture greater than 0.06 (6%). The daylight area extends into the space perpendicular to the side aperture a distance equal to daylight extension factor (DEF) multiplied by the head height of the side aperture or till higher opaque partition, whichever is less. In the direction parallel to the window, the daylight area extends a horizontal dimension equal to the width of the window plus either 1 meter on each side of the aperture, or the distance to an opaque partition, or one-half the distance to an adjacent skylight or window, whichever is least.



Daylight Extension Factor (DEF): factor to manually calculate the daylight area on floor plates. It is to be multiplied by the head height of windows. It is dependent on orientation and glazing VLT, shading devices adjacent to it and building location.

Daytime Business Building: Business building operated typically only during daytime on weekdays upto 12 hours each day.

Deadband: the range of values within which a sensed variable can vary without initiating a change in the controlled process.

Demand: maximum rate of electricity (kW) consumption recorded for a building or facility during a selected time frame.

Demand control ventilation (DCV): a ventilation system capability that provides automatic reduction of outdoor air intake below design rates when the actual occupancy of spaces served by the system is less than design occupancy

Design capacity: output capacity of a mechanical or electrical system or equipment at design conditions

Design conditions: specified indoor environmental conditions, such as temperature, humidity and light intensity, required to be produced and maintained by a system and under which the system must operate

Distribution system: network or system comprising controlling devices or equipment and distribution channels (cables, coils, ducts, pipes etc.) for delivery of electrical power or, cooled or heated water or air in buildings

Door: all operable opening areas, that are not more than one half glass, in the building envelope, including swinging and roll-up doors, fire doors, and access hatches. For the purposes of determining building envelope requirements, the door types are defined as follows:

(a) Door, non-swinging: roll-up sliding, and all other doors that are not swinging doors.

(b) Door, swinging: all operable opaque panels with hinges on one side and opaque revolving doors.

Door area: total area of the door measured using the rough opening and including the door slab and the frame.

E

Economizer, air: a duct and damper arrangement with automatic controls that allow a cooling system to supply outdoor air to reduce or eliminate the need for mechanical cooling during mild or cold weather

Economizer, water: a system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling

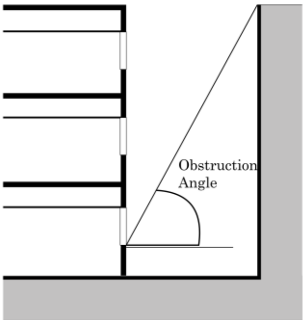
ECBC Building: a building that complies with the mandatory requirements of §4 to §7 and also complies either with the prescriptive requirements stated under the ECBC Building categories of §4 to §7, or, with the whole building performance compliance method of §9.

ECBC+ Building: a building that complies with the mandatory requirements of §4 to §7 and also complies either with the prescriptive requirements stated under the ECBC+ Building categories of §4 to §7, or, with the whole building performance compliance method of §9. This is a voluntary level of compliance with ECBC.

Effective aperture: Visible Light Transmittance x window-to-wall Ratio. (EA = VLT x WWR)

Effective aperture, horizontal fenestration: a measure of the amount of daylight that enters a space through horizontal fenestration (skylights). It is the ratio of the skylight area times the visible light transmission divided by the gross roof area above the daylight area. See also daylight area.

Effective aperture, vertical fenestration: a measure of the amount of daylight that enters a space through vertical fenestration. It is the ratio of the daylight window area times its visible light transmission plus half the vision glass area times its visible light transmission and the sum is divided by the gross wall area. Daylight window area is located 2.2 m or more above the floor and vision window area is located above 1 m but below 2.2 m. The window area, for the purposes of determining effective aperture shall not include windows located in light wells when the angle of obstruction (α) of objects obscuring the sky dome is greater than 70°, measured from the horizontal, nor shall it include window area located below a height of 1 m. See also daylight area.



Efficacy: the lumens produced by a lamp plus ballast system divided by the total watts of input power (including the ballast), expressed in lumens per watt

Efficiency: performance at a specified rating condition

Efficiency, thermal: ratio of work output to heat input

Efficiency, combustion: efficiency with which fuel is burned during the combustion process in equipment

Emittance: the ratio of the radiant heat flux emitted by a specimen to that emitted by a blackbody at the same temperature and under the same conditions

Energy: power derived from renewable or non-renewable resources to provide heating, cooling and light to a building or operate any building equipment and appliances. It has various forms such as thermal (heat), mechanical (work), electrical, and chemical that may be transformed from one into another. Customary unit of measurement is watts (W)

Energy Conservation Building Code (ECBC): the Energy Conservation Building Code as updated from time to time by the Bureau and displayed on its website (www.beeindia.gov.in).

Energy Efficiency Ratio (EER): the ratio of net cooling capacity in kW to total rate of electric input in watts under design operating conditions

Energy recovery system: equipment to recover energy from building or space exhaust air and use it to treat (pre-heat or pre-cool) outdoor air taken inside the building or space by ventilation systems

Envelope Performance Factor (EPF): value for the building envelope performance compliance option calculated using the procedures specified in 4.3.5 and 4.3.6. For the purposes of determining building envelope requirements the classifications are defined as follows:

(a) Standard Building EPF: envelope performance factor calculated for the Standard Building using prescriptive requirements for walls, vertical fenestrations and roofs

(b) Proposed Building EPF: the building envelope performance factor for the Proposed Building using proposed values for walls, vertical fenestrations and roofs

Energy Performance Index (EPI): of a building means its annual energy consumption in kilowatt-hours per square meter of the area of the building which shall be calculated in the existing or proposed building as per the formula below,

$$= \frac{\text{annual energy consumption in kWh}}{\text{total built} - \text{up area (excluding storage area and the parking in the basement)in m}^2}$$

EPI Ratio: of a building means the ratio of the EPI of the Proposed Building to the EPI of the Standard Building.

Equipment: mechanical, electrical or static devices for operating a building, including but not limited to those required for providing cooling, heating, ventilation, lighting, service hot water, vertical circulation

Equipment, existing: equipment previously installed in an existing building

Equivalent SHGC: SHGC for a fenestration with a permanent external shading projection. It is calculated using the Projection Factor (PF) of the permanent external shading projection and Shading Equivalent Factor (SEF) listed in §4.3.1.

Exemption: any exception allowed to compliance with ECBC requirements

F

Fan system power: sum of the nominal power demand (nameplate W or HP) of motors of all fans that are required to operate at design conditions to supply air from the heating or cooling source to the conditioned space(s) and return it to the point where is can be exhausted to outside the building.

Fenestration: all areas (including the frames) in the building envelope that let in light, including windows, plastic panels, clerestories, skylights, glass doors that are more than one-half glass, and glass block walls.

(a) Skylight: a fenestration surface having a slope of less than 60 degrees from the horizontal plane. Other fenestration, even if mounted on the roof of a building, is considered vertical fenestration.

(b) Vertical fenestration: all fenestration other than skylights. Trombe wall assemblies, where glazing is installed within 300 mm of a mass wall, are considered walls, not fenestration.

Fenestration area: total area of the fenestration measured using the rough opening and including the glazing, sash, and frame. For doors where the glazed vision area is less than 50% of the door area, the fenestration area is the glazed vision area. For all other doors, the fenestration area is the door area.

Finished floor level: level of floor achieved after finishing materials have been added to the subfloor or rough floor or concrete floor slab.

Fossil fuel: fuel derived from a hydrocarbon deposit such as petroleum, coal, or natural gas derived from living matter of a previous geologic time

Fuel: a material that may be used to produce heat or generate power by combustion

Fuel utilization efficiency (FUE): a thermal efficiency measure of combustion equipment like furnaces, boilers, and water heaters

G

Gathering hall (Type of Assembly): any building, its lobbies, rooms and other spaces connected thereto, primarily intended for assembly of people, but which has no theatrical stage or permanent theatrical and/or cinematographic accessories and has gathering space for greater or equal to 100 persons, for example, stand-alone dance halls, stand-alone night clubs, halls for incidental picture shows, dramatic, theatrical or educational presentation, lectures or other similar purposes having no theatrical stage except a raised platform and used without permanent seating arrangement; art galleries, community halls, marriage halls, places of worship, museums, stand-alone lecture halls, passenger terminals and heritage and archeological monuments, pool and billiard parlors, bowling alleys, community halls, courtrooms, gymnasiums, indoor swimming pools, indoor tennis court, any indoor stadium for sports and culture, auditoriums

Grade: finished ground level adjoining a building at all exterior walls

Guest room: any room or rooms used or intended to be used by a guest for sleeping purposes

H

Habitable spaces: space in a building or structure intended or used for working, meeting, living, sleeping, eating, or cooking. Bathrooms, water closet compartments, closets, halls, storage or utility space, and similar areas are not considered habitable spaces.

Heat capacity: amount of heat necessary to raise the temperature of a given mass by 1°C. Numerically, the heat capacity per unit area of surface ($W/m^2.K$) is the sum of the products of the mass per unit area of each individual material in the roof, wall, or floor surface multiplied by its individual specific heat.

Hospitals and sanatoria (Healthcare): Any building or a group of buildings under single management, which is used for housing persons suffering from physical limitations because of health or age and those incapable of self-preservation, for example, any hospitals, infirmaries, sanatoria and nursing homes.

HVAC system: equipment, distribution systems, and terminal devices that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning to a building or parts of a building.

Hyper Markets (Type F of Shopping Complex): large retail establishments that are a combination of supermarket and department stores. They are considered as a one-stop shop for all needs of the customer.

I

Infiltration: uncontrolled inward air leakage through cracks and crevices in external surfaces of buildings, around windows and doors due to pressure differences across these caused by factors such as wind or indoor and outside temperature differences (stack effect), and imbalance between supply and exhaust air systems

Installed interior lighting power: power in watts of all permanently installed general, task, and furniture lighting systems and luminaires

Integrated part-load value (IPLV): weighted average efficiency of chillers measured when they are operating at part load conditions (less than design or 100% conditions). It is more realistic measurement of chiller efficiency during its operational life.

K

Kilovolt-ampere (kVA): where the term “kilovolt-ampere” (kVA) is used in this Code, it is the product of the line current (amperes) times the nominal system voltage (kilovolts) times 1.732 for three-phase currents. For single-phase applications, kVA is the product of the line current (amperes) times the nominal system voltage (kilovolts).

Kilowatt (kW): the basic unit of electric power, equal to 1000 W.

L

Labeled: equipment or materials to which a symbol or other identifying mark has been attached by the manufacturer indicating compliance with specified standard or performance in a specified manner.

Lamp: a generic term for man-made light source often called bulb or tube

Lighted floor area, gross: gross area of lighted floor spaces

Lighting, emergency: battery backed lighting that provides illumination only when there is a power outage and general lighting luminaries are unable to function.

Lighting, general: lighting that provides a substantially uniform level of illumination throughout an area. General lighting shall not include decorative lighting or lighting that provides a dissimilar level of illumination to serve a specialized application or feature within such area.

Lighting system: a group of luminaires circuited or controlled to perform a specific function.

Lighting power allowance:

(a) Interior lighting power allowance: the maximum lighting power in watts allowed for the interior of a building

(b) Exterior lighting power allowance: the maximum lighting power in watts allowed for the exterior of a building

Lighting Power Density (LPD): maximum lighting power per unit area of a space as per its function or building as per its classification.

Low energy comfort systems: space conditioning or ventilation systems that are less energy intensive then vapor compression based space condition systems. These primarily employ alternate heat transfer methods or materials (adiabatic cooling, radiation, desiccant, etc.), or renewable sources of energy (solar energy, geo-thermal) so that minimal electrical energy input is required to deliver heating or cooling to spaces.

Luminaires: a complete lighting unit consisting of a lamp or lamps together with the housing designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

Luminous Efficacy (LE): total luminous flux (visible light) emitted from a lamp or lamp/ballast combination divided by input power, expressed in lumens per Watt.

M

Man-made daylight obstruction: any permanent man-made object (equipment, adjacent building) that obstructs sunlight or solar radiation from falling on a portion or whole of a building’s external surface at any point of time during a year is called as a man-made sunlight obstructer.

Manual (non-automatic): requiring personal intervention for control. Non-automatic does not necessarily imply a manual controller, only that personal intervention is necessary.

Manufacturing processes: processes through which raw material is converted into finished goods for commercial sale using machines, labor, chemical or biological processes, etc.

Manufacturer: company or person or group of persons who produce and assemble goods or purchases goods manufactured by a third party in accordance with their specifications.

Mean temperature: average of the minimum daily temperature and maximum daily temperature.

Mechanical cooling: reducing the temperature of a gas or liquid by using vapor compression, absorption, and desiccant dehumidification combined with evaporative cooling, or another energy-driven thermodynamic cycle. Indirect or direct evaporative cooling alone is not considered mechanical cooling.

Metering: practice of installing meters in buildings to acquire data for energy consumption and other operational characteristics of individual equipment or several equipment grouped on basis of their function (lighting, appliances, chillers, etc.). Metering is done in buildings to monitor their energy performance.

Mixed mode air-conditioned building: building in which natural ventilation is employed as the primary mode of ventilating the building, and air conditioning is deployed as and when required.

Mixed use development: a single building or a group of buildings used for a combination of residential, commercial, business, educational, hospitality and assembly purposes

N

National Building Code 2016 (NBC): model building code that provides guidelines for design and construction of buildings. In this code, National Building Code 2016 refers to the latest version by the Bureau of Indian Standards.

Natural daylight obstruction: any natural object, like tree, hill, etc., that obstructs sunlight from falling on part or whole of a building's external surface at any point of time during a year and casts a shadow on the building surface.

Naturally ventilated building: a building that does not use mechanical equipment to supply air to and exhaust air from indoor spaces. It is primarily ventilated by drawing and expelling air through operable openings in the building envelope.

Non-cardinal directions: any direction which is not a cardinal direction, i.e. perfect north, south, east, or west, is termed as non-cardinal direction.

No Star hotel (Type of Hospitality): any building or group of buildings under the same management, in which separate sleeping accommodation on commercial basis, with or without dining facilities or cooking facilities, is provided for individuals. This includes lodging rooms, inns, clubs, motels, no star hotel and guest houses and excludes residential apartments rented on a lease agreement of 4 months or more. These shall also include any building in which group sleeping accommodation is provided, with or without dining facilities for persons who are not members of the same family, in one room or a series of adjoining rooms under joint occupancy and single management, for example, school and college dormitories, students, and other hostels and military barracks.

O

Occupant sensor: a device that detects the presence or absence of people within an area and causes lighting, equipment, or appliances to be dimmed, or switched on or off accordingly.

Opaque assembly or opaque construction: surface of the building roof or walls other than fenestration and building service openings such as vents and grills.

Opaque external wall: external wall composed of materials which are not transparent or translucent, usually contains the structural part of the building, and supports the glazed façade. This type may be composed of one or more materials, and can accommodate various physical processes at a time, as the insulation and thermal inertia.

Open Gallery Mall (Type of Shopping Complex): a large retail complex containing a variety of stores and often restaurants and other business establishments housed in a series of connected or adjacent buildings or in a single large building. The circulation area and atrium of the open gallery mall is an unconditioned space and is open to sky.

Orientation: the direction a building facade faces, i.e., the direction of a vector perpendicular to and pointing away from the surface of the facade. For vertical fenestration, the two categories are north-oriented and all other.

Outdoor (outside) air: air taken from the outside the building and has not been previously circulated through the building.

Out-patient Healthcare (Type of Healthcare): any building or a group of buildings under single management, which is used only for treating persons requiring treatment or diagnosis of disease but not requiring overnight or longer accommodation in the building during treatment or diagnosis.

Overcurrent: any current in excess of the rated current of the equipment of the ampacity of the conductor. It may result from overload, short circuit, or ground fault.

Owner: a person, group of persons, company, trust, institute, Registered Body, state or central Government and its attached or sub-ordinate departments, undertakings and like agencies or organization in whose name the property stands registered in the revenue records for the construction of a building or building complex

P

Party wall: a firewall on an interior lot line used or adapted for joint service between two buildings.

Permanently installed: equipment that is fixed in place and is not portable or movable.

Plenum: a compartment or chamber to which one or more ducts are connected, that forms a part of the air distribution system, and that is not used for occupancy or storage.

Plug loads: energy used by products that are powered by means of an AC plug. This term excludes building energy that is attributed to major end uses specified in § 5, § 6, § 7 (like HVAC, lighting, water heating, etc.).

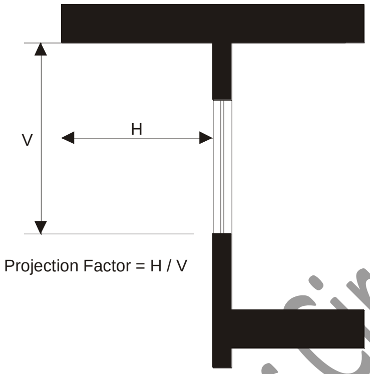
Pool: any structure, basin, or tank containing an artificial body of water for swimming, diving, or recreational bathing. The terms include, but no limited to, swimming pool, whirlpool, spa, hot tub.

Potential daylit time: amount of time in a day when there is daylight to light a space adequately without using artificial lighting. Potential daylit time is fixed for 8 hours per day i.e. from 09:00 AM to 5:00 PM local time, resulting 2920 hours in total for all building types except for Type E-1 - Educational, which shall be analyzed for 7 hours per day i.e. from 08:00 AM to 3:00 PM local time.

Primary inter-cardinal direction: any of the four points of the compass, midway between the cardinal points; northeast, southeast, southwest, or northwest are called primary inter-cardinal direction.

Process load: building loads resulting from the consumption or release of energy due to industrial processes or processes other than those for providing space conditioning, lighting, ventilation, or service hot water heating.

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection to the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection, in consistent units.



Projection factor, side fin: the ratio of the horizontal depth of the external shading projection to the distance from the window jamb to the farthest point of the external shading projection, in consistent units.

Projection Factor, overhang and side fin: average of ratio projection factor for overhang only and projection factor of side fin only.

Proposed Building: is consistent with the actual design of the building and complies with all the mandatory requirements of ECBC.

Proposed Design: a computer model of the proposed building, consistent with its actual design, which complies with all the mandatory requirements of ECBC.

R

R-value (thermal resistance): the reciprocal of the time rate of heat flow through a unit area induced by a unit temperature difference between two defined surfaces of material or construction under steady-state conditions. Units of R value are m^2.K /W.

Readily accessible: capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, chairs, etc. In public facilities, accessibility may be limited to certified personnel through locking covers or by placing equipment in locked rooms.

Recirculating system: a domestic or service hot water distribution system that includes a close circulation circuit designed to maintain usage temperatures in hot water pipes near terminal devices (e.g., lavatory faucets, shower heads) in order to reduce the time required to obtain hot water when the terminal device valve is opened. The motive force for circulation is either natural (due to water density variations with temperature) or mechanical (recirculation pump).

Reflectance: ratio of the light or radiation reflected by a surface to the light or radiation incident upon it.

Renewable Energy Generating Zone: a contiguous or semi-contiguous area, either on rooftop or elsewhere within site boundary, dedicated for installation of renewable energy systems.

Resort (Type of Hospitality): commercial establishments that provide relaxation and recreation over and above the accommodation, meals and other basic amnesties. The characteristics of resort are as below –

i. Includes 1 or more recreation(s) facility like spa, swimming pool, or any sport;
ii. Is located in the midst of natural and picturesque surroundings outside the city;
iii. Comprises of 2 or more blocks of buildings within the same site less than or equal to 3 floors (including the ground floor).

Reset: automatic adjustment of the controller set point to a higher or lower value.

Roof: the upper portion of the building envelope, including opaque areas and fenestration, that is horizontal or tilted at an angle of less than 60° from horizontal. This includes podium roof as well which are exposed to direct sun rays.

Roof area, gross: the area of the roof measured from the exterior faces of walls or from the centerline of party walls

S

Selectivity ratio of a glass: ratio between light transmission and solar factor of glass.

Service: the equipment for delivering energy from the supply or distribution system to the premises served.

Service water heating equipment: equipment for heating water for domestic or commercial purposes other than space heating and process requirements.

Set point: the desired temperature (°C) of the heated or cooled space that must be maintained by mechanical heating or cooling equipment.

Shading Coefficient (SC): measure of thermal performance of glazing. It is the ratio of solar heat gain through glazing due to solar radiation at normal incidence to that occurring through 3 mm thick clear, double-strength glass. Shading coefficient, as used herein, does not include interior, exterior, or integral shading devices.

Shading Equivalent Factor: coefficient for calculating effective SHGC of fenestrations shaded by overhangs or side fins.

Shopping Mall (Shopping Complex): a large retail complex containing a variety of stores and often restaurants and other business establishments housed in a series of connected or adjacent buildings or in a single large building. The circulation area and atrium of the mall is an enclosed space covered completely by a permanent or temporary structure.

Simulation program: software in which virtual building models can be developed to simulate the energy performance of building systems.

Single-zone system: an HVAC system serving a single HVAC zone.

Site-recovered energy: waste energy recovered at the building site that is used to offset consumption of purchased fuel or electrical energy supplies.

Slab-on-grade floor: floor slab of the building that is in contact with ground and that is either above grade or is less than or equal to 300 mm below the final elevation of the nearest exterior grade.

Soft water: water that is free from dissolved salts of metals such as calcium, iron, or magnesium, which form insoluble deposits on surfaces. These deposits appear as scale in boilers or soap curds in bathtubs and laundry equipment.

Solar energy source: source of thermal, chemical, or electrical energy derived from direction conversion of incident solar radiation at the building site.

Solar Heat Gain Coefficient (SHGC): the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space.

Space: an enclosed area within a building. The classifications of spaces are as follows for purpose of determining building envelope requirements:

(a) Conditioned space: a cooled space, heated space, or directly conditioned space.

(b) Semi-heated space: an enclosed space within a building that is heated by a heating system whose output capacity is greater or equal to 10.7 W/m^2 but is not a conditioned space.

(c) Non-conditioned space: an enclosed space within a building that is not conditioned space or a semi-heated space. Crawlspaces, attics, and parking garages with natural or mechanical ventilation are not considered enclosed spaces.

Star Hotels/motels (Star Hotel): any building or group of buildings under single management and accredited as a starred hotel by the Hotel and Restaurant Approval and Classification Committee, Ministry of Tourism, in which sleeping accommodation, with or without dining facilities is provided.

Stand-alone Retail (Shopping Complex): a large retail store owned or sublet to a single management which may offer customers a variety of products under self-branding or products of different brands. The single management shall have a complete ownership of all the spaces of the building and no space within the building is further sold or sublet to a different management.

Standard Building: a building that minimally complies with all the mandatory and prescriptive requirements of Energy Conservation Building Code and has same floor area, gross wall area, and gross roof area of the Proposed Building.

Standard Design: a computer model of a hypothetical building, based on actual building design, that fulfils all the mandatory requirements and minimally complies with the prescriptive requirements of ECBC, as described in the Whole Building Performance method.

Story: portion of a building that is between one finished floor level and the next higher finished floor level or building roof. Basement and cellar shall not be considered a story.

Summer Solar Insolation: measure of solar radiation energy received on a given surface area from the month of March to October within the same calendar year. Units of measurement are watts per square meter (W/m^2) or kilowatt-hours per square meter per day ($kW•h/(m^2•day)$) (or hours/day).

SuperECBC Building: a building that complies with the mandatory requirements of §4 to §7 and also complies either with the prescriptive requirements stated under the SuperECBC Building categories of §4 to §7, or, with the whole building performance compliance method of §9. This is a voluntary level of compliance with ECBC.

Super Market (Shopping Complex): supermarkets are large self-service grocery stores that offer customers a variety of foods and household supplies. The merchandise is organized into an organized aisle format, where each aisle has only similar goods placed together.

System: a combination of equipment and auxiliary devices (e.g., controls, accessories, interconnecting means, and terminal elements) by which energy is transformed so it performs a specific function such as HVAC, service water heating, or lighting.

System Efficiency: the system efficiency is the ratio of annual kWh electricity consumption of equipment of water cooled chilled water plant (i.e. chillers, chilled and condenser water pumps, cooling tower) to chiller thermal kWh used in a building.

System, existing: a system or systems previously installed in an existing building.

T

Tenant lease agreement: The formal legal document entered into between a Landlord and a Tenant to reflect the terms of the negotiations between them; that is, the lease terms have been negotiated and agreed upon, and the agreement has been reduced to writing. It constitutes the entire agreement between the parties and sets forth their basic legal rights.

Tenant leased area: area of a building that is leased to tenant(s) as per the tenant lease agreement.

Terminal device: a device through which heated or cooled air is supplied to a space to maintain its temperature. It usually contains dampers and heating and cooling coils. Or a device by which energy form a system is finally delivered, e.g., registers, diffusers, lighting fixtures, faucets, etc.

Theater or motion picture hall (Type of Assembly): any building primarily meant for theatrical or operatic performances and which has a stage, proscenium curtain, fixed or portable scenery or scenery loft, lights, mechanical appliances or other theatrical accessories and equipment for example, theaters, motion picture houses, auditoria, concert halls, television and radio studios admitting an audience and which are provided with fixed seats.

Thermal block: a collection of one or more HVAC zones grouped together for simulation purposes. Spaces need not be contiguous to be combined within a single thermal block.

Thermal comfort conditions: conditions that influence thermal comfort of occupants. Environmental conditions that influence thermal comfort air and radiant temperature, humidity, and air speed.

Thermostat: device containing a temperature sensor used to automatically maintain temperature at a desirable fixed or adjustable set point in a space.

Tinted: (as applied to fenestration) bronze, green, or grey coloring that is integral with the glazing material. Tinting does not include surface applied films such as reflective coatings, applied either in the field or during the manufacturing process.

Transformer: a piece of electrical equipment used to convert electric power from one voltage to another voltage.

Transformer losses: electrical losses in a transformer that reduces its efficiency.

Transport Buildings (Assembly): any building or structure used for the purpose of transportation and transit like airports, railway stations, bus stations, and underground and elevated mass rapid transit system example, underground or elevated railways.

U

Unconditioned buildings: building in which more than 90% of spaces are unconditioned spaces.

Unconditioned space: mechanically or naturally ventilated space that is not cooled or heated by mechanical equipment.

Universities and all others coaching/training institutions (Educational): a building or a group of buildings, under single management, used for imparting education to students numbering more than 100 or public or private training institution built to provide training/coaching etc.

Useful Daylight Illuminance: percentage of annual daytime hours that a given point on a work plane height of 0.8 m above finished floor level receives daylight between 100 lux to 2,000 lux.

U-factor (Thermal Transmittance): heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on each side. Unit of U value is $W/m^2.K$.

V

Variable Air Volume (VAV) system: HVAC system that controls the dry-bulb temperature within a space by varying the volumetric flow of heated or cooled air supplied to the space

Vegetative roofs: also known as green roofs, they are thin layers of living vegetation installed on top of conventional flat or sloping roofs.

Ventilation: the process of supplying or removing air by natural or mechanical means to or from any space. Such air is not required to have been conditioned.

Vision Windows: windows or area of large windows that are primarily for both daylight and exterior views. Typically, their placement in the wall is between 1 meter and 2.2 meter above the floor level.

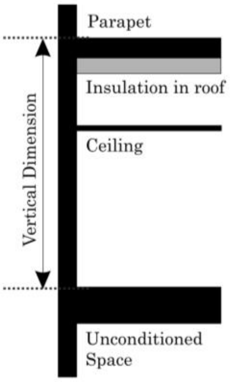
W

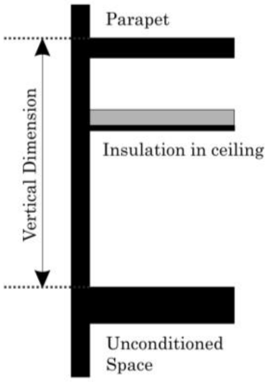
Wall: that portion of the building envelope, including opaque area and fenestration, that is vertical or tilted at an angle of 60° from horizontal or greater. This includes above- and below-grade walls, between floor spandrels, peripheral edges of floors, and foundation walls.

(a) Wall, above grade: a wall that is not below grade

(b) Wall, below grade: that portion of a wall in the building envelope that is entirely below the finish grade and in contact with the ground

Wall area, gross: the overall area off a wall including openings such as windows and doors measured horizontally from outside surface to outside service and measured vertically from the top of the floor to the top of the roof. If roof insulation is installed at the ceiling level rather than the roof, then the vertical measurement is made to the top of the ceiling. The gross wall area includes the area between the ceiling and the floor for multi-story buildings.





Water heater: vessel in which water is heated and withdrawn for use external to the system.

Z

Zone, HVAC: a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor).

8.3 SI to IP Conversion Factors

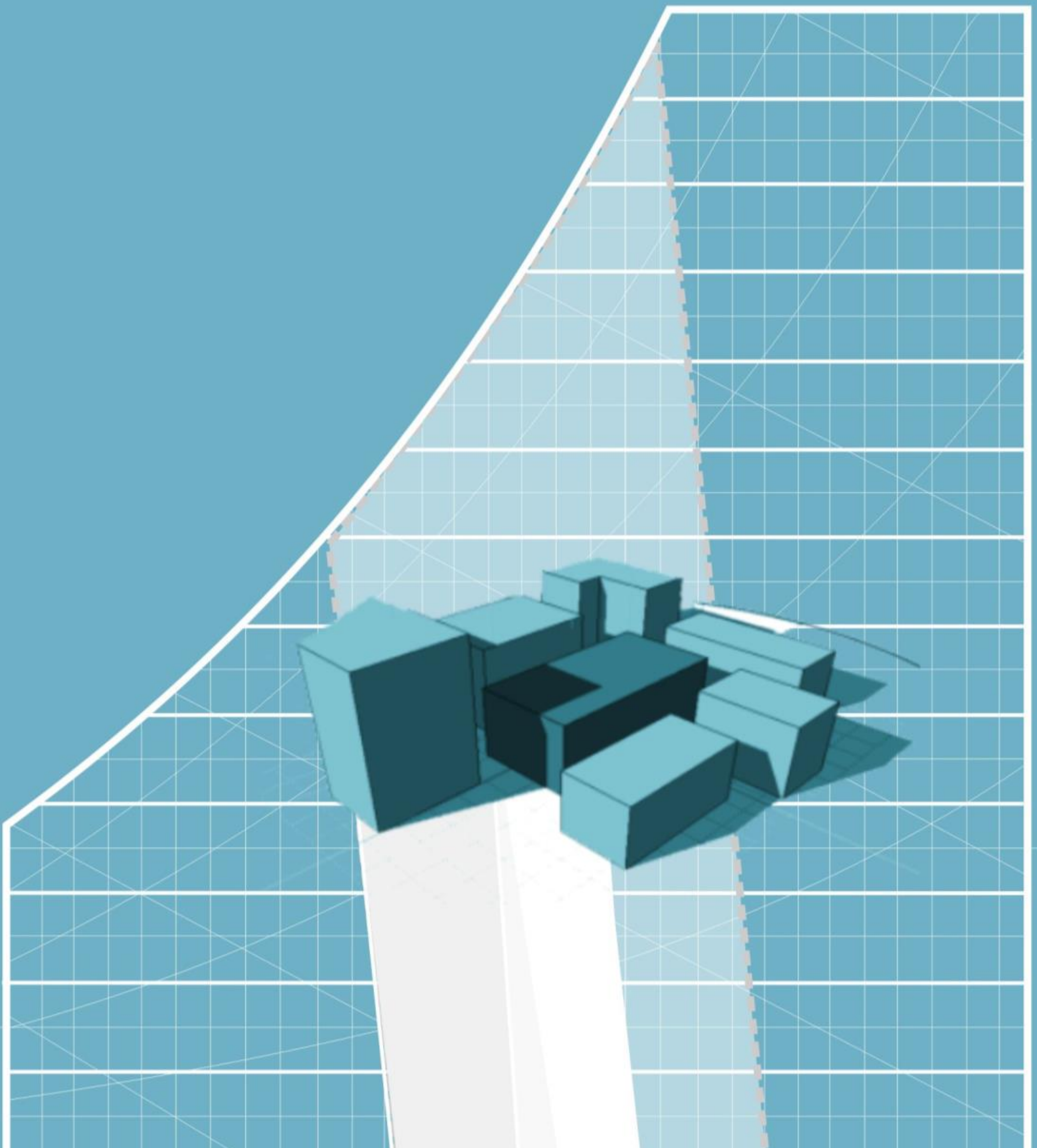
SI Unit	IP Unit
1 cmh	1.7 cfm
1 Pa	0.0040 inch of water gauge
1m	3.28 ft
1m	39.37 in
1mm	0.039 in
1 l/s	2.12 cfm
1 m^2	10.76 ft^2
1 W/m^2	10.76 W/ ft^2
1 W/ lin m	3.28 W/ ft
1 W/m^2.K	5.678 Btu/ h-ft^2-°F
1 W/ l-s^{-1}	0.063 W/ gpm
1 m^2.K/W	0.1761 ft^2-h-ºF/ Btu
1 ºC	((ºC X 9/5) + 32) ºF
1 kW_r	0.284 TR
1 kW	1.34 hp
1 kW	3412.142 Btu/hr

8.4 Abbreviations and Acronyms

AFUE	Annual fuel utilization efficiency
AHRI	Air-conditioning, Heating and Refrigeration Institute
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
Btu	British thermal unit
Btu/h	British thermal units per hour
Btu/h-ft^2-°F	British thermal units per hour per square foot per degree Fahrenheit
BUA	Built up area
C	Celsius
cmh	cubic meter per hour
cm	centimeter
COP	coefficient of performance
DEF	daylight extent factor
EER	energy efficiency ratio
EPI	energy performance index
F	Fahrenheit
ft	foot
h	hour
h-ft^2-°F/Btu	hour per square foot per degree Fahrenheit per British thermal unit
h-m^2-°C/W	hour per square meter per degree Celsius per Watt
hp	horsepower
HVAC	heating, ventilation, and air conditioning
I-P	inch-pound
in.	inch
IPLV	integrated part-load value
IS	Indian Standard
ISO	International Organization for Standardization
kVA	kilovolt-ampere
kW	Kilowatt of electricity
kW$_r$	kilowatt of refrigeration
kWh	kilowatt-hour
l/s	liter per second

LE	luminous efficacy
lin	linear
lin ft	linear foot
lin m	linear meter
lm	lumens
Lm/W	lumens per watt
LPD	lighting power density
m	meter
mm	millimeter
m^2	square meter
m^2.K/W	square meter Kelvin per watt
NBC	National Building Code 2016
Pa	pascal
PF	projection factor
R	R-value (thermal resistance)
SC	shading coefficient
SEF	Shading equivalent factor
SHGC	solar heat gain coefficient
TR	tons of refrigeration
UPS	uninterruptible power supply
VAV	variable air volume
VLT	visible light transmission
W	watt
W/ l-s^{-1}	watt per litre per second
W/m^2	watts per square meter
W/m^2.K	watts per square meter per Kelvin
W/m^2	watts per hour per square meter
W/m.K	watts per lineal meter per Kelvin
Wh	watthour

9 Whole Building Performance Method



9. Whole Building Performance Method

9.1 General

9.1.1 Scope

The Whole Building Performance Method is an alternative to the Prescriptive Method compliance path contained in §4 through §7 of this Code. It applies to all building types covered by the Code as mentioned in §2.5.

9.1.2 Compliance

A building complies with the Code using the Whole Building Performance (WBP) Method, when the estimated EPI Ratio is equal to or less than 1, even though it may not comply with the specific provisions of the prescriptive requirements in §4 trough §7. The mandatory requirements of §4 through §7 (§4.2, §5.2, §6.2, and §7.2) shall be met when using the WBP Method.

9.1.3 Annual Energy Use

Annual energy use for the purposes of the WBP Method shall be calculated in kilowatt-hours (kWh) of electricity use per year per unit area. Energy sources other than electricity that are used in the building shall be converted to kWh of electric energy at the rate of 0.75 kWh per megajoule.

Note: *The annual energy use calculation as per the Whole Building Performance Method is not a prediction of the actual energy use of the building once it gets operational. Actual energy performance of a building depends on a number of factors like weather, occupant behaviour, equipment performance and maintenance, among others, which are not covered by this Code.*

9.1.4 Trade-offs Limited to Building Permit

The WBP Method may be used for building permit applications that include less than the whole building; however, any design parameters that are not part of the building permit application shall be identical for both the Proposed Design and the Standard Design. Future improvements to the building shall comply with both the mandatory and prescriptive requirements of concurrent code.

9.1.5 Documentation Requirements

Compliance shall be documented and compliance forms shall be submitted to the authority having jurisdiction. The information submitted shall include, at a minimum, the following:

(a) Summary describing the results of the analysis, including the annual energy use for the Proposed Design and the Standard Design, and software used.

(b) Brief description of the project with location, number of stories, space types, conditioned and unconditioned areas, hours of operation.

(c) List of the energy-related building features of the Proposed Design. This list shall also document features different from the Standard Design.

(d) List showing compliance with the mandatory requirements of this code.

(e) The input and output report(s) from the simulation program including a breakdown of energy usage by at least the following components: lights, internal equipment loads, service water heating equipment, space heating equipment, space cooling and heat rejection equipment, fans, and other HVAC equipment (such as pumps). The output reports shall also show the number of hours any loads are not met by the HVAC system for both the Proposed Design and Standard Design.

(f) Explanation of any significant modelling assumptions made.

(g) Explanation of any error messages noted in the simulation program output.

(h) Building floor plans, building elevations, and site plan.

9.2 Mandatory Requirements

All requirements of §4.2, §5.2, §6.2, and §7.2 shall be met. These sections contain the mandatory provisions of the Code and are prerequisites for demonstrating compliance using the WBP Method.

9.3 Simulation Requirements

9.3.1 Energy Simulation Program

The simulation software shall be a computer-based program for the analysis of energy consumption in buildings and be approved by the authority having jurisdiction. The simulation program shall, at a minimum, have the ability to model the following:

(a) Energy flows on an hourly basis for all 8,760 hours of the year,

(b) Hourly variations in occupancy, lighting power, miscellaneous equipment power, thermostat set points, and HVAC system operation, defined separately for each day of the week and holidays,

(c) Thermal mass effects,

(d) Ten or more thermal zones,

(e) Part-load and temperature dependent performance of heating and cooling equipment,

(f) Air-side and water-side economizers with integrated control.

In addition to the above, the simulation tool shall be able to produce hourly reports of energy use by energy source and shall have the capability to performing design load calculations to determine required HVAC equipment capacities, air, and water flow rates in accordance with §5 for both the proposed and Standard building designs.

The simulation program shall be tested according to ASHRAE Standard 140 Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ANSI approved) and the results shall be furnished by the software provider.

9.3.2 Climate Data

The simulation program shall use hourly values of climatic data, such as temperature and humidity, from representative climatic data for the city in which the Proposed Design is to be located. For cities or urban regions with several climate data entries, and for locations where weather data are not available, the designer shall select available weather data that best represent the climate at the construction site.

9.3.3 Compliance Calculations

The Proposed Design and Standard Design shall be calculated using the following:

(a) Same simulation program,

(b) Same weather data, and

(c) Identical building operation assumptions (thermostat set points, schedules, equipment and occupant loads, etc.) unless an exception is allowed by this Code or the authority having jurisdiction for a given category.

9.4 Calculating Energy Consumption of Proposed Design and Standard Design

9.4.1 Energy Simulation Model

The simulation model for calculating the Proposed Design and the Standard Design shall be developed in accordance with the requirements in Table 9-1. The Standard Design is based on the mandatory and prescriptive requirements of the ECBC compliant building. The Standard Design will be the same for all compliance levels (ECBC, ECBC+, Super ECBC).

9.4.2 HVAC Systems

The HVAC system type and related performance parameters for the Standard Design shall be determined from Table 9-2 and the following rules:

(a) Other components: Components and parameters not listed in Table 9-2 or otherwise specifically addressed in this subsection shall be identical to those in the Proposed Design.

Exception to § 9.4.2(a): Where there are specific requirements in §5.2.2, the component efficiency in the Standard Design shall be adjusted to the lowest efficiency level allowed by the requirement for that component type.

(b) All HVAC and service water heating equipment in the Standard Design shall be modeled at the minimum efficiency levels, both part load and full load, in accordance with §5.2.2.

(c) Where efficiency ratings, such as EER and COP, include fan energy, the descriptor shall be broken down into its components so that supply fan energy can be modeled separately.

(d) Minimum outdoor air ventilation rates shall be the same for both the Standard Design and the Proposed Design except for conditions specified in §9.4.2.1.

(e) The equipment capacities for the Standard Design shall be sized proportionally to the capacities in the Proposed Design based on sizing runs; i.e., the ratio between the capacities used in the annual simulations and the capacities determined by the sizing runs shall be the same for both the Proposed Design and Standard Design.

(f) Unmet load hours for the Proposed Design shall not differ from unmet load hours for the Standard Design by more than 50 hours. Maximum number of unmet hours shall not exceed 300 for either case.

Table 9-1 Modelling Requirements for Calculating Proposed and Standard Design

Case	*Proposed Design*	*Standard Design*
1. Design Model	(a) The simulation model of the Proposed Design shall be consistent with the design documents, including proper accounting of fenestration and opaque envelope types and area; interior lighting power and controls; HVAC system types, sizes, and controls; and service water heating systems and controls. (b) When the whole building performance method is applied to buildings in which energy-related features have not been designed yet (e.g., a lighting system), those yet-to-be-designed features shall be described in the Proposed Design so that they minimally comply with applicable mandatory and prescriptive requirements of §4.2, §5.2 , §6.2, and §7.2 and §4.3, §5.3, and §6.3 respectively.	The Standard Design shall be developed by modifying the Proposed Design as described in this table. Unless specified in this table, all building systems and equipment shall be modeled identically in the Standard Design and Proposed Design.
2. Space Use Classification	The building type or space type classifications shall be chosen in accordance with §2.5. More than one building type category may be used in a building if it is a mixed-use facility.	Same as Proposed Design.
3. Schedules	Operational schedules (hourly variations in occupancy, lighting power, equipment power, HVAC equipment operation, etc.) suitable for the building and/or space type shall be modeled for showing compliance.	Same as Proposed Design. Exception: Schedules may be allowed to differ between the Standard and Proposed models wherever it is necessary to model nonstandard efficiency

	Schedules must be modeled as per §9.6. In case a schedule for an occupancy type is missing in §9.6, appropriate schedule may be used. Temperature and humidity schedules and set points shall be identical in the Standard and Proposed Designs. Temperature control/thermostat throttling ranges shall also be modeled identically in both the Designs.	measures and/or measures which can be best approximated by a change in schedule. Measures that may warrant a change in operating schedules include but are not limited to automatic controls for lighting, natural ventilation, demand controlled ventilation systems, controls for service water heating load reduction. Schedule change is not allowed for manual controls under any category. This is subject to approval by the authority having jurisdiction.
4. Building Envelope	All components of the building envelope in the Proposed Design shall be modeled as shown on architectural drawings or as installed for existing building envelopes. Exceptions: The following building elements are permitted to differ from architectural drawings. (a) Any envelope assembly that covers less than 5% of the total area of that assembly type (e.g., exterior walls) need not be separately described. If not separately described, the area of an envelope assembly must be added to the area of the adjacent assembly of that same type. (b) Exterior surfaces whose azimuth orientation and tilt differ by no more than 45 degrees and are otherwise the same may be described as either a single surface or by using multipliers. (c) For exterior roofs, other than roofs with ventilated attics, the reflectance and emittance of the roof surface shall be modeled in accordance with §4.3.1.1. (d) Manually operated fenestration shading devices such as blinds or shades shall not be modeled. Permanent shading devices such as fins, overhangs, and light shelves shall be modeled. (e) The exterior roof surface shall be modeled using the solar reflectance in accordance with ASTM E903-96 and thermal emittance determined in accordance with ASTM E408-71. Where cool roof is proposed, emittance and reflectance shall be modeled as per ASTM E408-71 and ASTM E903-96 respectively. Where cool roof is not proposed, the exterior roof surface shall be modeled with a reflectance of 0.3 and a thermal emittance of 0.9.	The Standard Design shall have identical conditioned floor area and identical exterior dimensions and orientations as the Proposed Design, except as noted in (a), (b), (c), and (d) below. (a) Orientation. The Standard Design performance shall be generated by simulating the building with its actual orientation and again after rotating the entire building 90, 180, 270 degrees, then averaging the results. The building shall be modeled so that it does not shade itself. (b) Opaque assemblies such as roof, floors, doors, and walls shall be modeled as having the same heat capacity as the Proposed Design but with the maximum U-factor allowed in §4.3.1 and §4.3.1.1. (c) Fenestration. Fenestration areas shall equal that in the Proposed Design or 40% of gross above grade wall area, whichever is smaller, and shall be distributed on each face in the same proportions as in the Proposed Design No shading projections are to be modeled; fenestration shall be assumed to be flush with the exterior wall or roof. Manually operated fenestration shading devices such as blinds or shades shall not be modeled. Fenestration U-factor shall be the maximum allowed for the climate, and the solar heat gain coefficient shall be the maximum allowed for the climate and orientation. (d) Roof Solar Reflectance and Thermal Emittance: The exterior roof surfaces shall be modeled using a solar reflectance of 0.6 and a thermal emittance of 0.9.

5. Lighting	Lighting power in the Proposed Design shall be determined as follows: Where a complete lighting system exists, the actual lighting power shall be used in the model. Where a lighting system has been designed, lighting power shall be determined in accordance with either §6.3.4. Where no lighting exists, or is specified, lighting power shall be determined in accordance with the §6.3.2 or §6.3.3 for the appropriate building type. Lighting system power shall include all lighting system components shown or provided for on plans (including lamps, ballasts, task fixtures, and furniture-mounted fixtures). Lighting power for parking garages and building facades shall be modeled. Minimum Lighting controls, as per the ECBC requirements of §6.2.1, shall be modeled in the Proposed case. Automatic daylighting controls shall be modeled directly in the software or through schedule adjustments determined by a separate daylight analysis approved by the authority having jurisdiction. Other automatic lighting controls shall be modeled directly in the software by adjusting the lighting power as per Table 9-4.	Lighting power in the Standard Design shall be determined using the same categorization procedure (building area or space function) and categories as the Proposed Design with lighting power set equal to the maximum allowed for the corresponding method and category in either §6.3.2 or §6.3.3. Power for fixtures not included in the lighting power density calculation shall be modeled identically in the Proposed Design and Standard Design. Lighting controls shall be as per the ECBC requirements of §6.2.1.
6. HVAC Thermal Zones	HVAC Zones Designed: Where HVAC zones are defined on design drawings, each HVAC zone shall be modeled as a separate thermal block. Exception: Identical zones (similar occupancy and usage, similar internal loads, similar set points and type of HVAC system, glazed exterior walls face the same orientation or vary by less than 45°) may be combined for simplicity. HVAC Zones Not Designed: Where HVAC zones are not defined on design drawings, HVAC zones shall be defined based on similar occupancy and usage, similar internal loads, similar set points and type of HVAC system, glazed exterior walls that face the same orientation or vary by less than 45° in combination with the following rules: Perimeter Core Zoning: Separate thermal block shall be modeled for perimeter and core spaces. Perimeter spaces are defined	Same as Proposed Design

	as spaces located within 5 meters of an exterior or semi exterior wall. Core spaces are defined as spaces located greater than 5 meters of an exterior or semi exterior wall. Separate thermal blocks shall be modeled for floors in contact with ground and for floors which have a ceiling/roof exposure to the ambient.	
7. HVAC Systems	The HVAC system type and all related performance parameters, such as equipment capacities and efficiencies, in the Proposed Design shall be determined as follows: (a) Where a complete HVAC system exists, the model shall reflect the actual system type using actual component capacities and efficiencies. (b) Where an HVAC system has been designed, the HVAC model shall be consistent with design documents. Mechanical equipment efficiencies shall be adjusted from actual design conditions to the rating conditions specified in §5, if required by the simulation model. (c) Where no heating system has been specified, the heating system shall be assumed to be electric. The system characteristics shall be identical to the system modeled in the Standard Design. (d) Where no cooling system has been specified, the cooling system and its characteristics shall be identical to the system modeled in the Standard Design.	The HVAC system type shall be as per Table 9-2 and related performance parameters for the Standard Design shall be determined from requirements of §9.4.2. Equipment performance shall meet the requirements of §5 for code compliant building.
8. Service Hot Water	The service hot water system type and all related performance parameters, such as equipment capacities and efficiencies, in the Proposed Design shall be determined as follows: (a) Where a complete service hot water system exists, the model shall reflect the actual system type using actual component capacities and efficiencies. (b) Where a service hot water system has been designed, the service hot water model shall be consistent with design documents. (c) Where no service hot water system exists, or is specified, no service hot water heating shall be modeled.	The service water heating system shall be of the same type as the Proposed Design. For residential facilities, hotels and hospitals the Standard Design shall have a solar hot water system capable of meeting 20% of the hot water demand. Systems shall meet the efficiency requirements of §5.2.9.2, the pipe insulation requirements of §5.2.9.4 and incorporate heat traps in accordance with §5.2.9.5.
9. Miscellaneous Loads	Receptacle, motor, and process loads shall be modeled and estimated based on the building type or space type category. These loads shall be included in simulations of the building and shall be included when	Receptacle, motor and process loads shall be modeled the same as the Proposed Design.

	calculating the Standard Design and Proposed Design. All end-use load components within and associated with the building shall be modeled, unless specifically excluded by this Table, but not limited to, exhaust fans, parking garage ventilation fans, exterior building lighting, swimming pool heaters and pumps, elevators and escalators, refrigeration equipment, and cooking equipment.	
10. Modelling Limitations to the Simulation Program	If the simulation program cannot model a component or system included in the Proposed Design, one of the following methods shall be used with the approval of the authority having jurisdiction: (a) Ignore the component if the energy impact on the trade-offs being considered is not significant. (b) Model the component substituting a thermodynamically similar component model. (c) Model the HVAC system components or systems using the HVAC system of the Standard Design in accordance with Section 6 of this table. Whichever method is selected, the component shall be modeled identically for both the Proposed Design and Standard Design models.	Same as Proposed Design.

Table 9-2 HVAC Systems Map for Standard Design

	Hotel/Motel, Hospital Patient Rooms, Hotel Guest Rooms, Resorts, Villas, Sleeping Quarters in Mixed-use Buildings, Schools, Classrooms/Lecture Rooms[1]	Buildings with Less than or Equal to 12,500 m^2 of Conditioned Area	Buildings with More than 12,500 m^2 of Conditioned Area	Data Centre/ Server/Computer Rooms
Name	System **A**	System **B**	System **C**	System **D**
System Type[2]	Split AC	VRF : Variable Refrigerant Flow	VAV: Central cooling plant with variable volume AHU for each zone	Computer Room air conditioners
Fan Control	Constant Volume	Constant volume	Variable volume	Constant volume
Cooling Type	Direct expansion with air cooled condenser	Direct expansion with air cooled condenser	Chilled Water with water cooled condenser	Direct expansion with air cooled condenser
Heating Type	1. Heat Pump: Where no heating system has been specified or where an electric heating system has been specified in the Proposed Design 2. Fossil Fuel Boiler: Where a heating system exists and a fossil fuel hot water boiler has been specified in the Proposed Design	1. Heat Pump: Where no heating system has been specified or where an electric heating system has been specified in the Proposed Design 2. Fossil Fuel Boiler: Where a heating system exists and a fossil fuel hot water boiler has been specified in the Proposed Design	1. Electric resistance: Where no heating system has been specified or where an electric heating system has been specified in the Proposed Design 2. Fossil Fuel Boiler: Where a heating system exists and a fossil fuel hot water boiler has been specified in the Proposed Design	NA

Notes:

1. Buildings of the listed occupancy types or spaces in Mixed-use Buildings with the listed occupancy types.
2. Where attributes make a building eligible for more than one system type; use the predominant condition to determine the Standard Design system type provided the non-predominant conditions apply to less than 1,000 m^2 of conditioned floor area. Use additional system type for non-predominant conditions if those conditions apply to more than 1,000 m^2 of conditioned floor area.

Use additional system type for any space which has a substantial difference in peak loads and/or operational hours compared to the predominant space type. Such spaces may include but are not limited to computer/server rooms, retail areas in residential, or office buildings.

9.4.2.1 Minimum Outdoor air rates:

Minimum outdoor air rates shall be identical for both the Standard Design and Proposed Design, except

(a) when modeling demand controlled ventilation (DCV) in the Proposed Design (DCV is not required in the Standard Design as per §5.2.1.4)
(b) when the Proposed Design has a minimum ventilation flow higher than the minimum required by the applicable code, the Standard Design shall be modeled as per the minimum ventilation rate required by the applicable code and the Proposed Design shall be modeled as per actual design (higher than Standard Design)

9.4.2.2 Fan Schedules

Supply and return fans shall operate continuously whenever the spaces are occupied and shall be cycled to meet heating and cooling loads during unoccupied hours.

9.4.2.3 Fan Power

(a) For Systems Types A, B and D,

P_{fan} = cmh x .51

Where P_{fan} = Standard Design fan power in watts

cmh = Standard Design supply airflow rate auto-sized by the simulation software

(b) For System Type C

Fan power shall be modeled as per power and efficiency limits specified in Table 5-12 using a static pressure of 622 Pa or the design static pressure, whichever is higher. The simulation software shall automatically calculate the Standard Design fan power based on the above inputs.

9.4.2.4 Design Airflow Rates

Design airflow rates for the Standard Design shall be sized based on a supply air to room air temperature difference of 11 °C. The Proposed Design airflow rates shall be as per design.

9.4.2.5 Economizers (airside and waterside)

Airside economizers shall be modeled in the Standard Design as per the requirements of §5.3.3.

Exception to §9.4.2.5: Airside economizer shall not be modeled for Standard Design HVAC System Type A.

9.4.2.6 Energy Recovery

Energy recovery shall be modeled in the Standard Design as per the requirements of §5.3.

9.4.2.7 Chilled Water Design Supply Temperatures

Chilled water design supply temperature shall be modeled at 6.7° C and return temperature at 13.3° C.

9.4.2.8 Chillers

Only electric chillers shall be modeled in the Standard Design for System C. Chillers shall meet the minimum efficiency requirements indicated in Table 5-1 and Table 5-2. Chillers in the Standard Design shall be selected as per Table 9-3 below:

Table 9-3 Modeling Requirements for Calculating Proposed and Standard Design

Peak Building Cooling Load (kW$_r$)	*Chiller Type*
< 1,055	1 Water Cooled Screw Chiller
1,055 to 2,110	2 Water Cooled Screw Chillers
> 2,110	2 Water Cooled Centrifugal Chillers minimum, equally sized such that no Chiller is greater than 2,813 kW$_r$

Exception to above: Air cooled chillers are allowed to be modeled in the Standard Design if the Proposed Design has air cooled chillers. If the proposed building has a mix of air and water cooled chillers, then the Standard Design shall be modeled with a mix of air and water cooled chillers in the same proportion as in the Proposed Design. However, this exception applies only for minimum ECBC compliance. Air cooled chillers shall not be modeled in the Standard Design when demonstrating compliance with ECBC+ and SuperECBC Building requirements.

9.4.2.9 Chilled Water Pumps

Chilled and condenser water pumps for the Standard Design shall be modeled as per power and efficiency limits specified in Table 5-15.

Standard Design chilled water pumps shall be modeled as primary-secondary with variable secondary flow.

9.4.2.10 Cooling Tower

Standard Design cooling tower shall be modeled as an open circuit axial flow tower with power and efficiency as per Table 5-18. The fans shall be modeled as two speed.

Condenser water design supply temperature shall be 29.4°C or 5.6°C approach to wet bulb temperature, whichever is lower, with a design temperature rise of 5.6°C.

9.4.2.11 Boiler

Standard Design boilers shall be modeled as natural draft boilers and shall use the same fuel as the Proposed Design. Boiler efficiency shall be modeled as per Table 5-19.

9.4.2.12 Hot Water Design Supply Temperatures

Hot water design supply temperature shall be modeled at 82°C and return temperature at 54°C.

9.4.2.13 Hot Water Pumps

The Standard Design hot water pumps shall be modeled with a minimum efficiency of 70% and a pump power of 300 W/l-s^{-1}.

Standard Design hot water pumps shall be modeled as primary-secondary with variable secondary flow.

9.4.2.14 Campus/District Cooling Systems

All district cooling plants shall be assumed to be on grid electricity, unless otherwise specified and supported through pertinent documents. New district plants shall comply with the mandatory requirements of ECBC irrespective of who owns and/or operates the district plant.

Projects may choose either option A or option B given below for modelling campus/district cooling systems.

Option A

The cooling source shall be modeled as purchased chilled water in both the Standard Design and Proposed Design. For the Standard Design, Table 9-2 HVAC Systems Map, shall be modified as follows:

a) For System Type C; purchased chilled water shall be modeled as the cooling source.
b) System Types A and B shall be replaced with a two-pipe fan coil system with purchased chilled water as the cooling source.

The chilled water/thermal energy consumption simulated by the software shall be converted to units of kWh and added to the overall building energy consumption. The following conversion factors shall be used to convert chilled water/thermal energy consumption to units of kWh.

1 ton hour = 0.85 kWh

1 MBtu = 1,000,000 Btu = 293 kWh

Option B

The Standard Design shall be modeled as per Table 9-2 HVAC Systems Map.

For the Proposed Design, model a virtual onsite chilled water plant with Chiller, Pumps and cooling towers modeled at minimum efficiency levels as per §9.4.2.7 to §9.4.2.10. Airside/low side capacities shall be modeled as per design and the plant capacities shall be auto-sized by the software.

Table 9-4 Power Adjustment Factors for Automatic Lighting Controls

Automatic Control Device	*Daytime occupancy and area <300 m^2*	*All Others*
Programmable Timing Control	10%	0%
Occupancy Sensor	10%	10%
Occupancy Sensor and Programmable Timing Control	15%	10%

9.4.3 Compliance Thresholds for ECBC compliant, ECBC+ and SuperECBC Buildings

For buildings to qualify as ECBC+ and SuperECBC Buildings, the WBP Method shall be followed for the Standard Design as detailed above. The Proposed Design for ECBC+ and SuperECBC Buildings shall meet the mandatory provisions of §4.2, §5.2, §6.2, and §7.2.

The EPI Ratio for ECBC+ and SuperECBC Buildings shall be equal to or less than the EPI Ratios listed under the applicable climate zone in Table 9-5 through Table 9-9 of §9.5.

9.5 Maximum Allowed EPI Ratios

Table 9-5 Maximum Allowed EPI Ratios for Building in Composite Climate

Building Type	*Composite*		
	ECBC	ECBC+	SuperECBC
Hotel (No Star and Star)	1	0.91	0.81
Resort	1	0.88	0.76
Hospital	1	0.85	0.77
Outpatient	1	0.85	0.75
Assembly	1	0.86	0.77
Office (Regular Use)	1	0.86	0.78
Office (24Hours)	1	0.88	0.76
Schools and University	1	0.77	0.66
Open Gallery Mall	1	0.85	0.76
Shopping Mall	1	0.86	0.74
Supermarket	1	0.81	0.70
Strip retail	1	0.82	0.68

Table 9-6 Maximum Allowed EPI Ratios for Buildings in Hot and Dry Climate

Building Type	*Hot and Dry*		
	ECBC	ECBC+	SuperECBC
Hotel (No Star and Star)	1	0.90	0.81
Resort	1	0.88	0.76
Hospital	1	0.84	0.76
Outpatient	1	0.85	0.75
Assembly	1	0.86	0.78
Office (Regular Use)	1	0.86	0.78
Office (24Hours)	1	0.88	0.76
Schools and University	1	0.77	0.66
Open Gallery Mall	1	0.85	0.77
Shopping Mall	1	0.84	0.72
Supermarket	1	0.73	0.69
Strip retail	1	0.82	0.68

Table 9-7 Maximum Allowed EPI Ratios for Buildings in Temperate Climate

Building Type	*Temperate*		
	ECBC	ECBC+	SuperECBC
Hotel (No Star and Star)	1	0.90	0.80
Resort	1	0.88	0.75
Hospital	1	0.82	0.73
Outpatient	1	0.85	0.75
Assembly	1	0.85	0.76
Office (Regular Use)	1	0.85	0.75
Office (24Hours)	1	0.87	0.74
Schools and University	1	0.77	0.66
Open Gallery Mall	1	0.83	0.74
Shopping Mall	1	0.84	0.71
Supermarket	1	0.81	0.69
Strip retail	1	0.81	0.67

Table 9-8 Maximum Allowed EPI Ratios for Buildings in Warm and Humid Climate

Building Type	*Warm and Humid*		
	ECBC	ECBC+	SuperECBC
Hotel (No Star and Star)	1	0.91	0.81
Resort	1	0.88	0.75
Hospital	1	0.86	0.77
Outpatient	1	0.86	0.76
Assembly	1	0.88	0.80
Office (Regular Use)	1	0.86	0.76
Office (24Hours)	1	0.88	0.76
Schools and University	1	0.77	0.66
Open Gallery Mall	1	0.86	0.77
Shopping Mall	1	0.85	0.72
Supermarket	1	0.82	0.70
Strip retail	1	0.83	0.68

Table 9-9 Maximum Allowed EPI Ratios for Buildings in Cold Climate

Building Type	*Cold*		
	ECBC	ECBC+	SuperECBC
Hotel (No Star and Star)	1	0.91	0.82
Resort	1	0.88	0.75
Hospital	1	0.88	0.80
Outpatient	1	0.85	0.75
Assembly	1	0.87	0.81
Office (Regular Use)	1	0.88	0.80
Office (24Hours)	1	0.87	0.75
Schools and University	1	0.85	0.73
Open Gallery Mall	1	0.82	0.73
Shopping Mall	1	0.96	0.93
Supermarket	1	0.80	0.68
Strip retail	1	0.80	0.66

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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

UNIT – III - BUILDING ENERGY CODES AND STANDARDS – SARA 5132

UNIT 3

FUNCTIONAL EFFICIENCY OF BUILDINGS – HEAT INSULATION AND VENTILATION

SP41 – Climate, Thermal comfort, Shading devices, energy requirement for cooling and heating. Heat Insulation - introduction, terminology, requirements, heat transmission through building sections, thermal performance of building sections, orientation of buildings, building characteristics for various climates, thermal design of buildings, influence of design parameters, mechanical controls. Ventilation - introduction, terminology, ventilation requirements, minimum standards for ventilation, ventilation design, energy conservation in ventilating systems..

Objective: To devise the applicability of the methodologies prescribed in the codes

Methodology:

Climate, Thermal comfort, Shading devices	Presentation & Lecture Discussion & Calculation sessions. Kahoot
Heat Insulation	Presentation & Lecture Discussion & Calculation sessions.
Ventilation	Presentation & Lecture; Discussion & Calculation sessions; Kahoot

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/m^2)

(*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

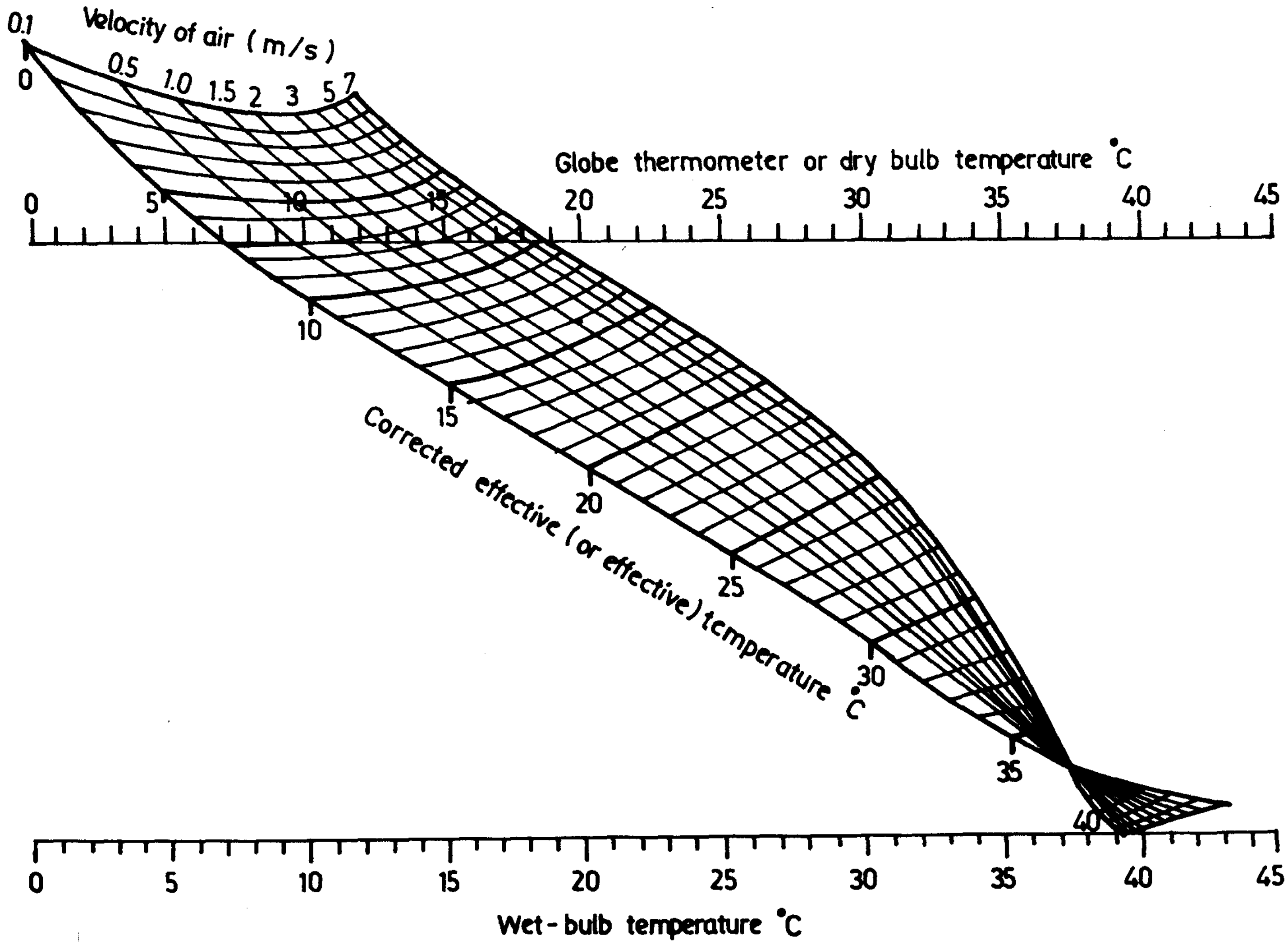


Fig. 1 Corrected Effective Temperature Nomogram

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 undergarments. 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

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

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

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

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

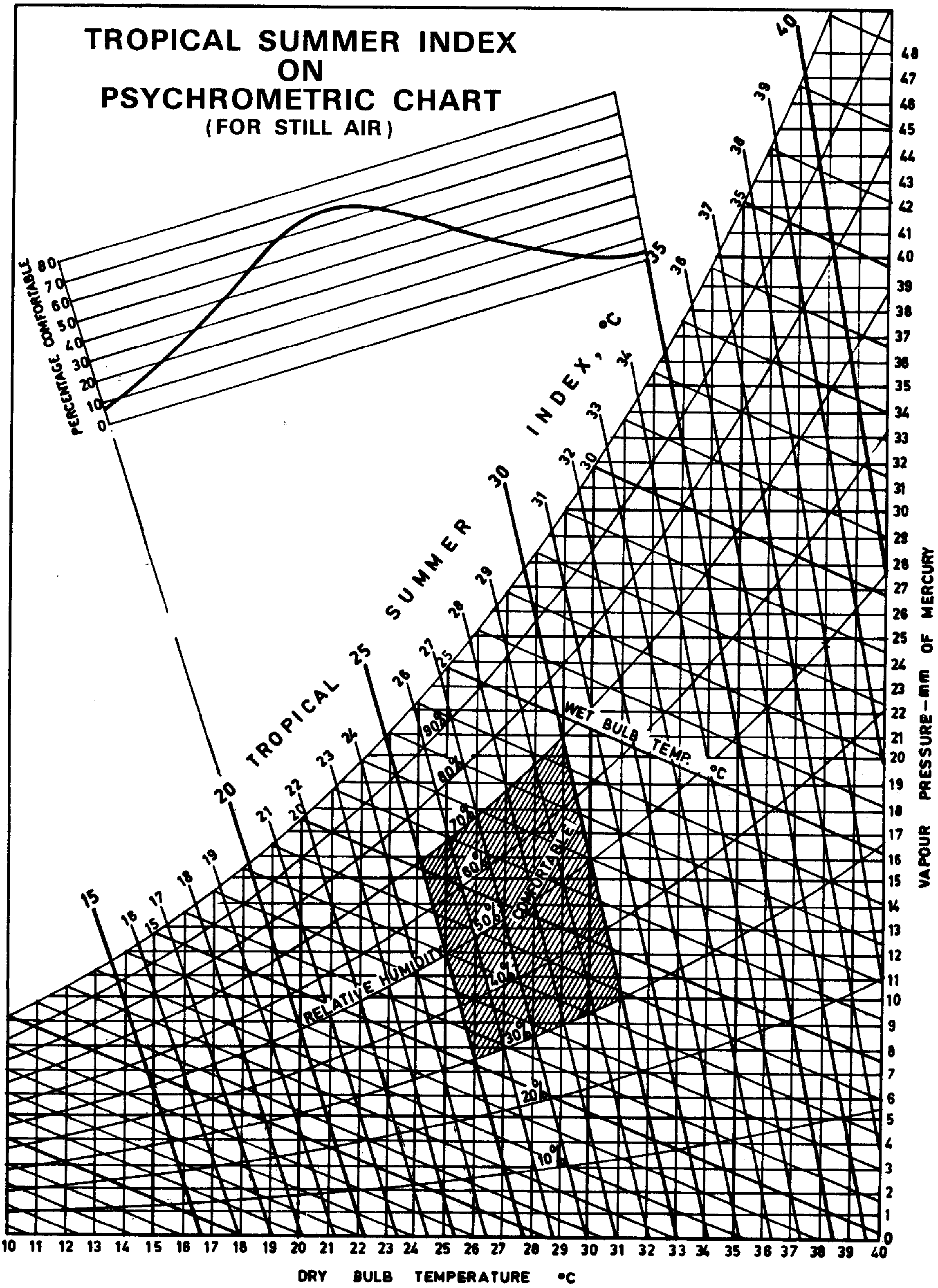


FIG. 2 TROPICAL SUMMER INDEX ON PSYCHROMETRIC CHART

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.

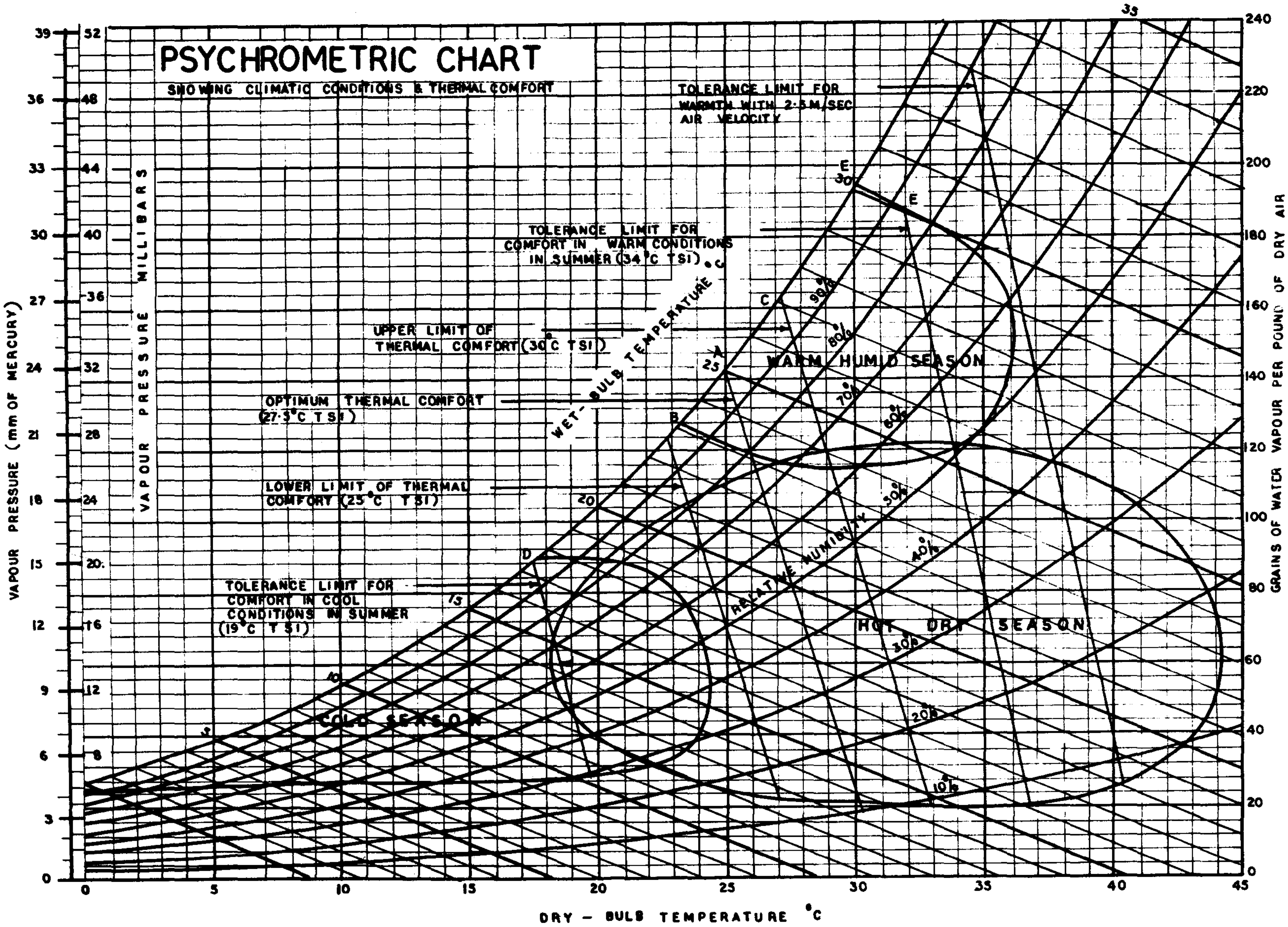


FIG. 3 PSYCHROMETRIC CHART (SHOWING CLIMATIC CONDITIONS AND THERMAL COMFORT)

SOLAR CHART

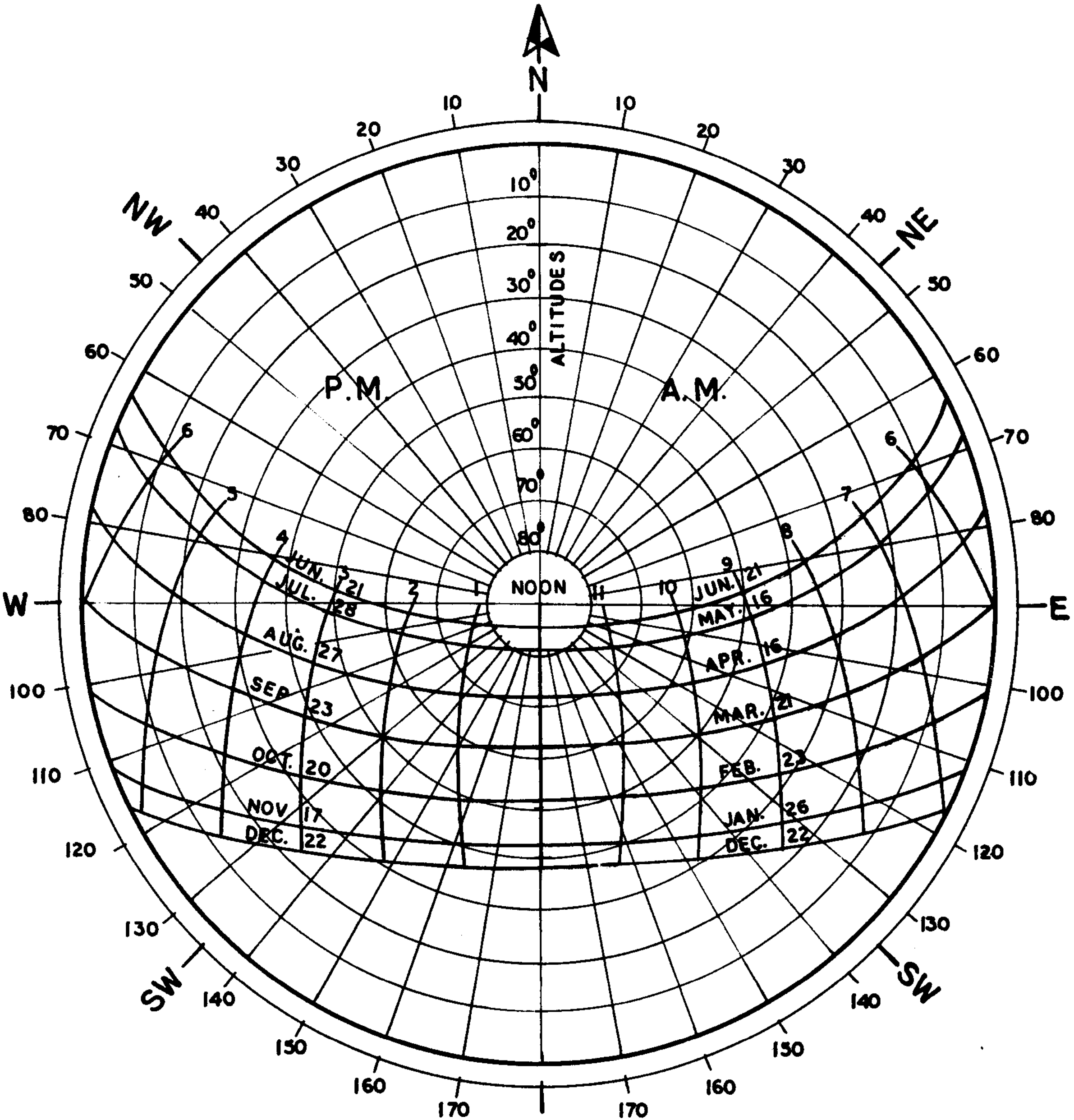


FIG. 4 LATITUDE 29° NORTH

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.

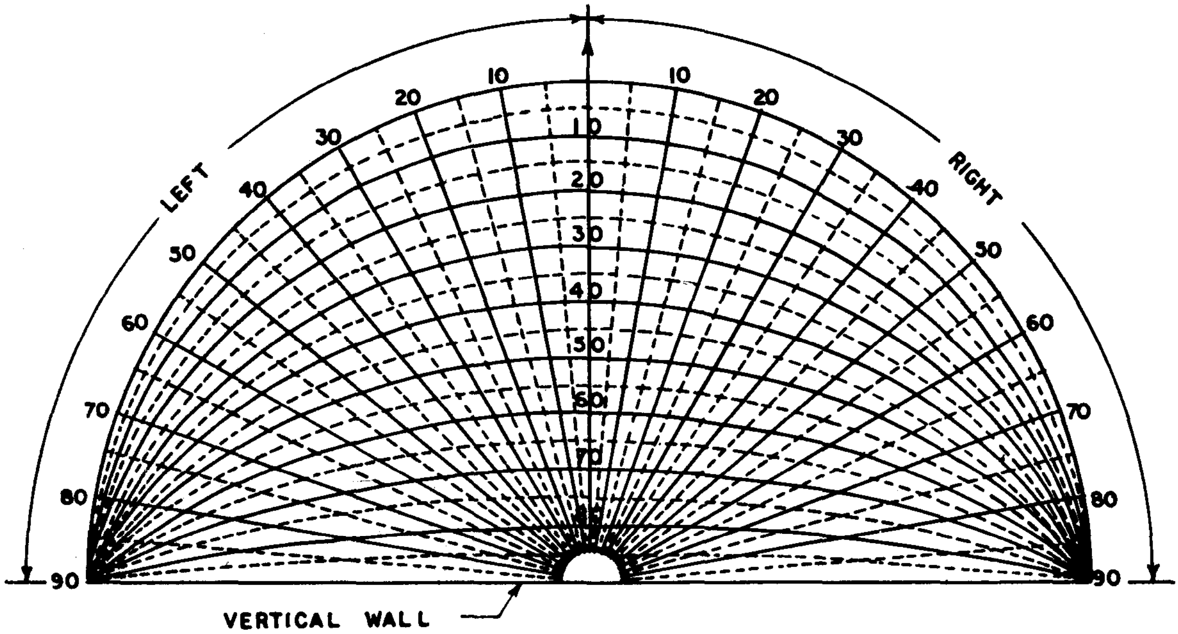


FIG. 5 SHADOW ANGLE PROTRACTOR

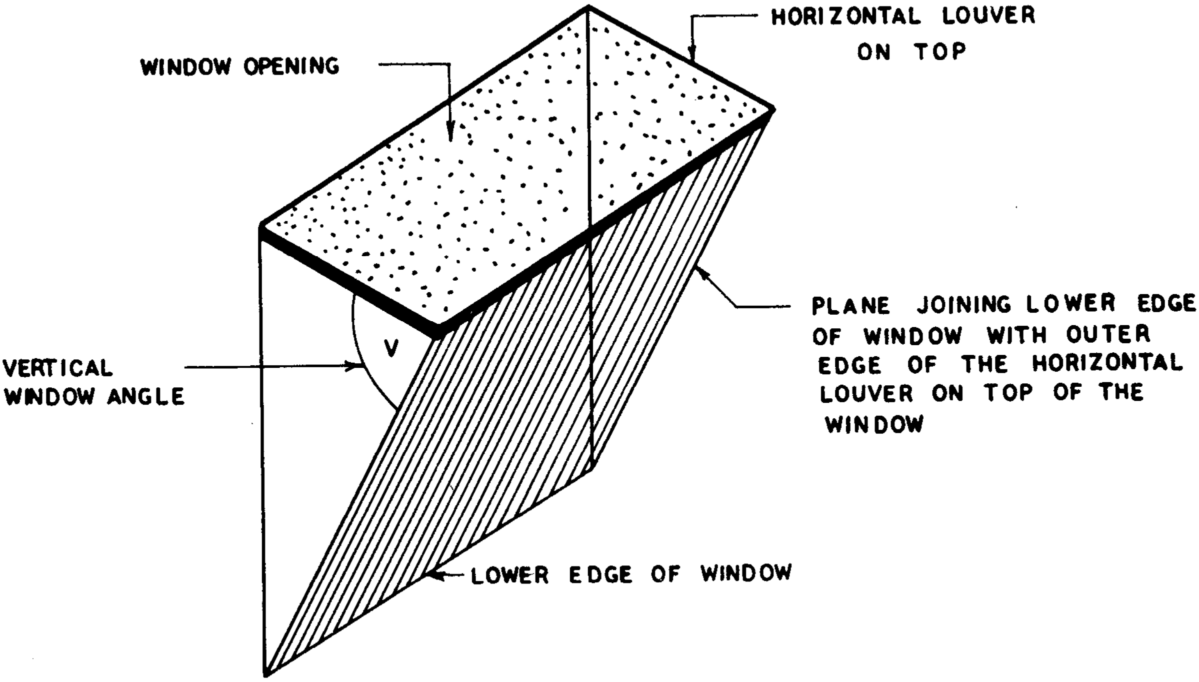


FIG. 6 VERTICAL WINDOW ANGLE

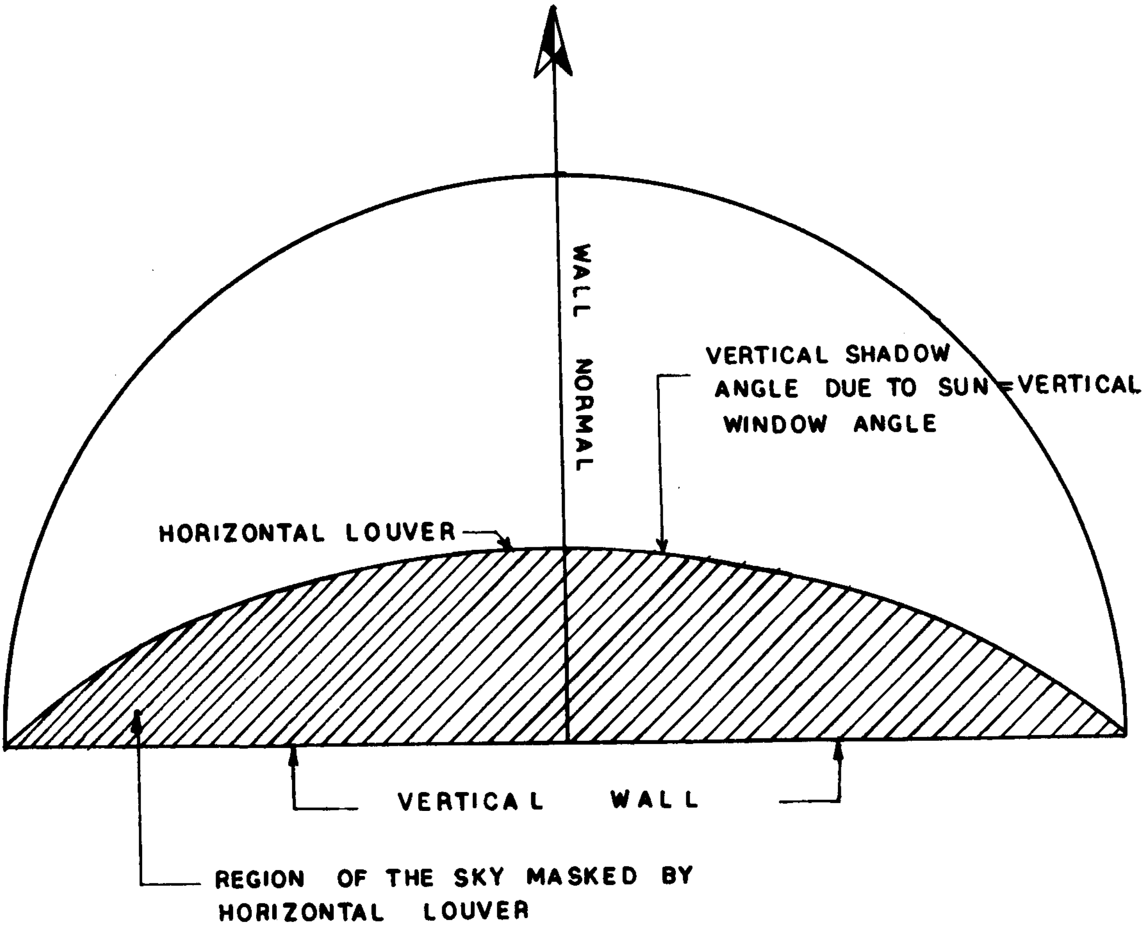


FIG. 7 REGION OF THE SKY MASKED BY HORIZONTAL LOUVER

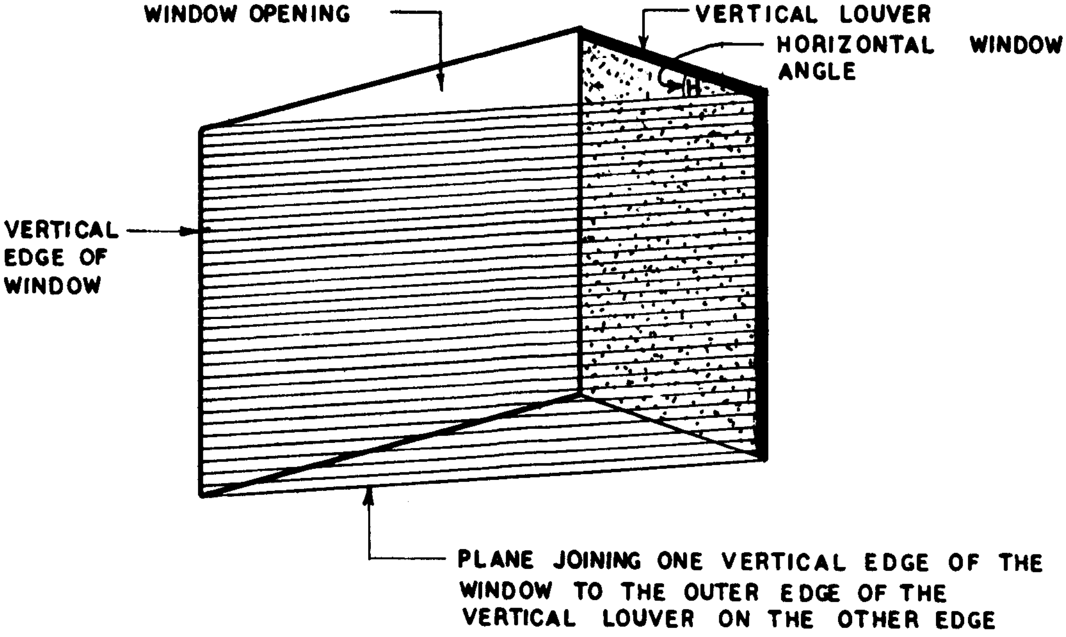


FIG. 8 HORIZONTAL WINDOW ANGLE

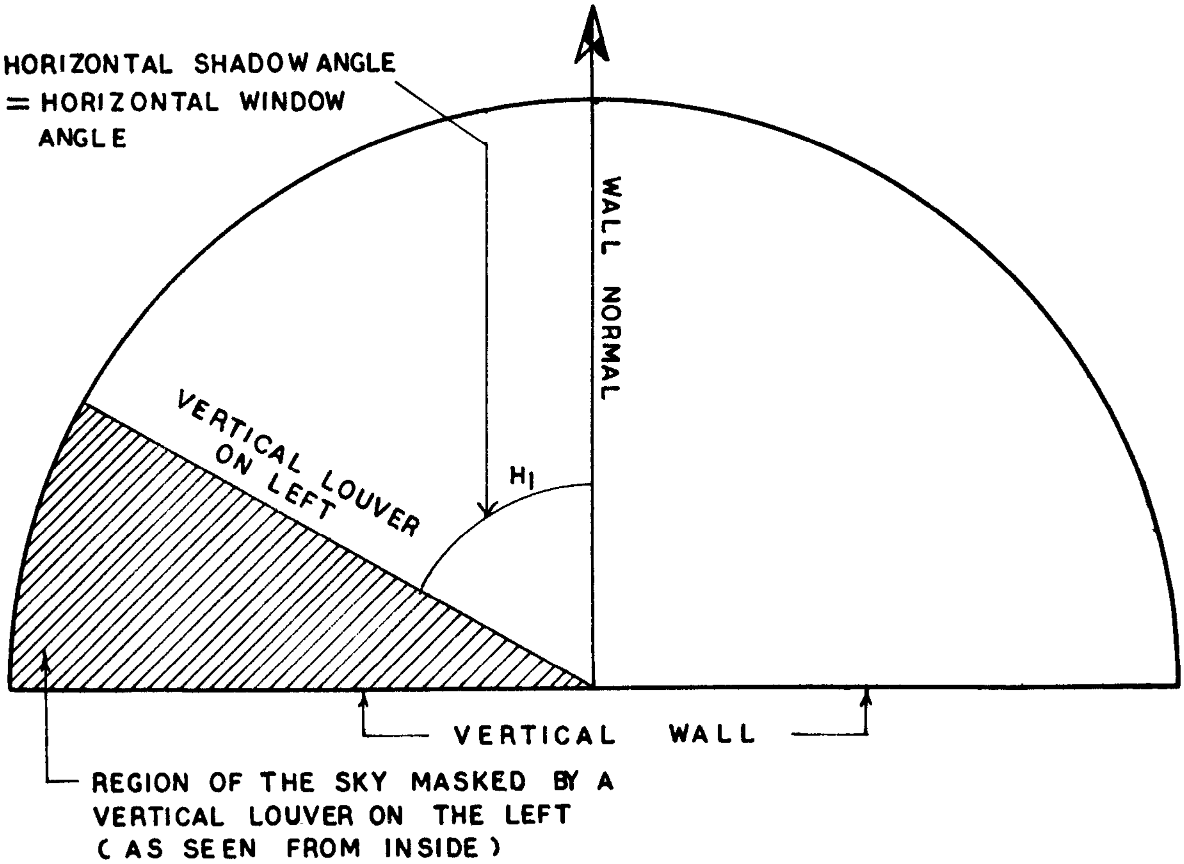


FIG. 9 REGION OF THE SKY MASKED BY A VERTICAL LOUVER ON THE LEFT SIDE

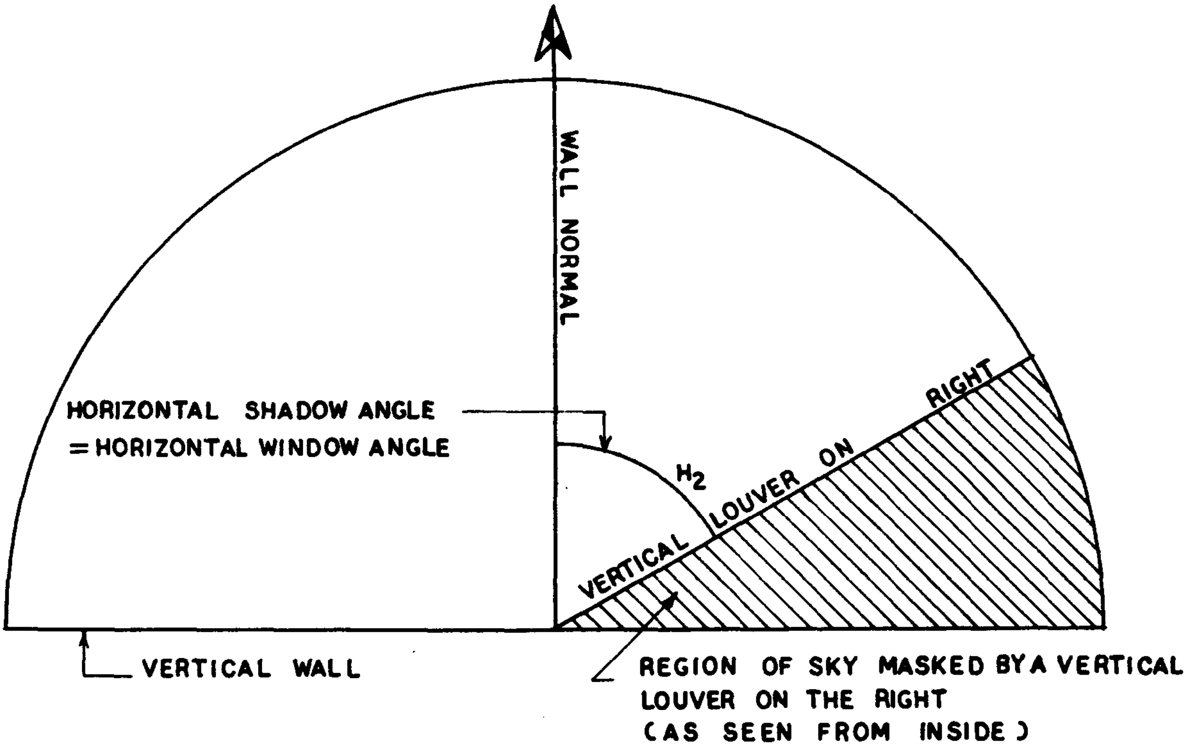


FIG. 10 REGION OF SKY MASKED BY A VERTICAL LOUVER ON THE RIGHT SIDE

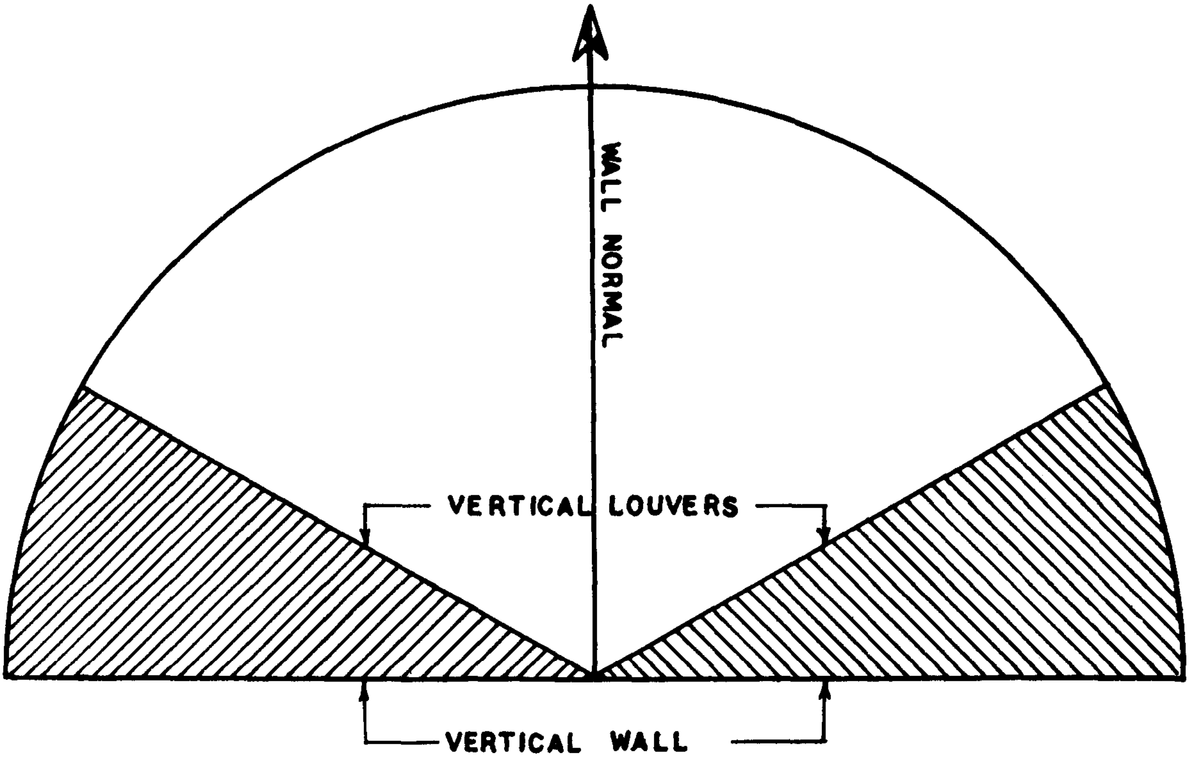


FIG. 11 SHADING MASK DUE TO VERTICAL LOUVERS ON BOTH SIDES

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.

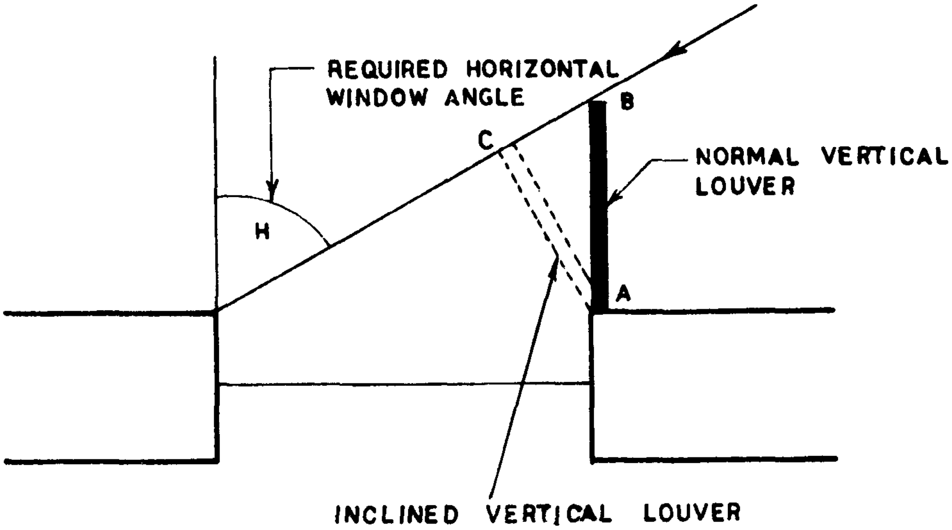
3.4.3.2 *Use of Tables 9 and 10*

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.

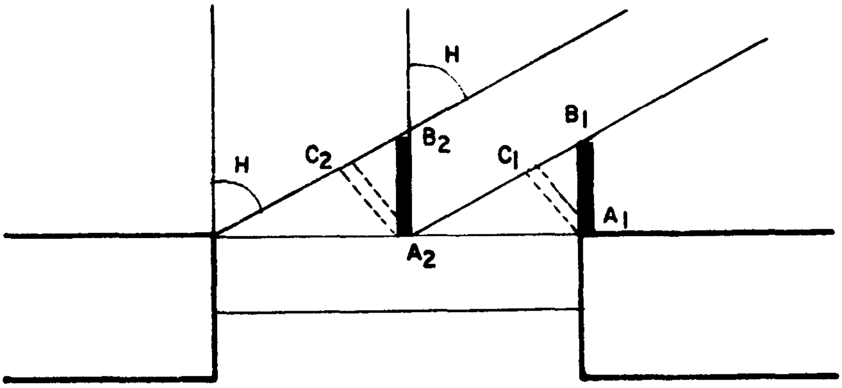
b) The performance of the louvers is such that the summer sun is fully excluded from reaching inside. The winter sun is generally allowed to come in but at times the winter sun is also excluded as a result of some shading devices meant for cutting off summer sun.

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
	Horizontal 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
		$B = 0^\circ$	$B = 15^\circ$	$B = 30^\circ$	$B = 45^\circ$	$B = 60^\circ$			
	Horizontal 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($B = 30^\circ$)
Case 2	H	0.36 P	0.63 P	0.94 P	1.36P	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
	Horizontal member	P	1.27P	1.58 P	2 P	3.73 P	Downwards		Combination of types V(B = 30°) and H($B = 0^\circ$)

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

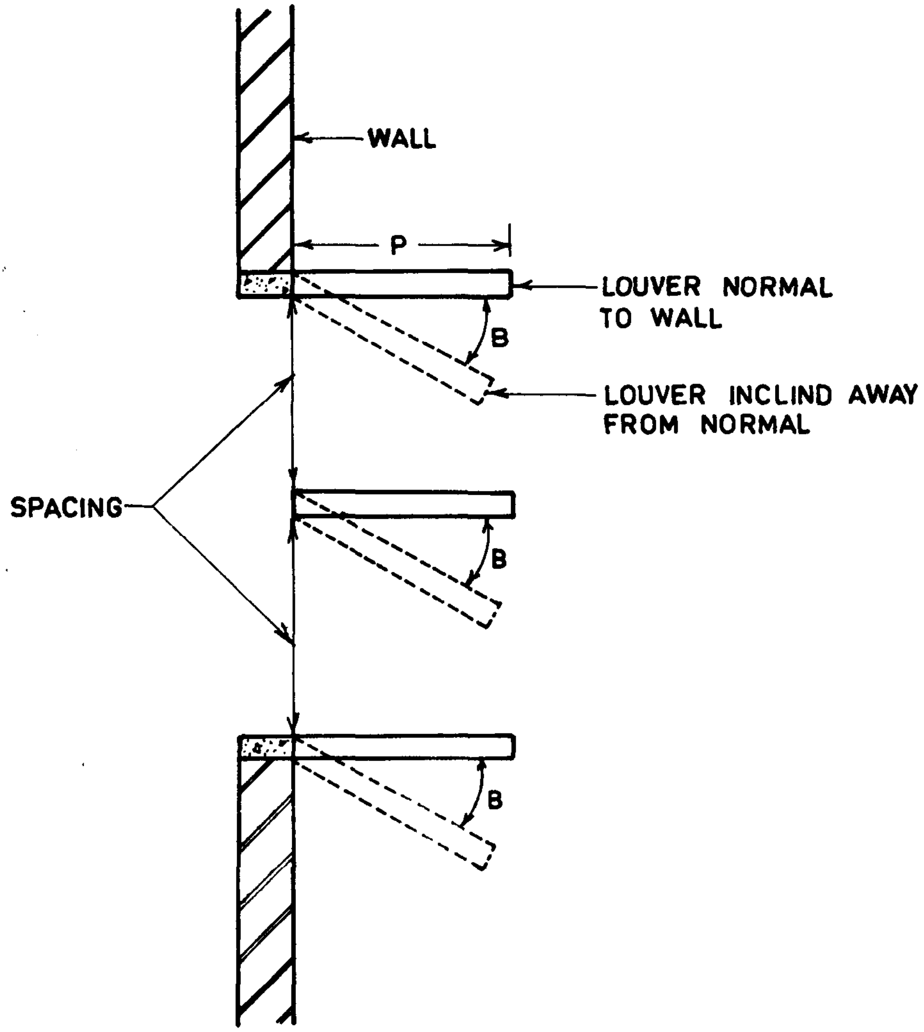


FIG. 13 TYPICAL PLAN OF LOUVER SHOWING THE OUTWARD PROJECTION AND ITS INCLINATION

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 $= 0.21 \times 71.5 = 15$ 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 $= 0.94 \times 60 = 56$ 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 $= 0.47 \times 60 = 28$ 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 = $0.84 \times 70 = 59$ 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 $0.94\ P = 0.94 \times 70 = 66$ 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. (1)	DIAMETER (2) (mm)	REVOLUATION PER MINUTE (3)	POWER CONSUMPTION (4) (Watts)	NOISE LEVEL (5) (dB)	AIR VOLUME (6) (m^3/h)	SUITABLE APPLICATION (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. (1)	FAN DIAMETER (2) (mm)	PAD AREA (3) (m²)	WATER TANK CAPACITY (4) (litres)	COOLING CAPACITY (5) (tons)	VOLUME OF THE ROOM COOLED (6) (m³)
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

- Agra
- Ajmer
- Akola
- Aligarh
- Allahabad
- Ambala
- Bareilly
- Bikaner
- Gaya
- Jabalpur
- Jaipur
- Kanpur
- Khandwa
- Kota
- Lucknow
- Ludhiana
- Nagpur
- Neemuch
- New Delhi
- Roorkee
- Sambalpur
- Sholapur
- Umaria
- Varanasi

Hot and Humid Zone

- Ahmadabad
- Asansol
- Bhavanagar
- Bhuj
- Bombay
- Calcutta
- Calicut
- Cuttack
- Dohad
- Jamnagar
- Jamshedpur
- Madras
- Madurai
- Mangalore
- Masulipatam
- Midnapur
- Nellore
- Patna
- Rajkot
- Ratnagiri
- Salem
- Surat
- Tiruchichirapalli
- Vellore
- Vishakhapatnam

Warm and Humid Zone

- Cochin
- Dwarka
- Guwahati
- Puri
- Sibsagar
- Silchar
- Tezpur
- Trivandrum
- Veraval

Cold Zone

- Darjeeling
- Dras
- Gulmarg
- Leh
- Mussoorie
- Nainital
- Ootacamund
- Shillong
- Shimla
- Skardu
- Srinagar

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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/(m^{2}K).

2.6 Surface Resistance ($1/f$) — It is the reciprocal of surface coefficient. It is expressed in m^{2}K/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/(m^{2}K).

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 be 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^{2}K)		h		W/(m^{2}K)		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^{2}K,
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^{2}K,
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 :

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

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

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

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/m^3	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/m^2)	—	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

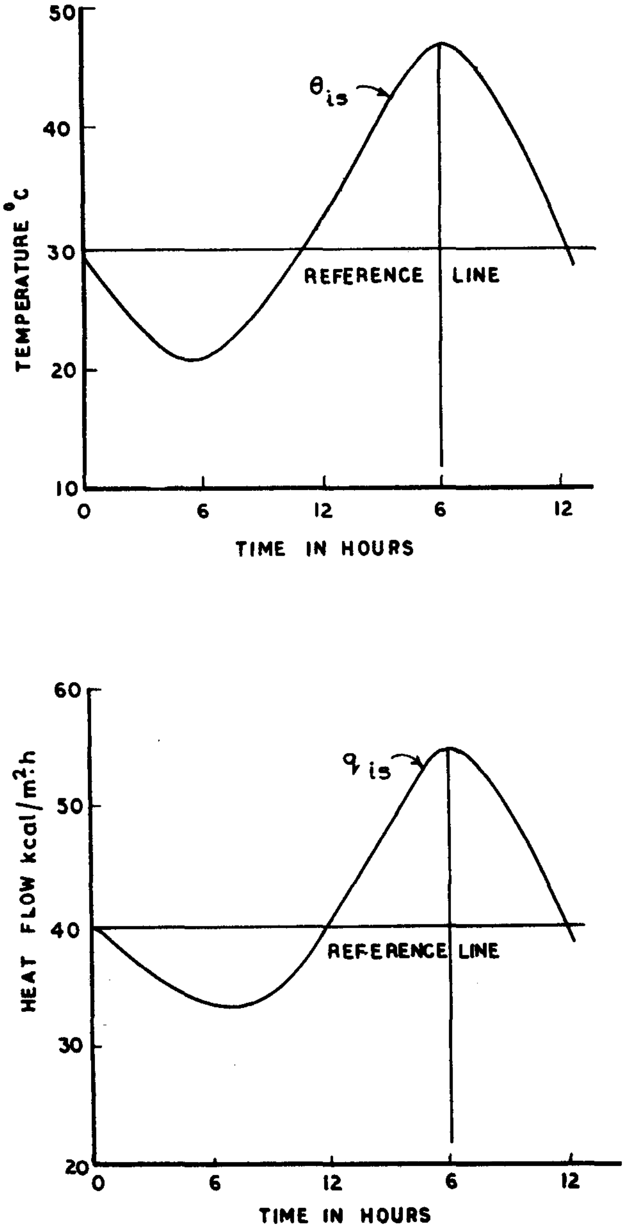


FIG. 1 RELATIONSHIP BETWEEN THERMAL PERFORMANCE

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/m^2, 46 W/m^2 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/m^2. 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				CLASS	QUALITY OF PERFORMANCE
Non-air-conditioned		Air-conditioned			
⩽ 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

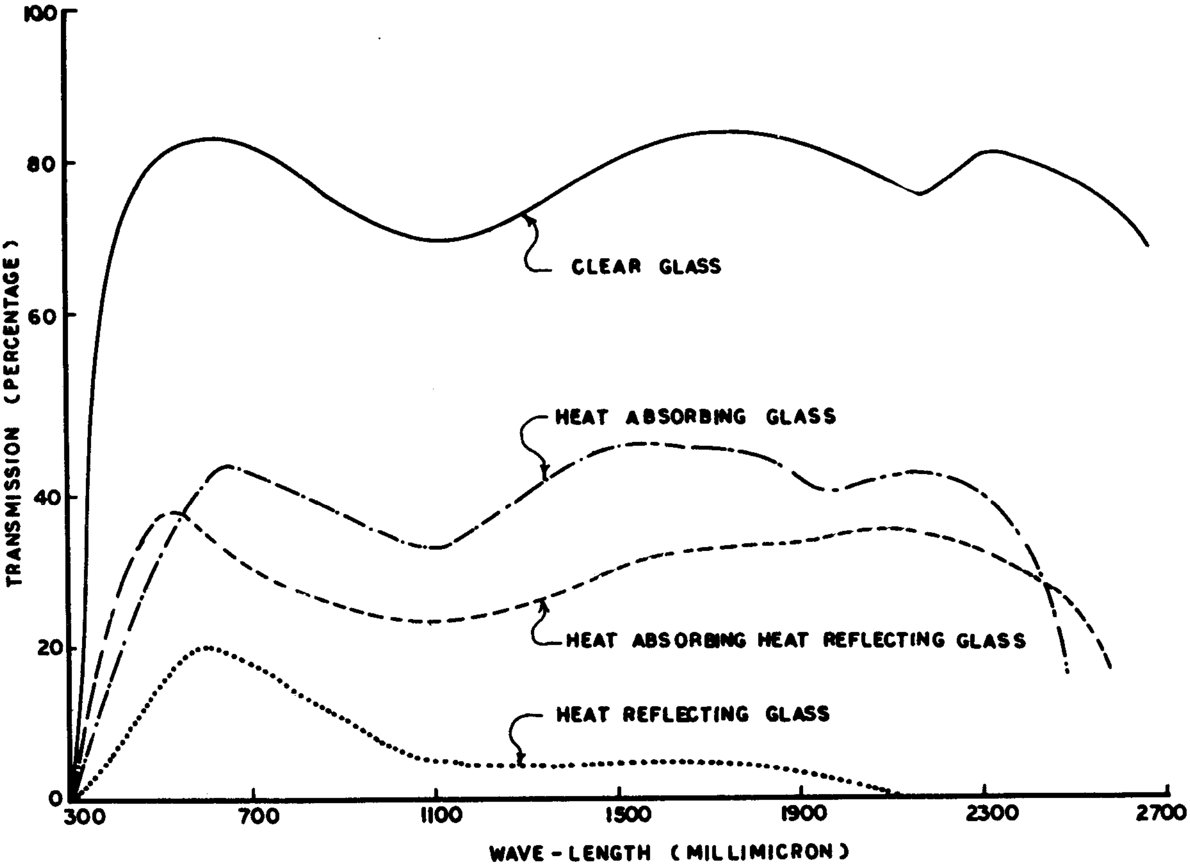


FIG. 2 TRANSMISSION CHARACTERISTICS OF VARIOUS TYPES OF GLASSES

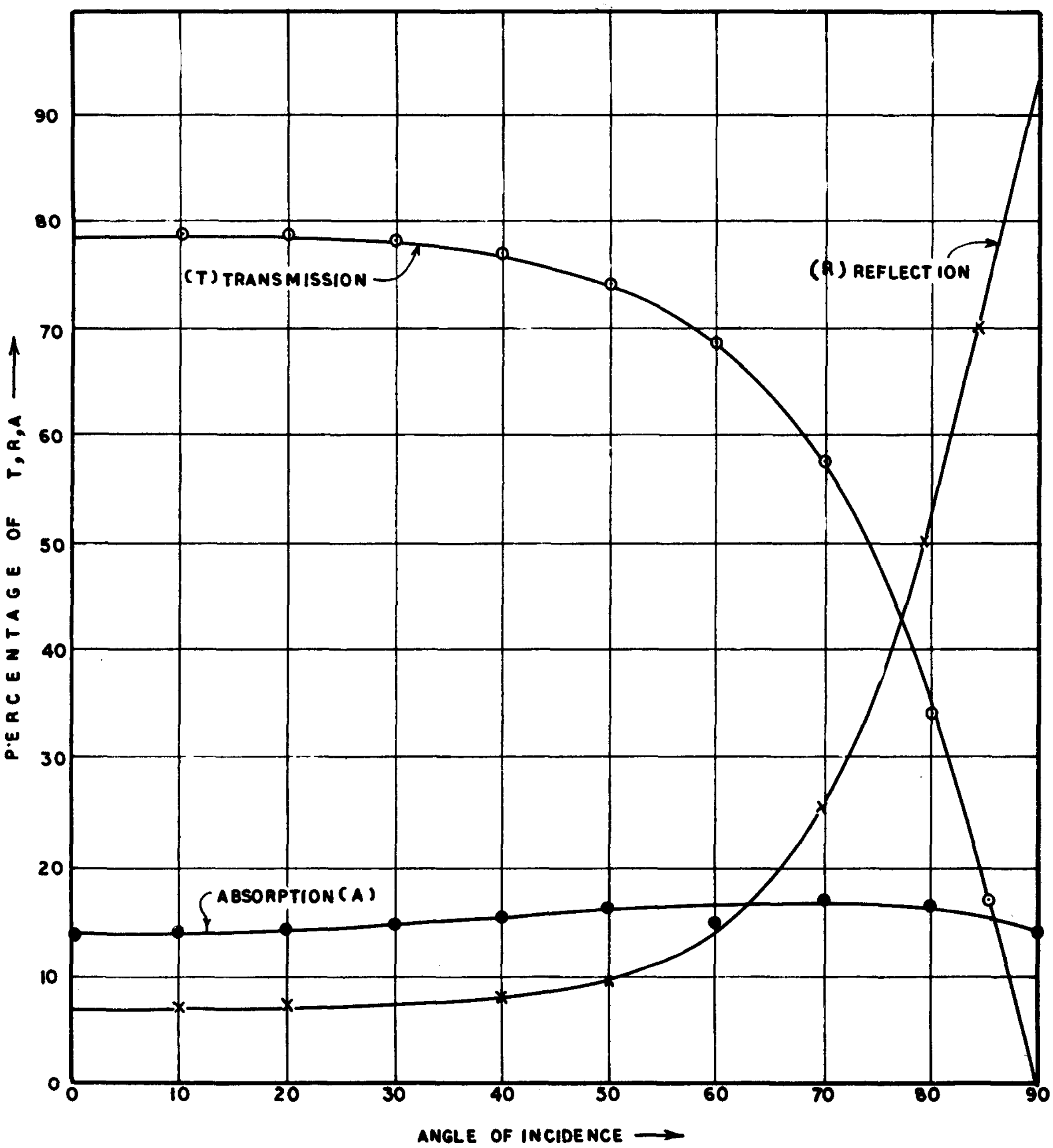


FIG. 3 VARIATION OF TRANSMISSION, ABSORPTION AND REFLECTION FOR 3.0 mm CLEAR PLATE GLASSES

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)	(4)	(5)
		cm	(4)	(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

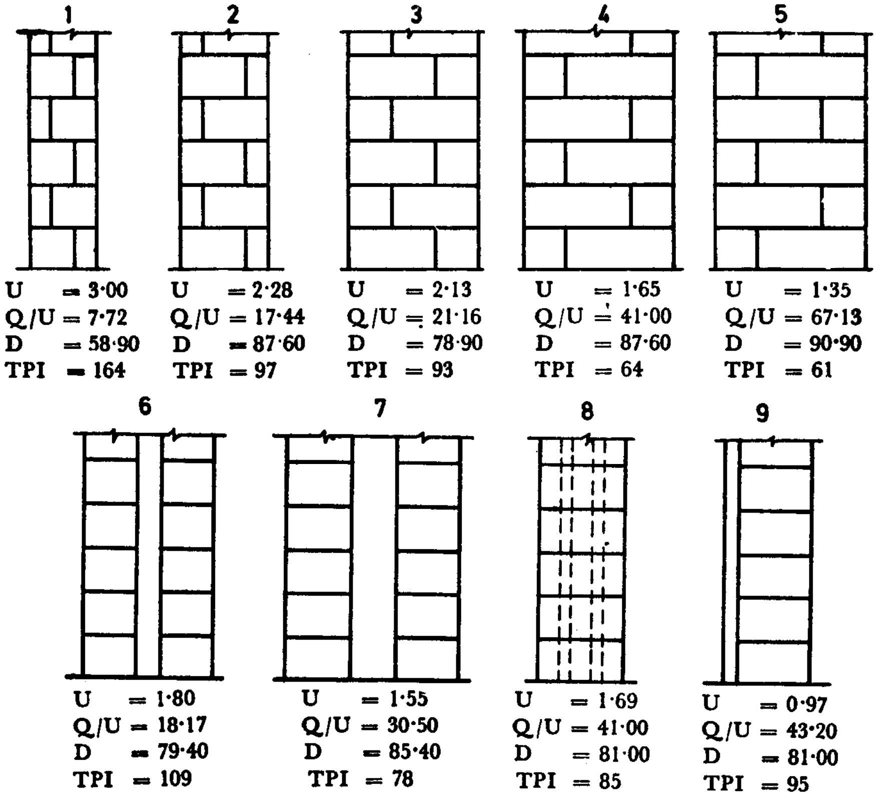
average value of f_i for building material surface is about 9.30 W/m^2K for still air and for wind velocity of 8.0 km/h, f_o is 19.90 W/m^2K.

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 ($\alpha = 0.7$). 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.

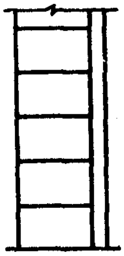


U = Transmittance [$W/(m^2K)$] Q/U = Thermal Time Constant (hours)
D = Damping (percentage) TPI = Thermal Performance Index (percentage

4A THERMAL PERFORMANCE OF WALLS

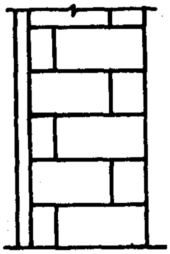
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS—*Contd.*

10



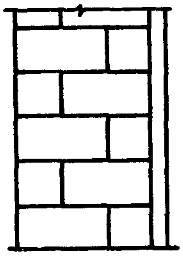
U = 0·97
Q/U = 11·30
D = 89·00
TPI = 92

11



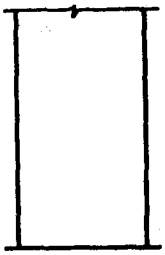
U = 0·85
Q/U = 52·00
D = 85·80
TPI = 79

12



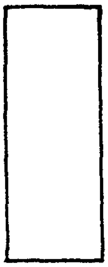
U = 0·85
Q/U = 16·70
D = 92·40
TPI = 82

13



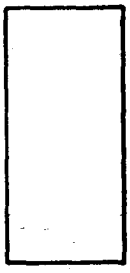
U = 2·09
Q/U = 31·90
D = 75·00
TPI = 102

14



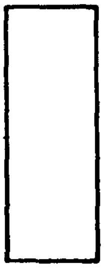
U = 4·12
Q/U = 12·5
D = 41
TPI = 223

15



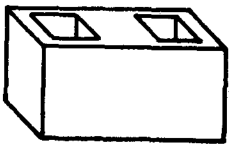
U = 3·29
Q/U = 14 0
D = 56
TPI = 173

16



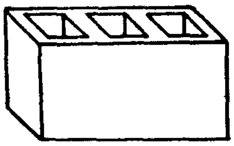
U = 2·12
Q/U = 14·00
D = 57·00
TPI = 112

17



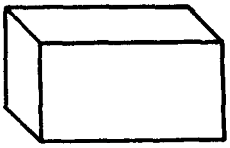
U = 3·01
Q/U = 14·50
D = 61·00
TPI = 136

18



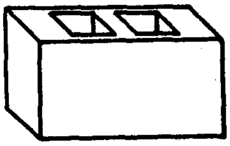
U = 2·79
Q/U = 12·00
D = 67·00
TPI = 131

19



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

20



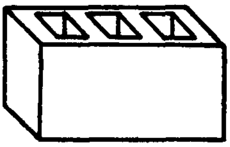
U = 2·07
Q/U = 40·00
D = 81·00
TPI = 101

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

4A THERMAL PERFORMANCE OF WALLS

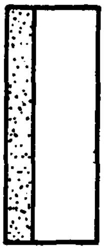
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*

21



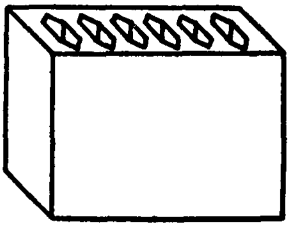
U = 1·93
Q/U = 18·00
D = 73·00
TPI = 107

22



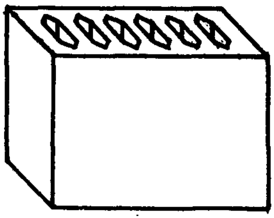
U = 0·99
Q/U = 45·00
D = 80·00
TPI = 90

23



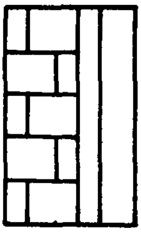
U = 3·27
Q/U = 14·00
D = 57·00
TPI = 214

24



U = 2·56
Q/U = 18·0
D = 68·0
TPI = 132

25

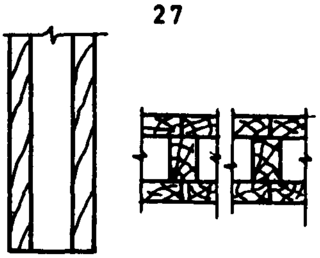


U = 0·80
Q/U = 56·40
D = 86·00
TPI = 79

26

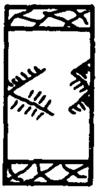
U = 3·47
Q/U = 6·50
D = 32 0
TPI = 103

27



U = 1·03
Q/U = 28·0
D = 82·0

28



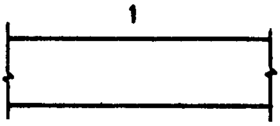
U = 4·88 to 6·28
Q/U = 4·90
D = 30

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

4A THERMAL PERFORMANCE OF WALLS

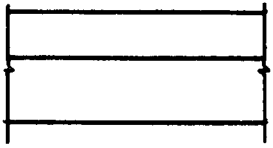
FIG. 4 THERMAL PERFORMANCE OF SOME TYPICAL CONSTRUCTIONS AND BUILDING COMPONENTS — *Contd.*

1



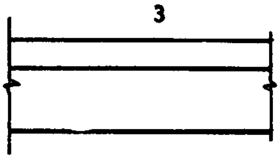
U = 3·59
Q/U = 4·30
D = 30·0
TPI = 184

2



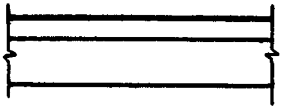
U = 2·78
Q/U = 10·30
D = 71·00
TPI = 131

3



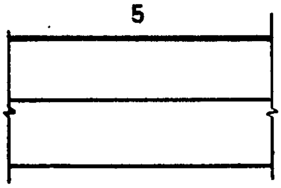
U = 1·08
Q/U = 59·0
D = 88·0
TPI = 70

4



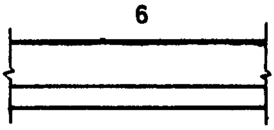
U = 1·08
Q/U = 1·80
D = 84·0
TPI = 64

5



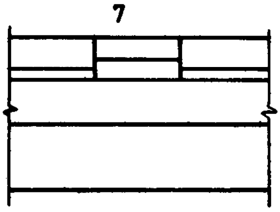
U = 0·62
Q/U = 40·0
D = 83 0
TPI = 61

6



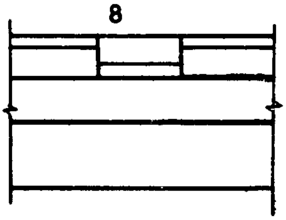
U = 1·09
Q/U = 21·0
D = 78·0
TPI = 72

7



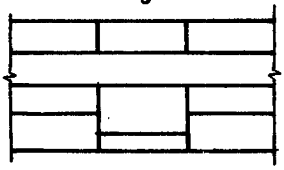
U = 2·07
Q/U = 14·00
D = 85·0
TPI = 90

8



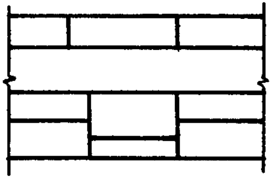
U = 1·76
Q/U = 15·0
D = 85·0
TPI = 80

9



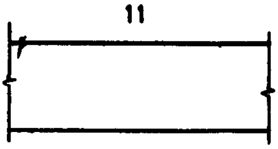
U = 2·31
Q/U = 24·50
D = 87·30
TPI = 84

10



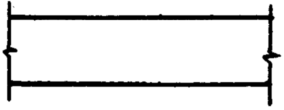
U = 2·01
Q/U = 31·20
D = 91·30
TPI = 84

11



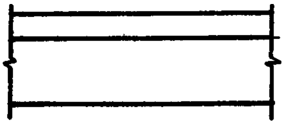
U = 3·15
Q/U = 22·70
D = 75·0
TPI = 125

12



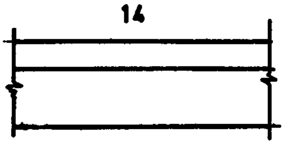
U = 2·99
Q/U = 14·50
D = 73·0
TPI = 115

13



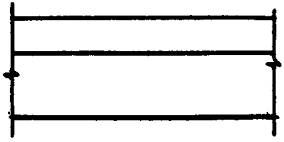
U = 2·21
Q/U = 22·70
D = 73·0
TPI = 125

14



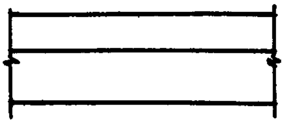
U = 2·14
Q/U = 14·50
D = 73 00
TPI = 115

15



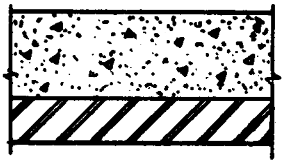
U = 2·27
Q/U = 16·50
D = 69·00
TPI = 104

16



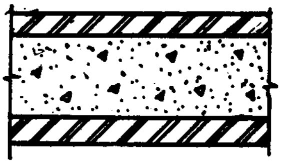
U = 2·13
Q/U = 16·50
D = 76·0
TPI = 95

17



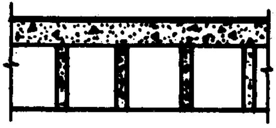
U = 3·07
Q/U = 12·60
D = 49·0
TPI = 173

18



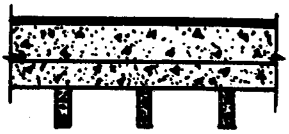
U = 3·65
Q/U = 6·70
D = 43·0
TPI = 181

19



U = 2·45
Q/U = 10·70
D = 53 0
TPI = 123

20

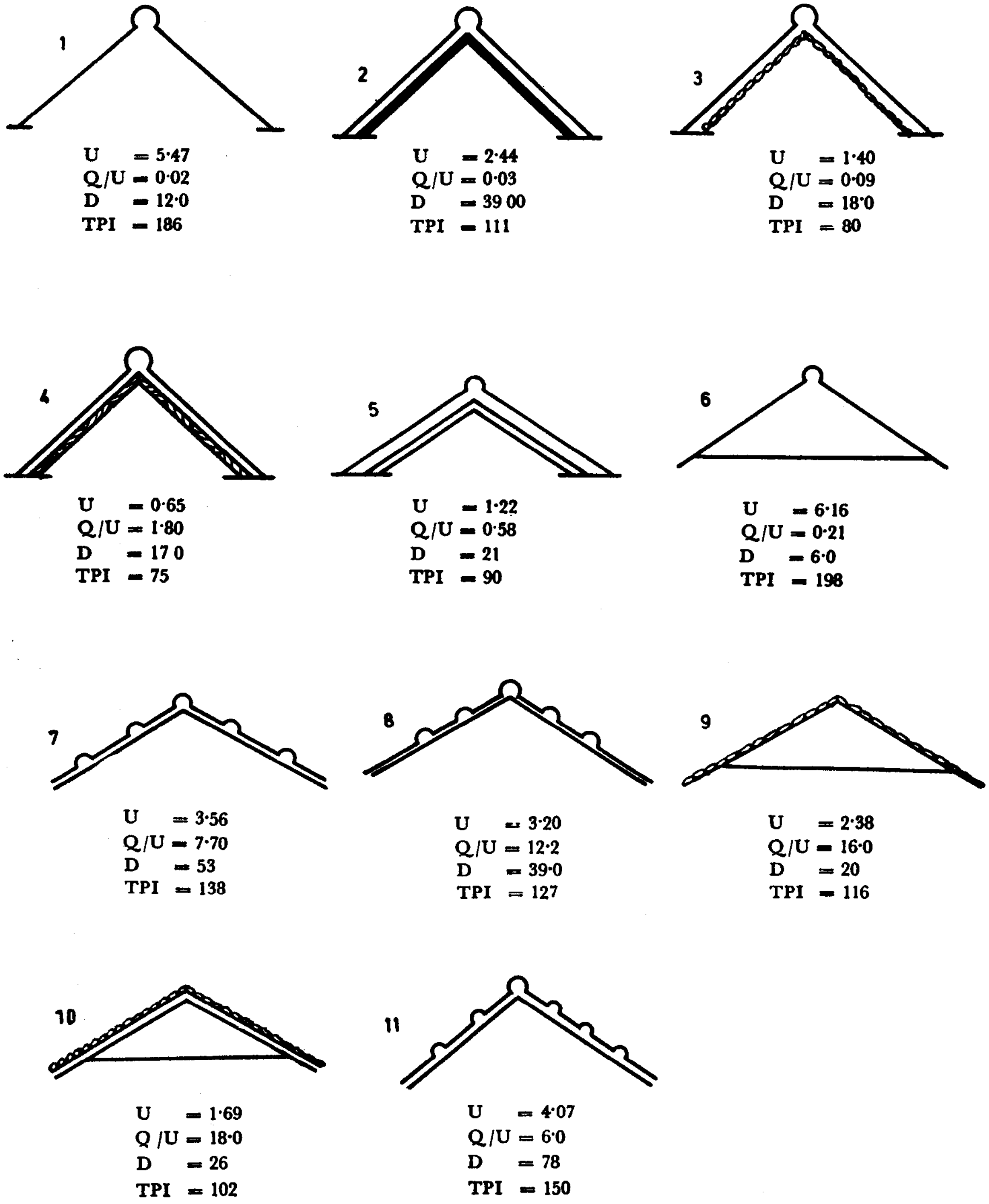


U = 4·02
Q/U = 3·50
D = 20·0
TPI = 211

U = Transmittance [W/(m²K)] 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.*



1

U = 5·47
Q/U = 0·02
D = 12·0
TPI = 186

2

U = 2·44
Q/U = 0·03
D = 39 00
TPI = 111

3

U = 1·40
Q/U = 0·09
D = 18·0
TPI = 80

4

U = 0·65
Q/U = 1·80
D = 17 0
TPI = 75

5

U = 1·22
Q/U = 0·58
D = 21
TPI = 90

6

U = 6·16
Q/U = 0·21
D = 6·0
TPI = 198

7

U = 3·56
Q/U = 7·70
D = 53
TPI = 138

8

U = 3·20
Q/U = 12·2
D = 39·0
TPI = 127

9

U = 2·38
Q/U = 16·0
D = 20
TPI = 116

10

U = 1·69
Q /U = 18·0
D = 26
TPI = 102

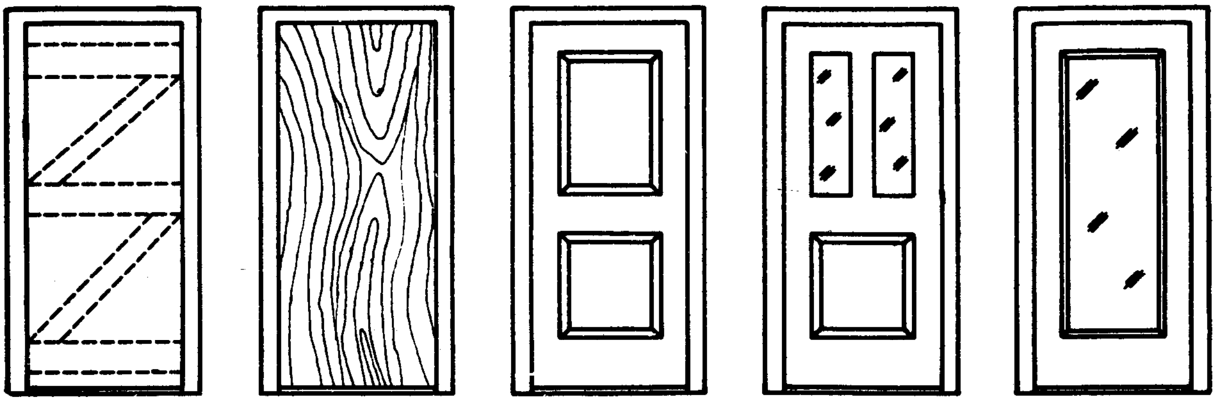
11

U = 4·07
Q/U = 6·0
D = 78
TPI = 150

U = Transmittance [W/(m^2K)]   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.*



U = 4·83
5A Door Ledged and Braced

U = 4·83
5B Door Flush Single Hung

U = 4·83
5C Door Panelled

U = 5·18
5D Door Panelled and Glazed

U = 5·68
5E Door Glazed

U = 5·12
5F Window Glazed

U = 5·23
5G Metal Window

U = Overall Thermal Transmittance

4D THERMAL TRANSMITTANCE OF DOORS AND WINDOWS

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

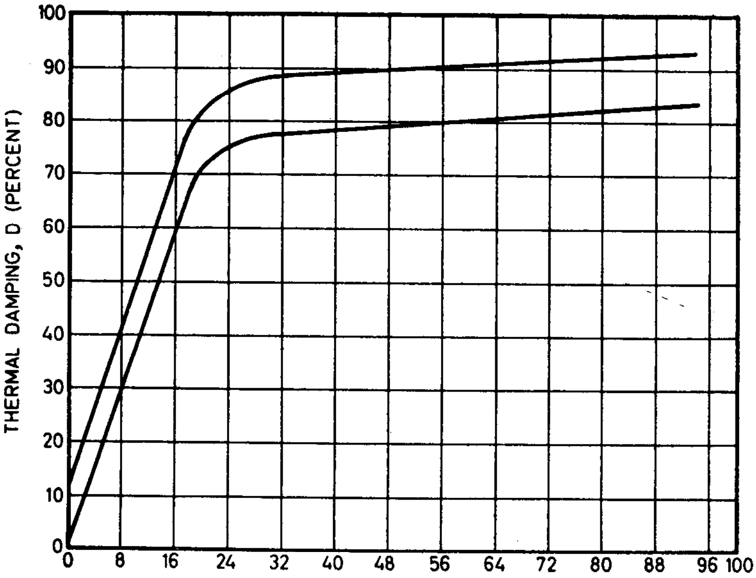


FIG. 5 LIMITING CURVES SHOWING RELATIONSHIP BETWEEN THERMAL TIME CONSTANT IN HOURS AND THERMAL DAMPING IN PERCENT

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) $W/(m^2.K)$	(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)	(4)	(5)	(6)
		$W/(m^2.K)$	h	percent	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)	(4)	(5)	(6)
		$W/(m^2.K)$	h	percent	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:

$$\text{Peak surface temperature} = 30 + 0.08 \times TPI \ (^\circ\text{C})$$

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

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		Maximum Thermal Conductivity Value	Optimum Thickness			
		Min	Max		Flat Roof		Sloped Roof	
					UC	C	UC	C
(1)	(2)	(3) kg/m^3	(4) kg/m^3	(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/m^2. 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

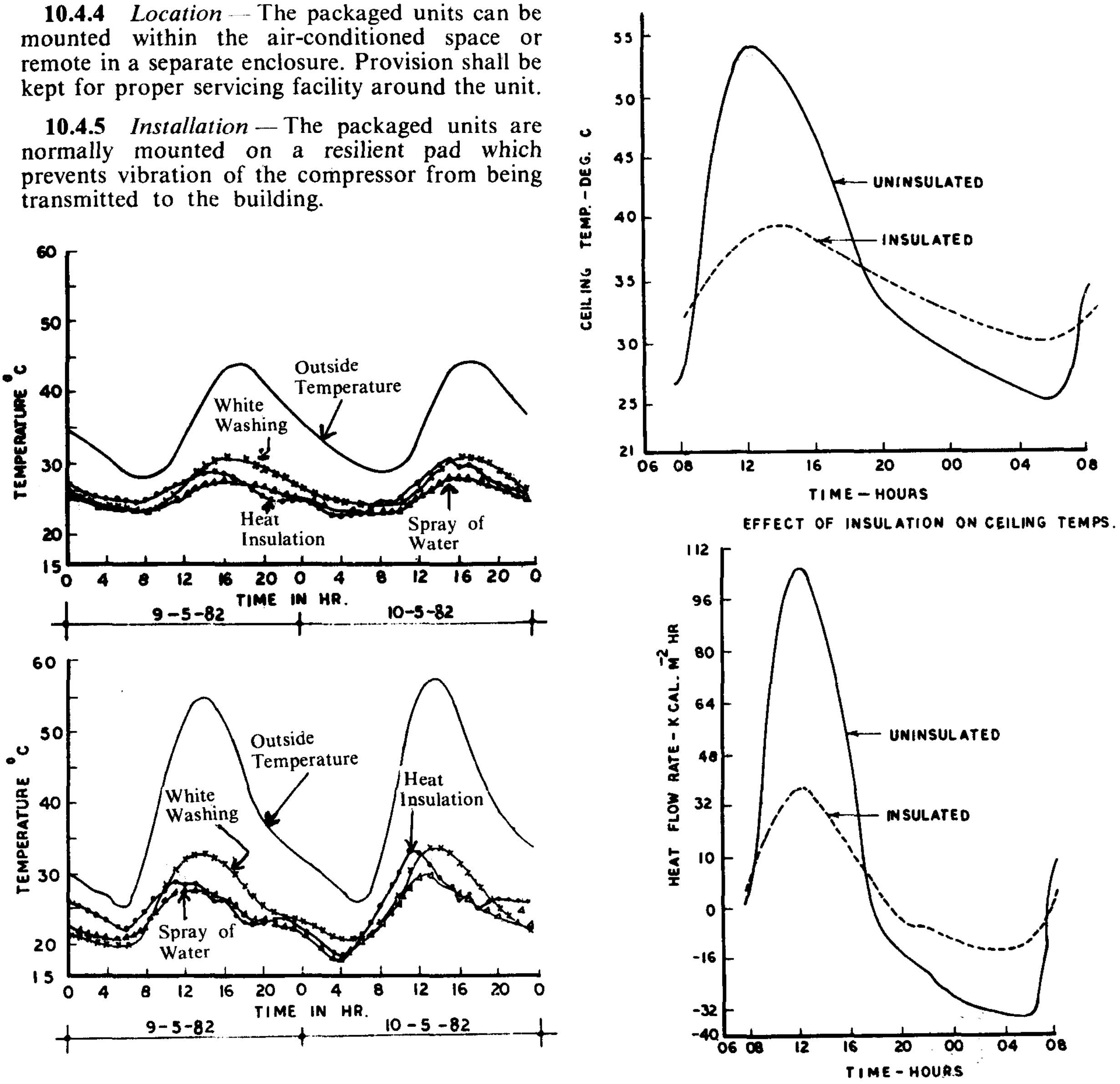
(*Clause* 9.4)

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 m³/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

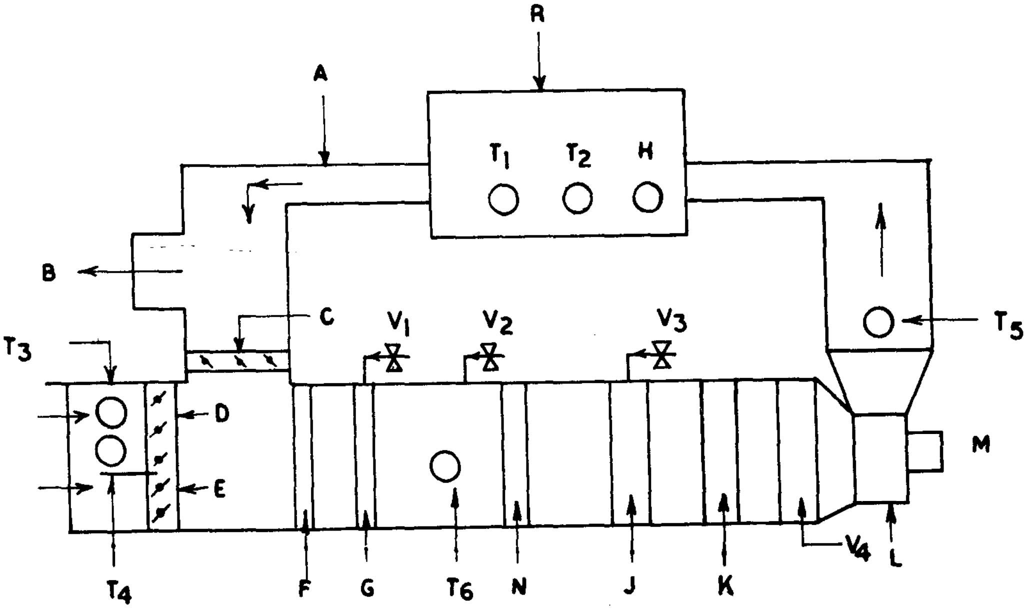
(*Clause* 10.8.3)

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)

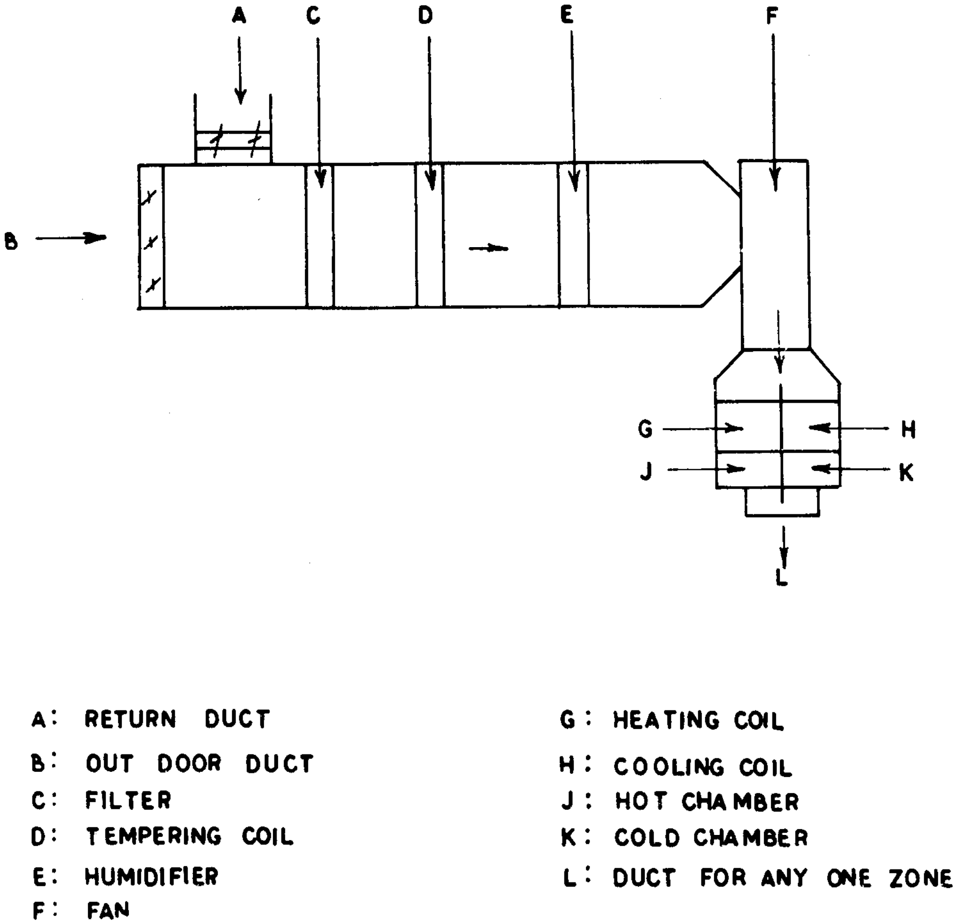
SL No.	OPTIMUM CONDITIONS		MAXIMUM CONDITIONS	
	Dry Bulb Temperature	Wet Temperature	Dry Bulb Temperature	Wet Bulb Temperature
(1)	(2) °C	(3) °C	(4) °C	(5) °C
i)	21.4	17.8	18.3	15.0
ii)	21.7	17.3	18.9	13.4
iii)	22.2	16.4	19.4	12.0
iv)	22.8	15.3	19.7	10.8
v)	23.3	14.4	—	—
vi)	23.6	13.4	—	—



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/(m^{2}K)	
b) Inside film coefficient at still air (f_i)	9.36 W/(m^{2}K)	
c) Enclosed air space conductance [W/(m^{2}K)]	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

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

Example 4

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

Solution

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

$k_2 = 0.811$ W/(mK)

$k_3 = 0.721$ 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) $U = \frac{1}{R_T} = \frac{1}{0.419\,3} = 2.385$ W/(m^{2}K)

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) $k_1 = k_5 = 0.721$ W/(mK)

$k_2 = k_4 = 0.811$ W/(mK)

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

$C_3 = 6.22$ W/(m^{2}K) (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) $U = \frac{1}{R_T} = \frac{1}{0.567\,8} = 1.761$ W/(m^{2}K)

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) $k_1 = k_2 = 0.721$ W/(mK)

$k_2 = 0.811$ W/(mK)

$k_3 = 0.035$ 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) $k_1 = k_3 = 0.721 \ \text{W/(mK)}$

$k_2 = 1.58 \ \text{W/(mK)}$

$L_1 = 0.01 \ \text{m}, \ L_2 = 0.15 \ \text{m}, \ L_3 = 0.01 \ \text{m}$

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

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

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

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

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

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) $k_1 = 0.798 \ \text{W/(mK)}$

$k_2 = 0.035 \ \text{W/(mK)}$

$k_3 = 1.58 \ \text{W/(mK)}$

$k_4 = 0.721 \ \text{W/(mK)}$

$L_1 = 0.04 \ \text{m}, \ L_2 = 0.05 \ \text{m}, \ L_3 = 0.15 \ \text{m}, \ L_4 = 0.01 \ \text{m}$

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

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

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

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

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

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

2) $R_T = 1.744\,7\,7$

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) $k_1 = k_3 = 0.721 \ \text{W/(mK)}$

$k_2 = 1.58 \ \text{W/(mK)}$

$k_5 = k_7 = 0.047 \ \text{W/(mK)}$

$C_4 = C_6 = 6.22 \ \text{W/(mK)}^2$ (fo82)

$L_1 = 0.01 \ \text{m}, \ L_2 = 0.15 \ \text{m}, \ L_3 = 0.01 \ \text{m}, \ L_5 = 0.012 \ \text{m},$

$L_7 = 0.012 \ \text{m}$

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

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

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

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

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

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

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

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

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

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

$L = 0.01$ m

$k = 0.721$ W/(mK)

$\rho = 1\,648$ kg/m^3

$c = 0.84$ kJ/(kgK)

2) For brick

$L = 0.19$ m

$k = 0.811$ W/(mK)

$\rho = 1\,820$ kg/m^3

$c = 0.88$ kJ/(kgK)

3) For plaster

$L_1 \rho_1 c_1 = 0.01 \times 1\,648 \times 0.84$

$= 13.843$ kJ/(m^{2}K)

$= 13\,843$ Ws/(m^{2}K)

$$\frac{L_1}{k_1} = \frac{0.01}{0.721} = 0.013\,9 \text{ m}^2\text{K/W}$$

4) For brick

$L_2 \rho_2 c_2 = 0.19 \times 1\,820 \times 0.88$

$= 304.304$ kJ/(m^{2}K)

$= 304/304$ Ws/m^2.K

$$= \frac{0.19}{0.811} = 0.234\,3 \text{ m}^2\text{K/W}$$

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

$$= \frac{1}{f_o} + \frac{L_1}{2k_1}(L_1 \rho_1 c_1) + \frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{2k_2} \times$$

$$(L_2 \rho_2 c_2) + \frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{2k_3} \times (L_3 \rho_3 c_3)$$

$= (0.050\,4 + 0.006\,95) \times 13\,843 + (0.050\,4 + 0.013\,9 + 0.117\,15) \times 304\,304 + (0.050\,4 + 0.013\,9 + 0.234\,3 + 0.006\,95) \times 13\,843$

$= 0.057\,4 \times 13\,843 + 0.181\,5 \times 304\,304 + 0.305\,6 \times 13\,843$

$= 794.59 + 55\,231.18 + 4\,230.42$

$= 60\,256.19$ seconds

$\cong 17$ 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

$L_1 = 0.006\,25$ m

$k_1 = 0.245$ W/(mK)

$\rho_1 = 1\,520$ kg/m^3

$c_1 = 0.84$ kJ/(kgK)

$$\frac{L_1}{k_1} = \frac{0.006\,25}{0.245} = 0.025\,5$$

$L_1 \rho_1 c_1 = 0.006\,25 \times 1\,520 \times 0.84$
$\doteq 7.98$ kJ/(m^{2}K) $= 7\,980$ Ws/(m^{2}K)

2) For air gap

$(L_2 \rho_2 c_2) = 0$

3) For softboard

$L_3 = 0.012$ m

$k_3 = 0.047$ W/(mK)

$\rho_3 = 249$ kg/m^3

$c_3 = 1.30$ kJ/(kgK)

$$\frac{L_3}{k_3} = \frac{0.012}{0.047} = 0.255\,3$$

$L_3 \rho_3 c_3 = 0.012 \times 249 \times 1.3$

$\doteq 3.884\,4$ kJ/(m^{2}K)

$\doteq 3\,884.4$ Ws/(m^{2}K)

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

$$\left(\frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{2k_2}\right)(L_2 \rho_2 c_2) +$$

$$\left(\frac{1}{f_o} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{2k_3}\right)(L_3 \rho_3 c_3)$$

$= (0.050\,4 + 0\,012\,75) \times 7\,980 + 0 + (0.050\,4 + 0.025\,5 + 0 + 0.127\,65) \times 3\,884.4$

$= 0.063\,2 \times 7\,980 + 0.203\,6 \times 3\,884.4$

$= 503.94 + 790.86$

$= 1\,294.8$ seconds

$\cong 0.36$ 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) $= \frac{80 \times 46}{100}$

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

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

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

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.

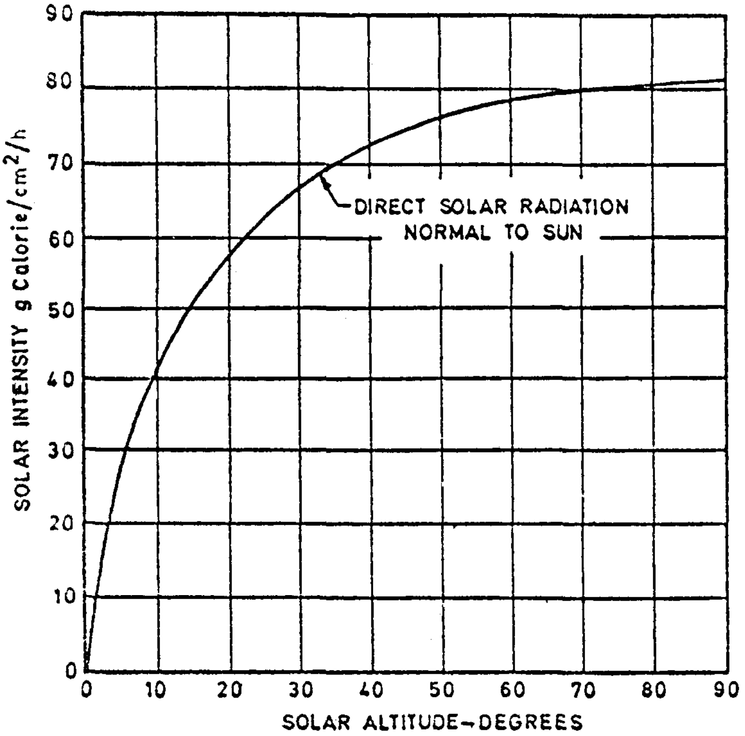


FIG. 9 DIRECT SOLAR INTENSITIES NORMAL TO SUN AT SEA LEVEL FOR STANDARD CONDITIONS (COMPUTED)

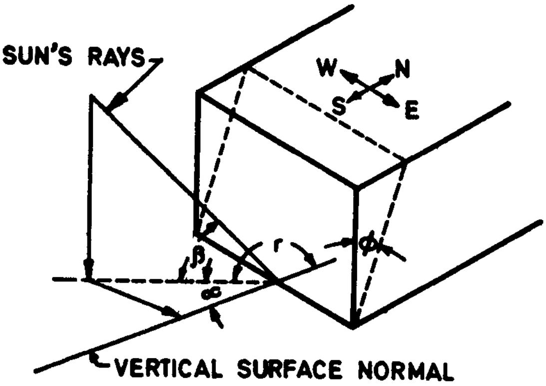


FIG. 10 DEFINITION OF SOLAR ANGLES

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)

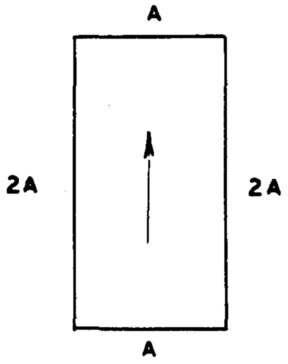
(*Clause* B-1.3)

		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 × A = 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.)

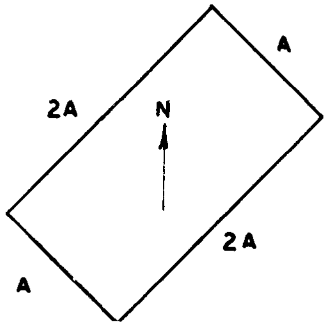
(*Clause* B-1.3)

		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



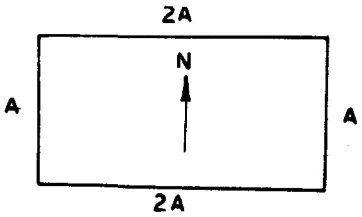
TYPE I

		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



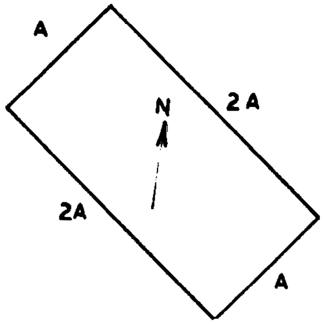
TYPE II

		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 m³ 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

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*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.

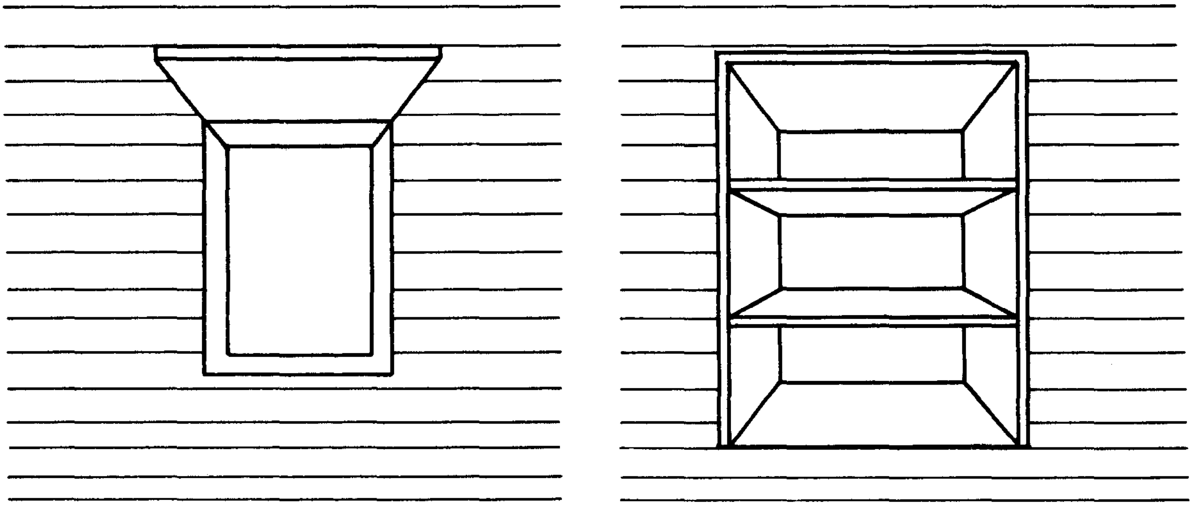
5.3.23 Ventilation conditions indoors can be ameliorated by constructing buildings on earth mound having a slant surface with a slope of 10° on upstream side.

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:

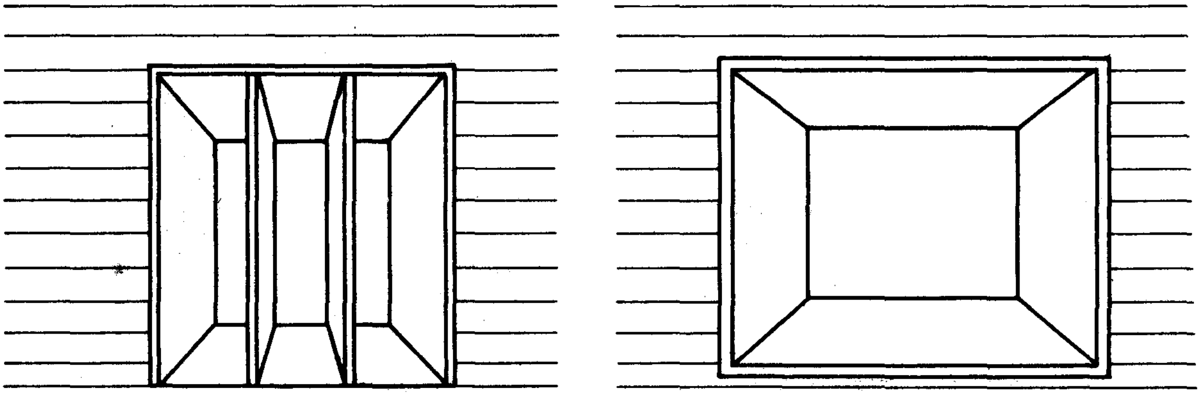
a) for health; and

b) for comfort.



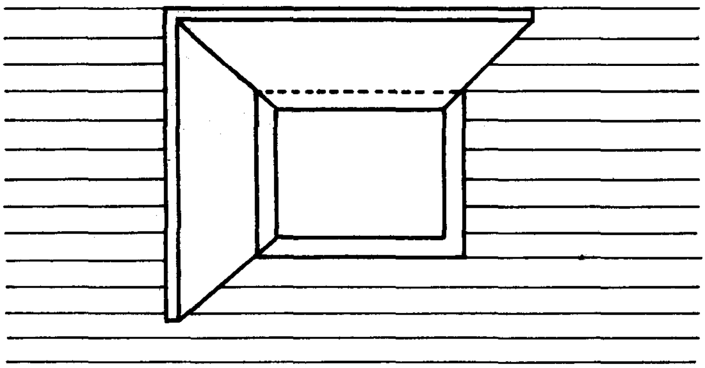
Horizontal Louver

Multiple Horizontal Louver



Multiple Vertical Louver

Box Type Louver



L - type Louver

FIG. 1A VARIOUS TYPES OF LOUVERS

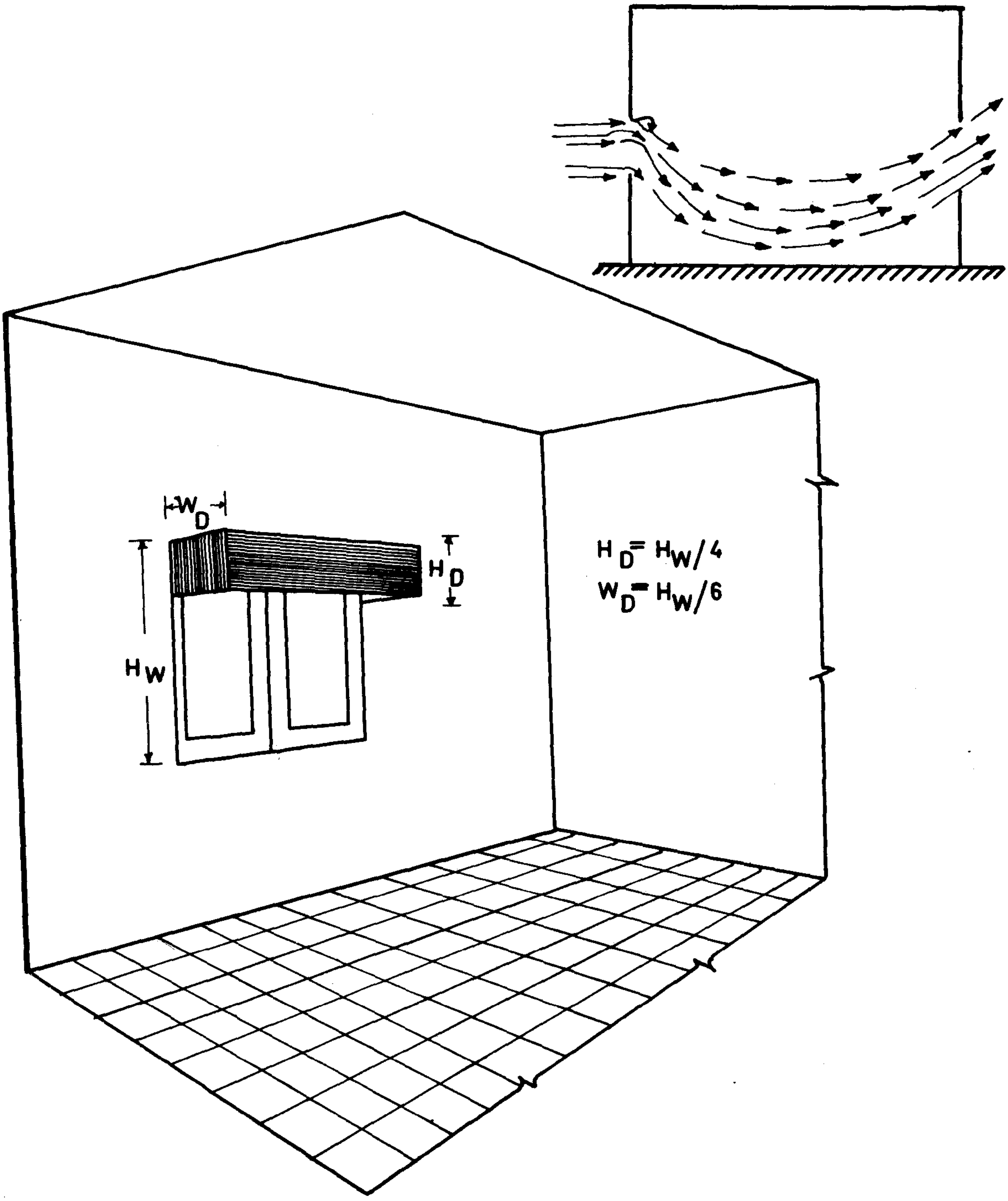
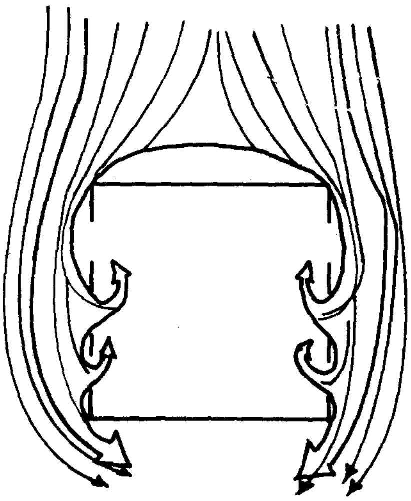


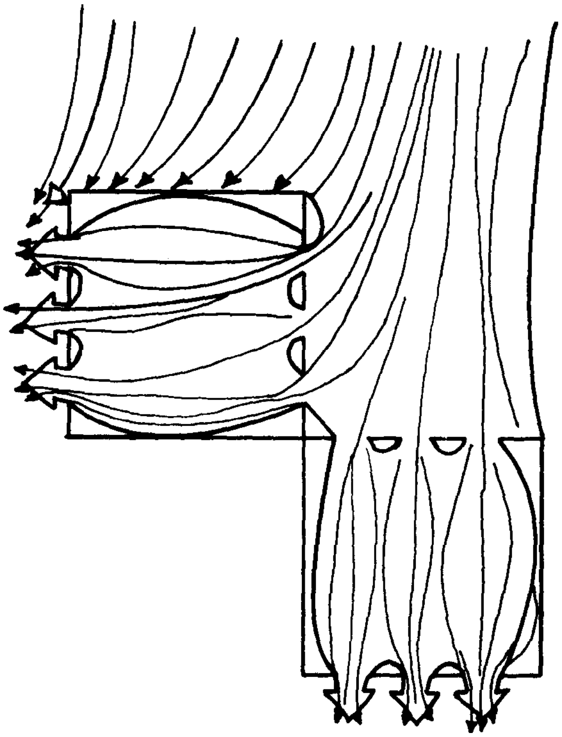
FIG. 1B SKETCH OF A PELMET TYPE WIND DEFLECTOR

(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

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

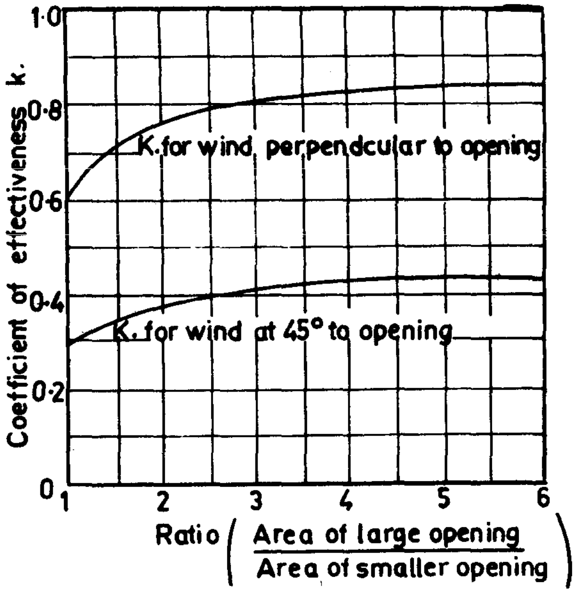


Fig. 3 Values of Coefficient of Effectiveness k for Flow Through Two Openings

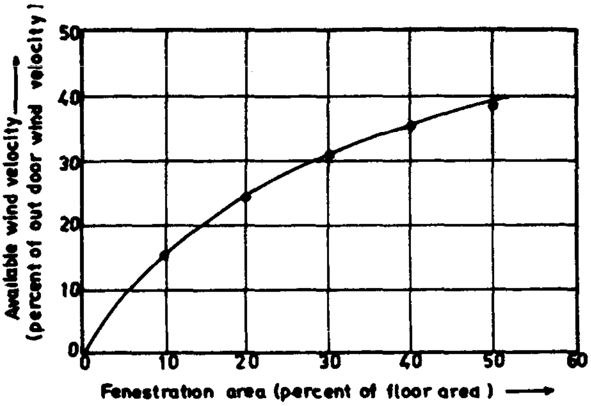


Fig. 4 Effect of Area of Openings on Average Indoor Wind Velocity

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.

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

$$V_s = V_{0.9} + 0.072\ (1 - 0.83)V_0$$
$$= V_{0.9} + 0.0123V_0$$

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

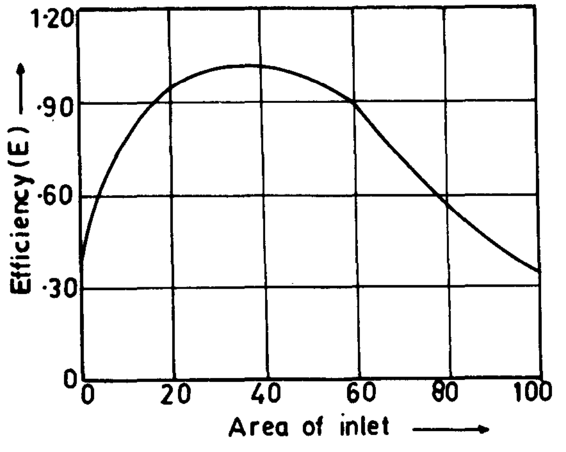


FIG. 5 EFFECT OF SIZE OF INLET ON THE PERFORMANCE EFFICIENCY

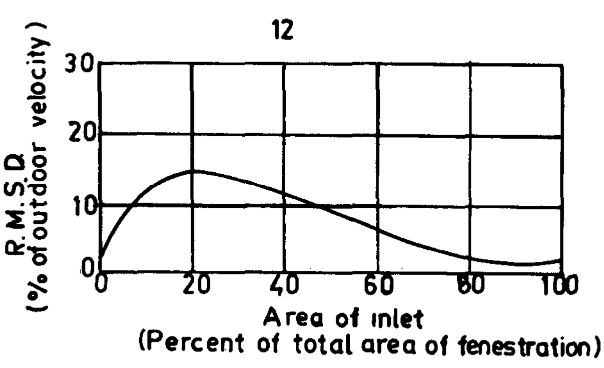


FIG. 6 EFFECT OF SIZE OF INLET ON ROOT MEAN SQUARE DEVIATIONS

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)

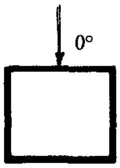
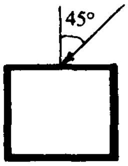
ORIENTATION → WINDOW LOCATION ↓	CHANGE IN v(% of v)	
		
	0	0
	−10	+40
	−10	−15
	−15	0
	−15	0
	0	0
	−10	+40
	−10	−15
	0	−60
	−20	−10
	−20	−60

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 m^2
= 31 percent of floor area.

∴ Indoor wind velocity ($V_{0.9}$) from Fig. 4 = 32 percent of outdoor velocity (V_0)

ii) $\frac{\text{Size of inlet} \times 100}{\text{Total area of fenestration}} = 45$ 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 m^2) having inlet of 2.1×1.2 m^2 and outlet of 2.2×1.1 m^2. 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 m^2
Size of outlet = 2.42 m^2
Floor area = 15.12 m^2
Total area of fenestration = 4.94 m^2
= 32.7 percent of floor area.

∴ Indoor wind speed, V_1 from Fig. 4 is equal to 32.2 percent of outdoor wind.

ii) $\frac{\text{Size of inlet}}{\text{Total area of fenestration}} = 0.51$ 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.

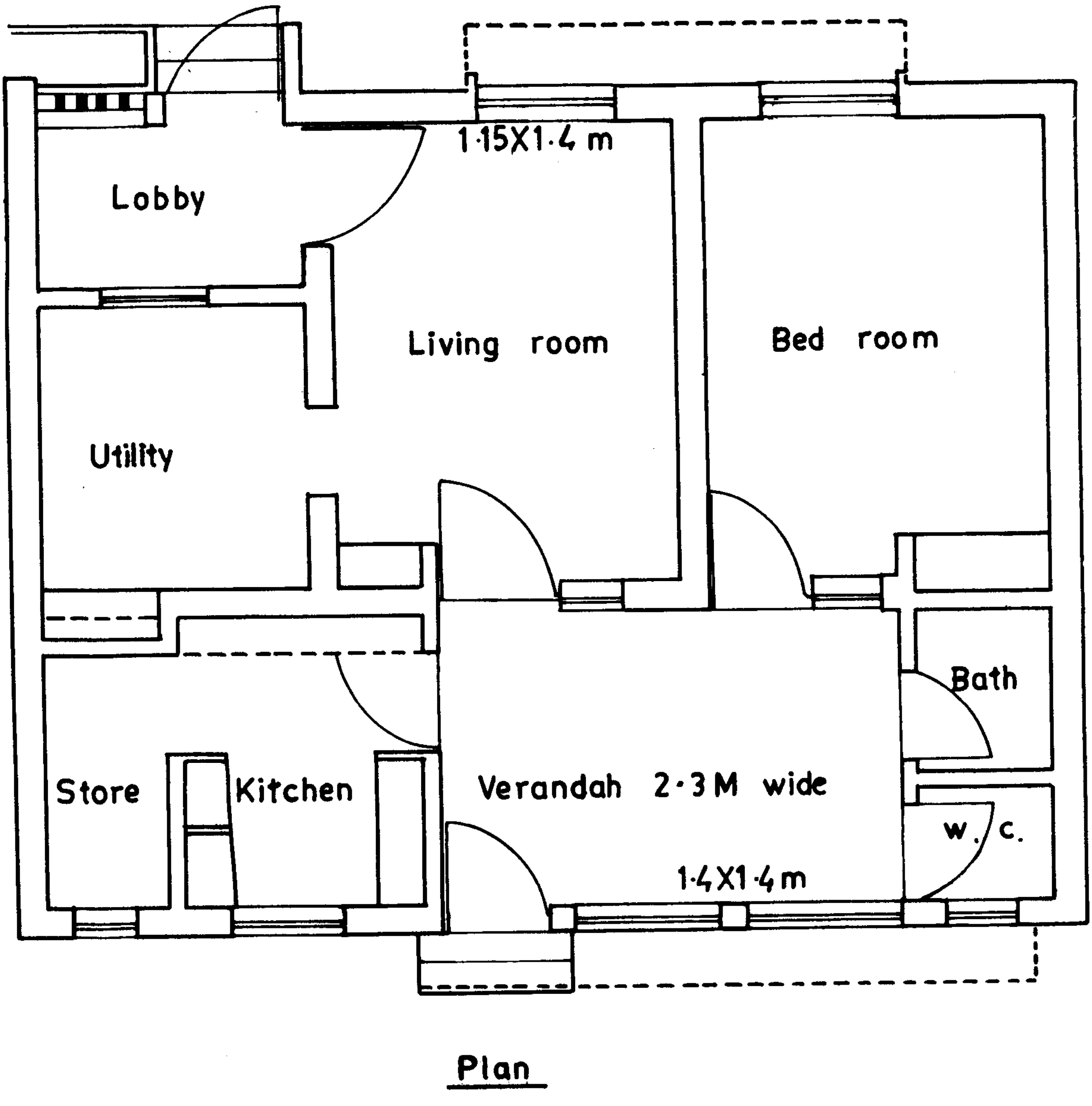
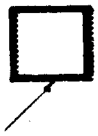
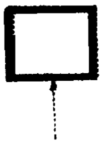
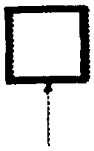
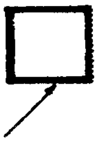


FIG. 7 PLAN OF A TYPICAL TWO ROOM HOUSE

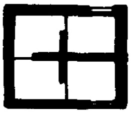
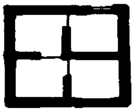
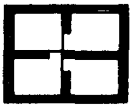
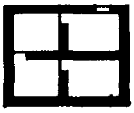
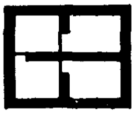
TABLE 8 EFFECT OF LOCATION OF INTER-CONNECTING DOORS ON AIR MOTION IN ROOMS

(*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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SCHOOL OF BUILDING AND ENVIRONMENT
DEPARTMENT OF ARCHITECTURE

UNIT – IV - BUILDING ENERGY CODES AND STANDARDS – SARA 5132

UNIT 4

FUNCTIONAL EFFICIENCY OF BUILDINGS – LIGHTING

Lighting – standards, general, illumination requirement, day lighting analysis, supplementary artificial lighting design, artificial lighting design, energy conservation

Objective: To devise the applicability of the methodologies prescribed in the codes

Methodology:

Lighting – standards, general, illumination requirement, day lighting analysis, supplementary artificial lighting design, artificial lighting design, energy conservation	Presentation & Lecture Discussion & Calculation sessions. Kahoot

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.

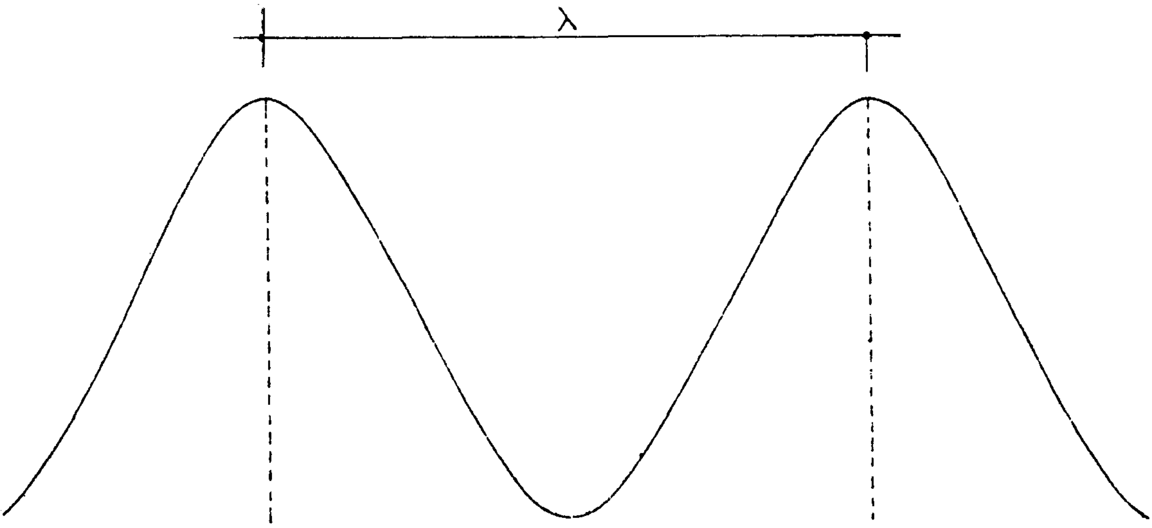


FIG. 1 CONCEPT OF WAVELENGTH IN WAVE PROPAGATION

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

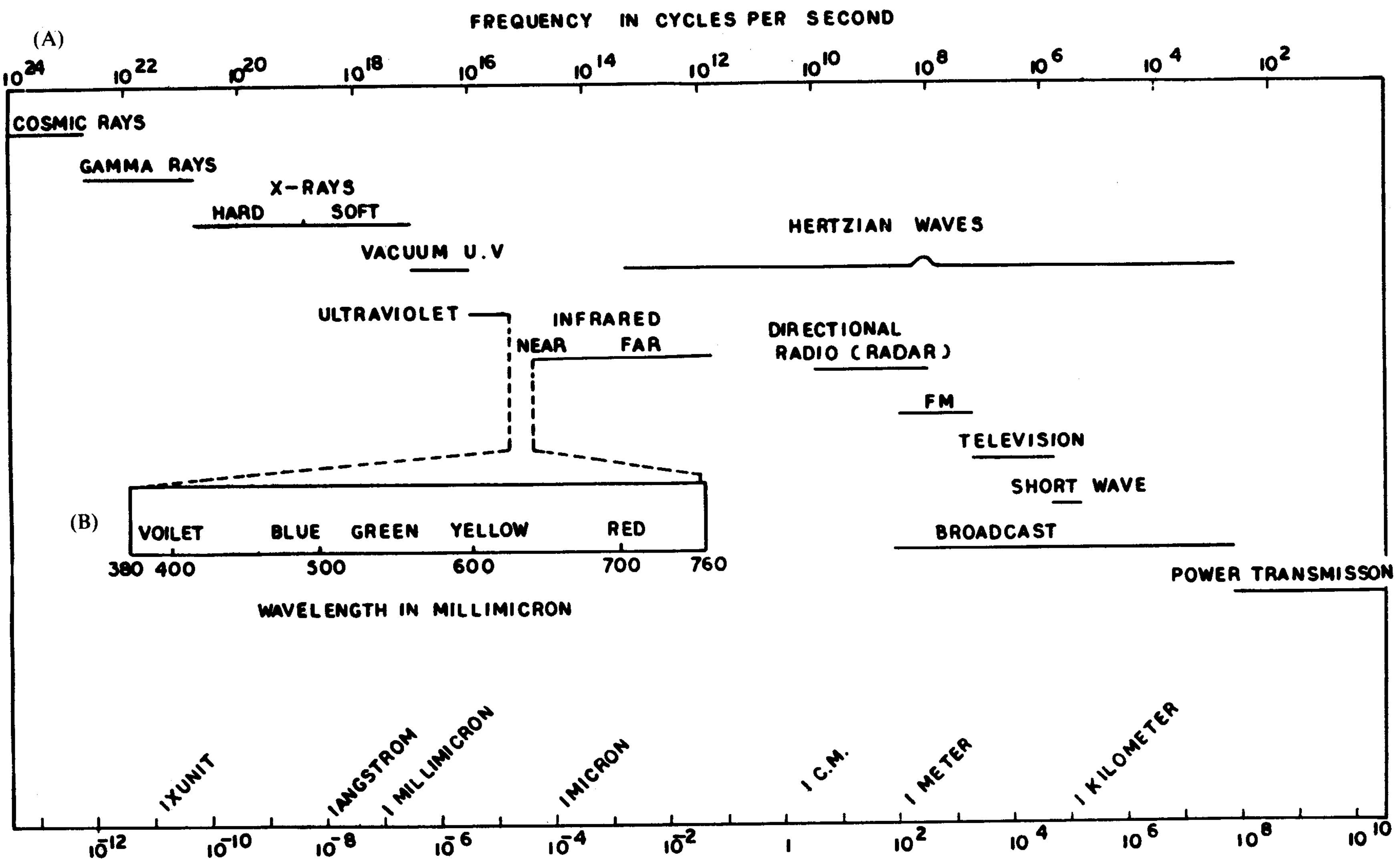


FIG. 2 LIGHT SPECTRUMS: (A) ELECTROMAGNETIC SPECTRUM AND (B) VISIBLE SPECTRUM

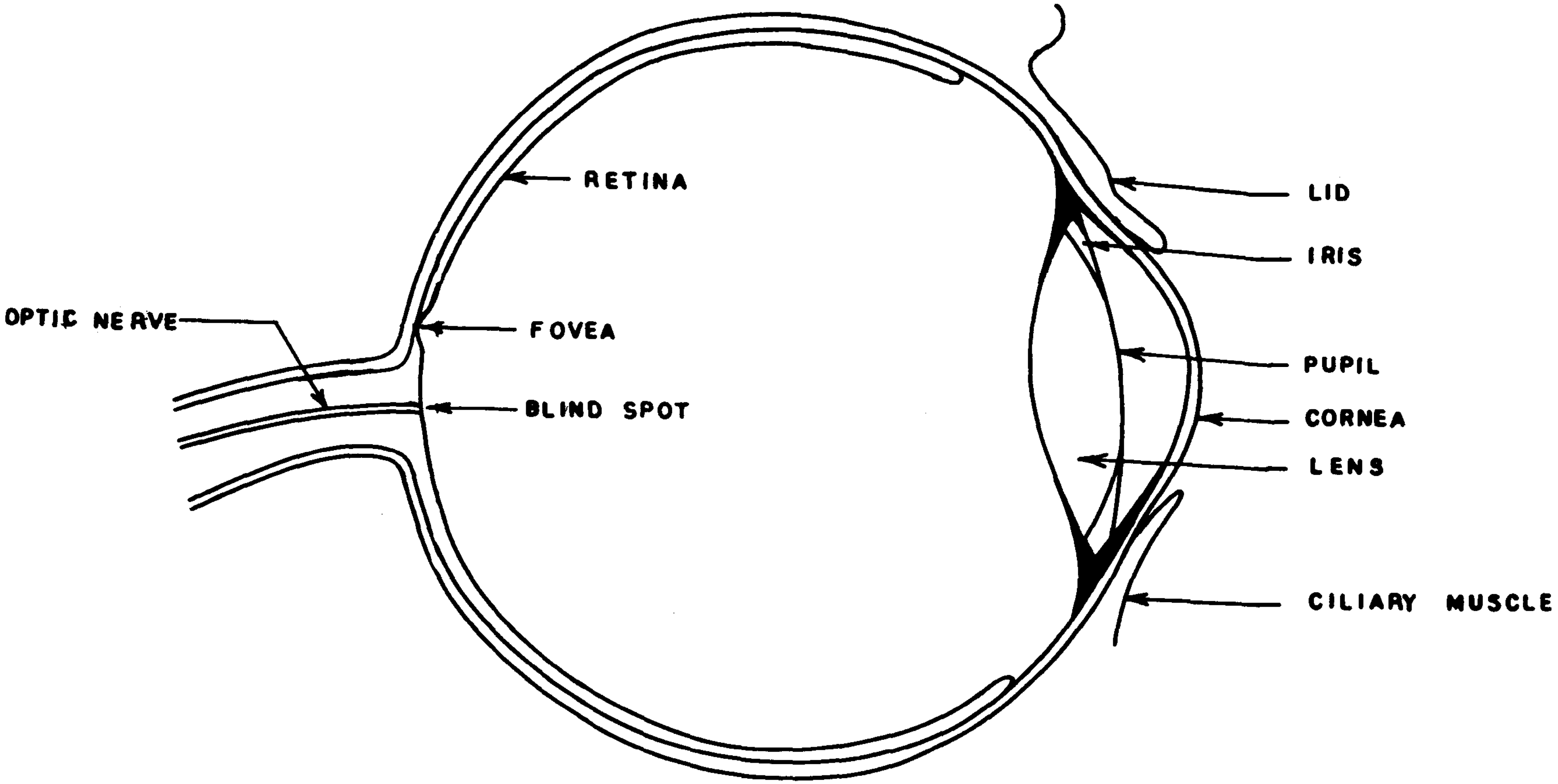


FIG. 3 VERTICAL CROSS-SECTION OF THE HUMAN EYE

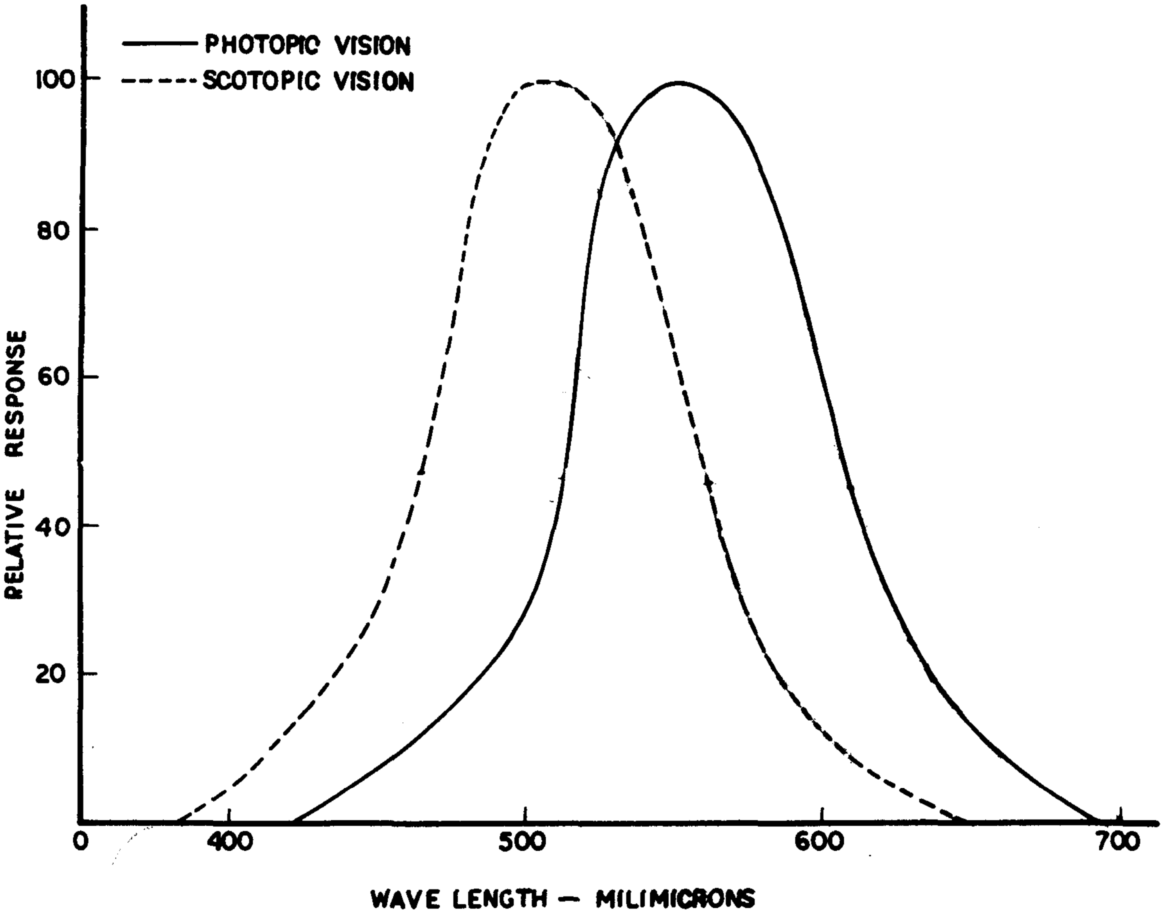


FIG. 4 RELATIVE SPECTRAL SENSITIVITY OF HUMAN EYE FOR PHOTOPIC AND SCOTOPIC VISION

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

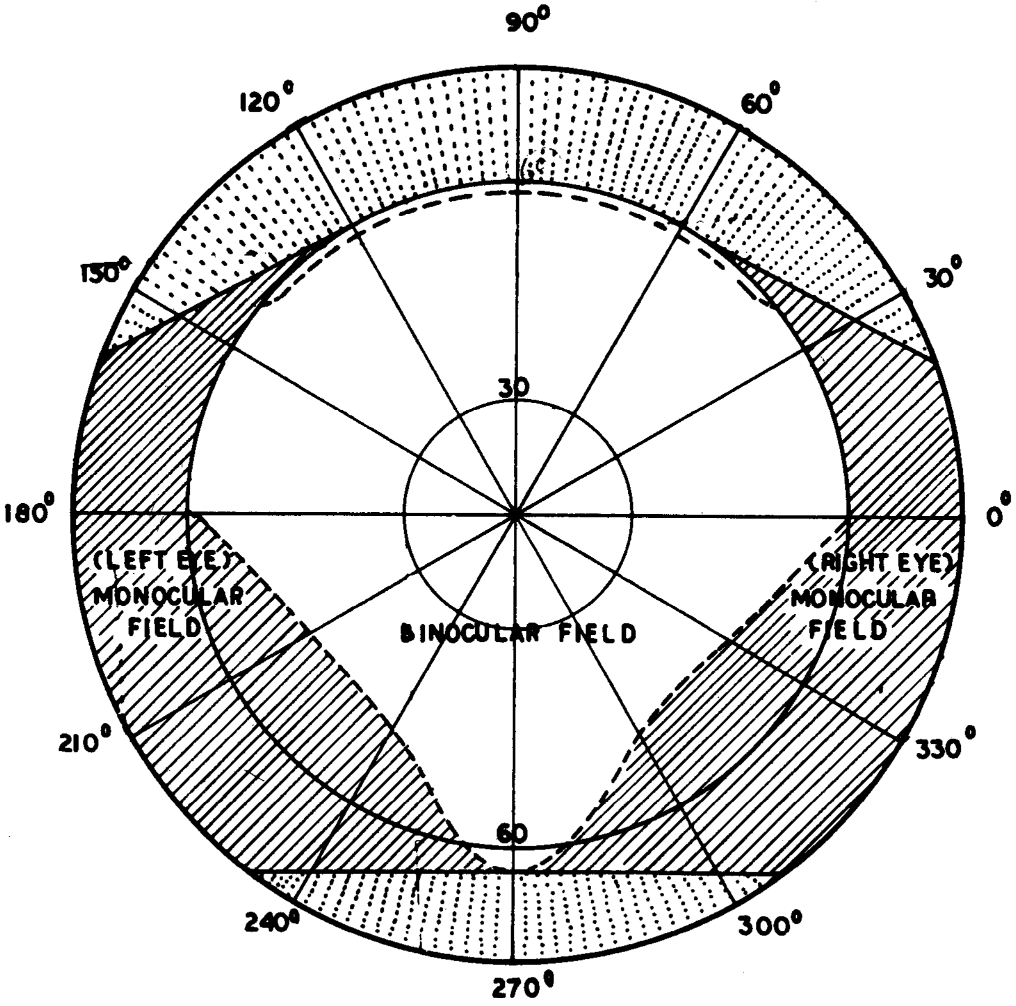


FIG. 5 BINOCULAR VISUAL FIELD OF HUMAN EYE

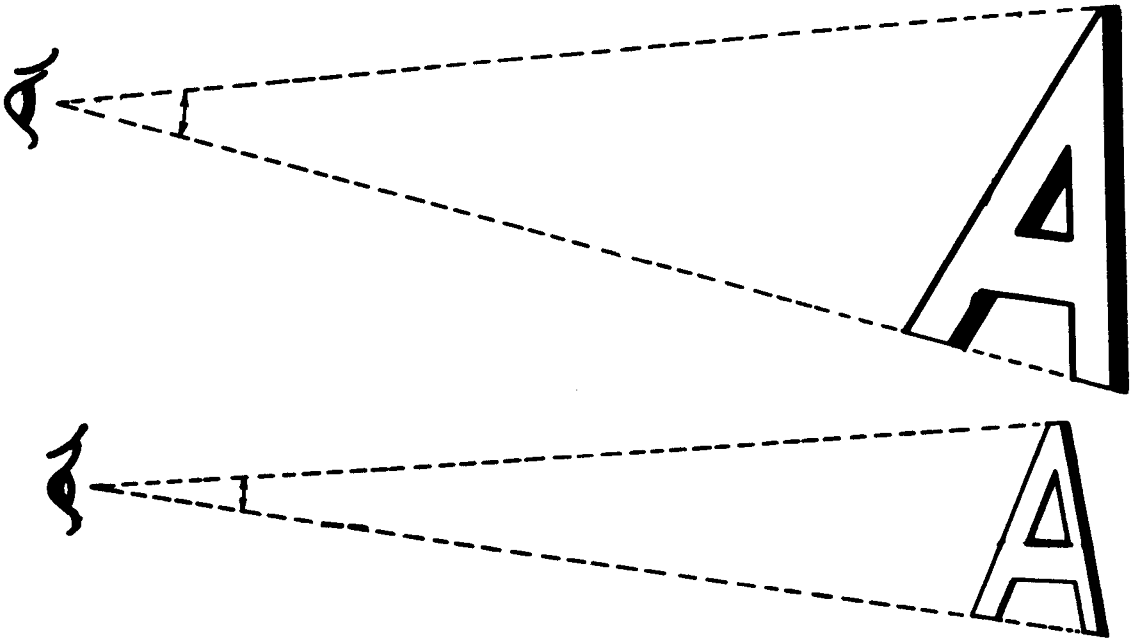


FIG. 6 VISUAL ANGLE SUBTENDED AT THE EYE

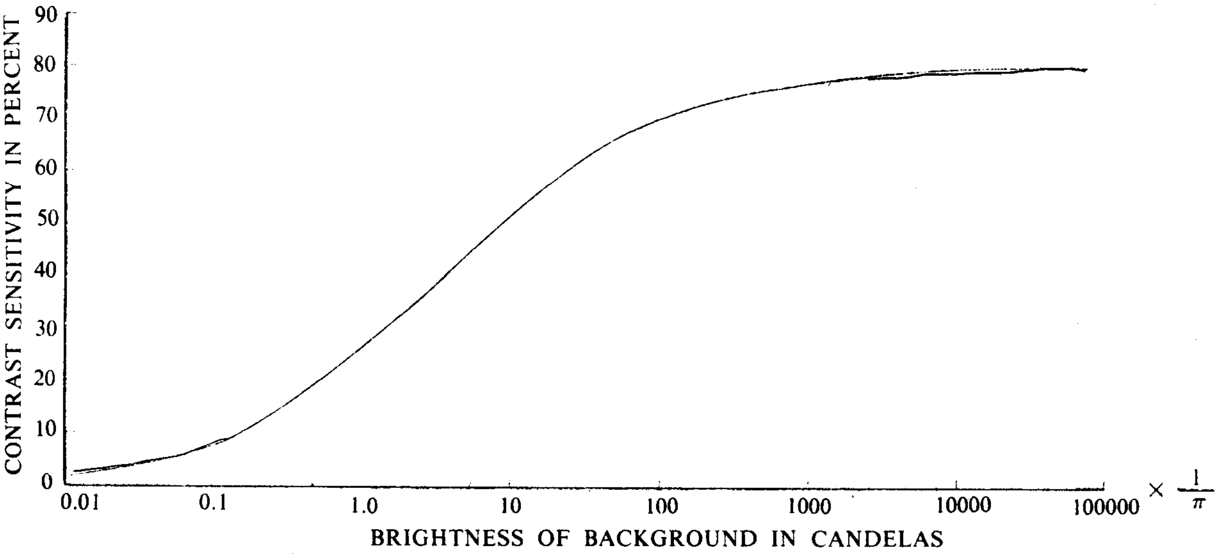


FIG. 7 VARIATION OF CONTRAST SENSITIVITY WITH BACKGROUND BRIGHTNESS

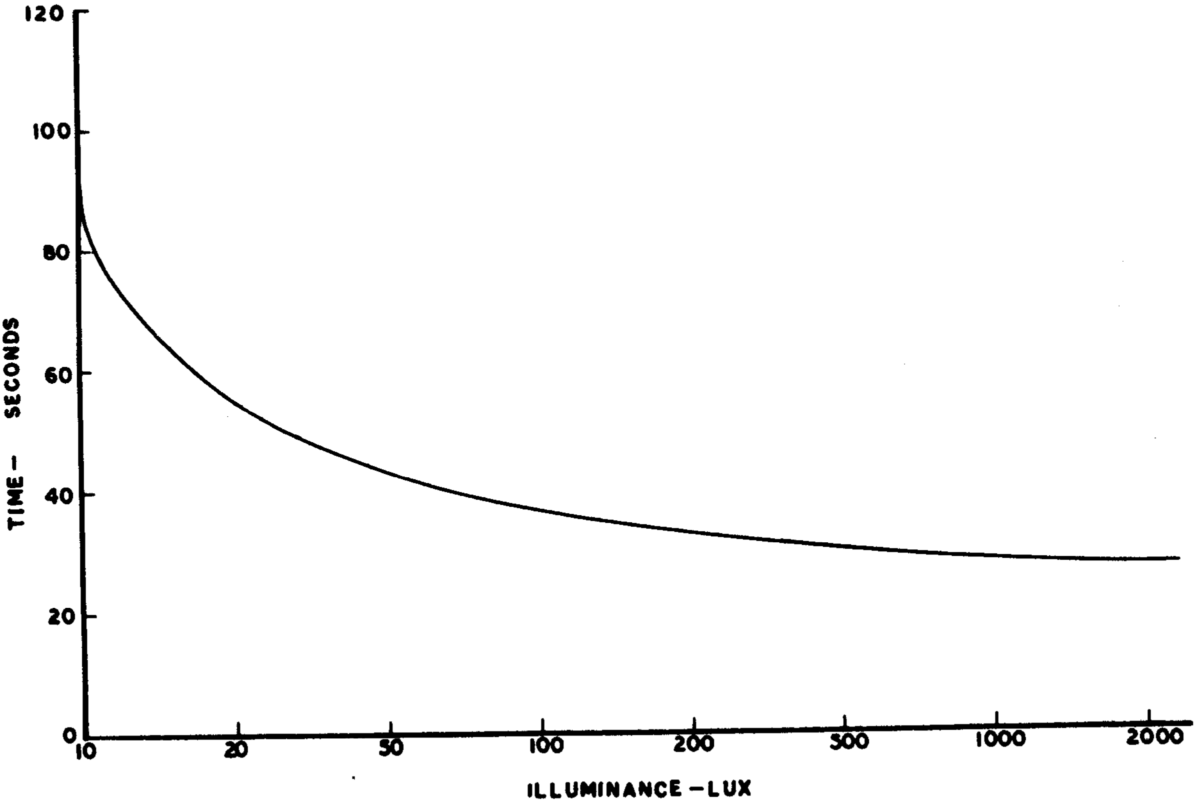


FIG. 8 VARIATION OF SPEED OF VISION WITH ILLUMINANCE

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.

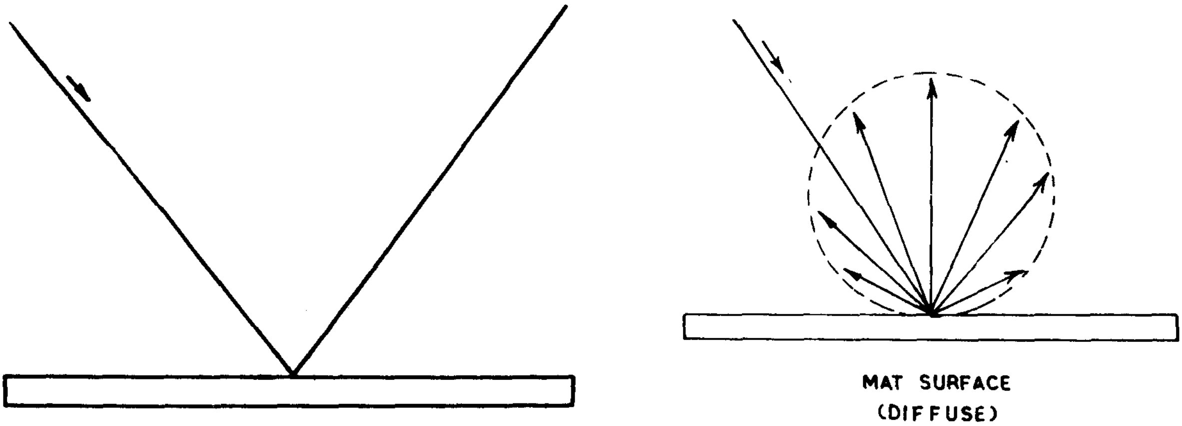
1.5.29 *Luminaire* — It is a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, protect the lamps and connect the lamps to the power supply.

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).

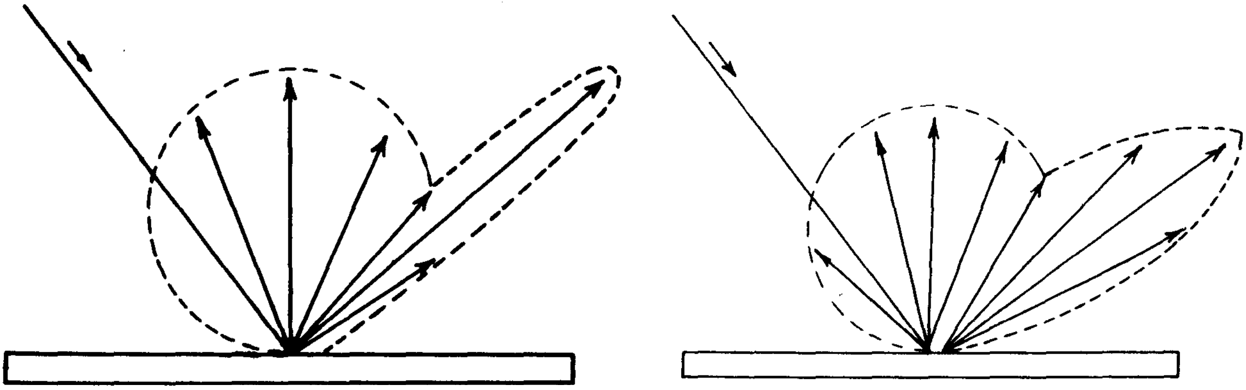
1.5.32 *Luminous Flux (F)* — It is the time rate of flow of light (luminous energy) and is the quantity characteristic of radiant flux which expresses its capacity to produce visual sensation evaluated according to the values of relative luminous efficiency for the light adopted eye. The unit of luminous 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



POLISHED - SURFACE (SPECULAR)

MAT SURFACE (DIFFUSE)



DIFFUSE AND SPECULAR

DIFFUSE AND SPREAD

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 4 π.

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

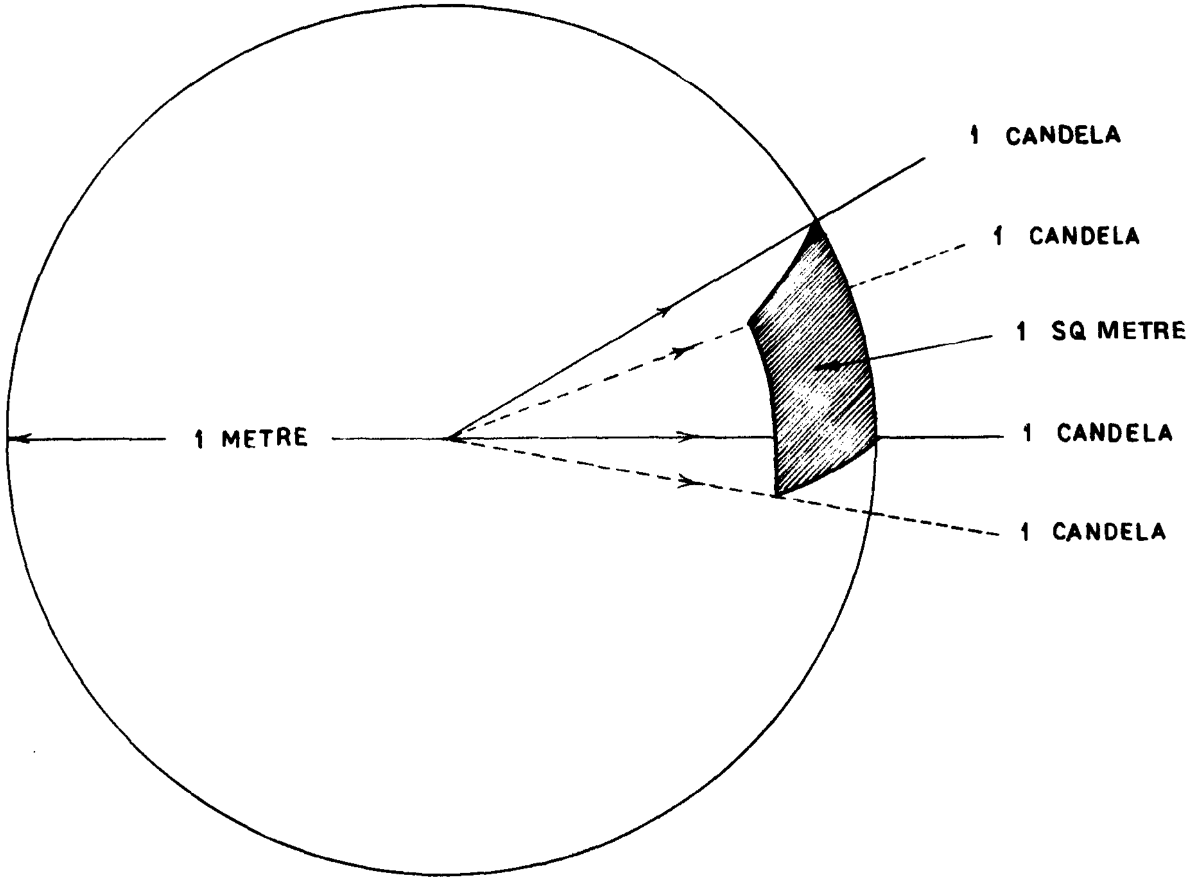


FIG. 10 UNIT SPHERE DEPICTING INCIDENCE OF LUMINOUS FLUX ON UNIT AREA FROM 1 CANDELA SOURCE AT ITS CENTRE

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

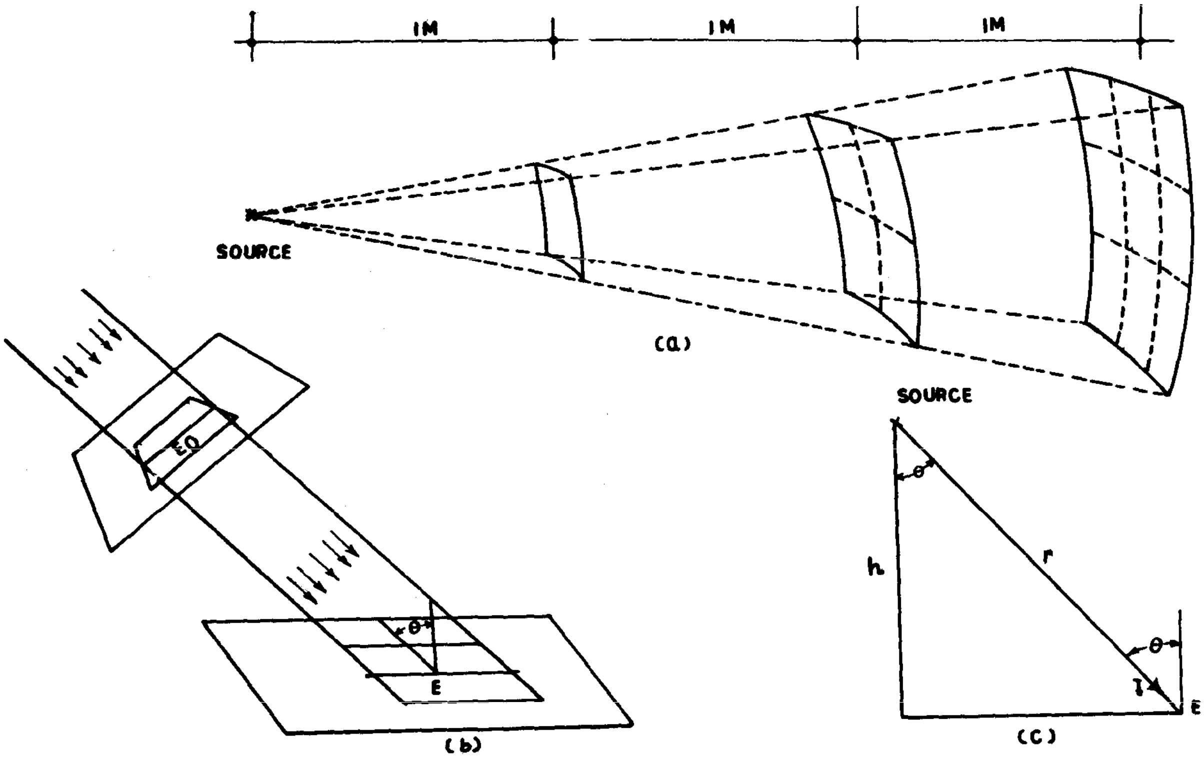


FIG. 11 DEPENDENCE OF ILLUMINANCE ON DISTANCE, ANGLE OF INCIDENCE AND MOUNTING HEIGHT (a) THE INVERSE SQUARE LAW (b) THE LAMBERT COSINE LAW (c) THE COSINE CUBED LAW

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:

$B_\theta = B_z \operatorname{cosec}\theta$ for θ between 15° and 90°

and B_θ = constant for θ between θ° 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.

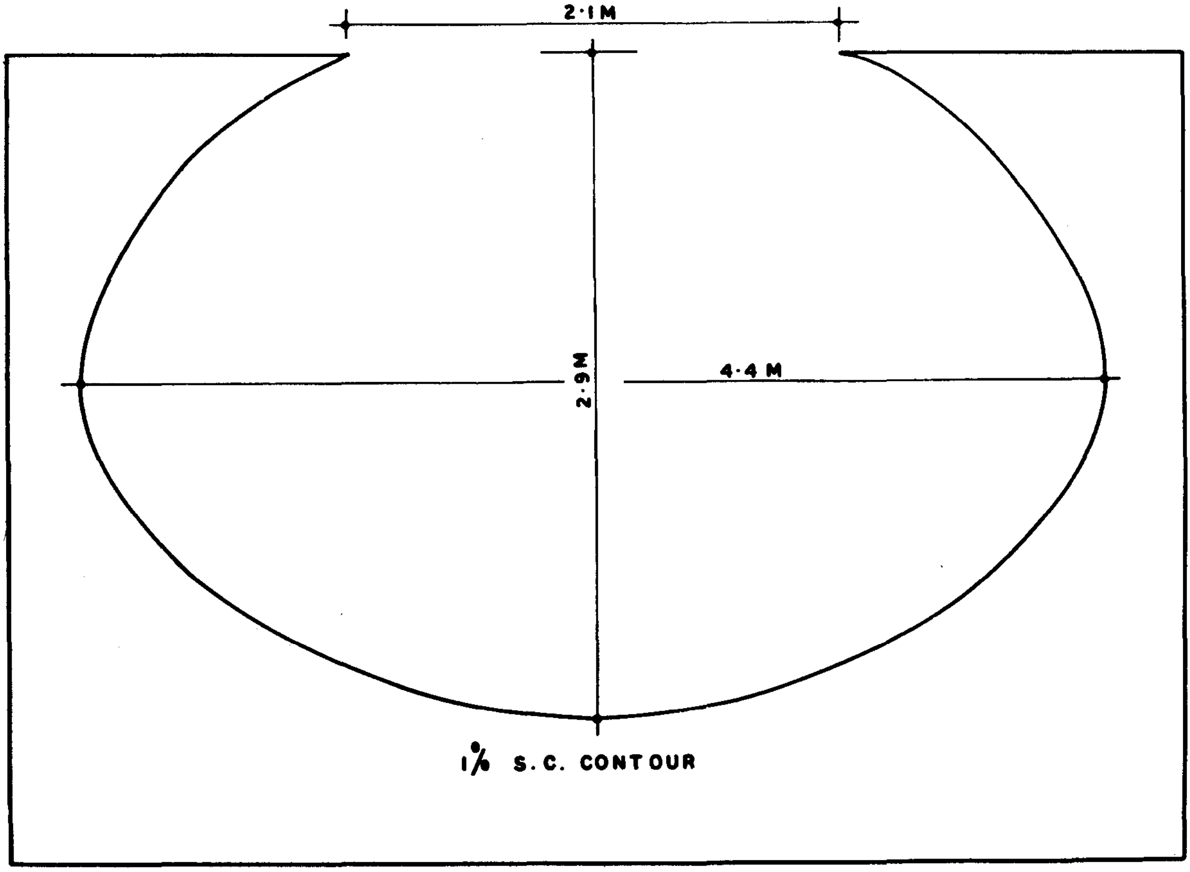


FIG. 12 TYPICAL SKY COMPONENT CONTOUR DEPICTING ITS PENETRATION AND SPREAD ON A HORIZONTAL PLANE

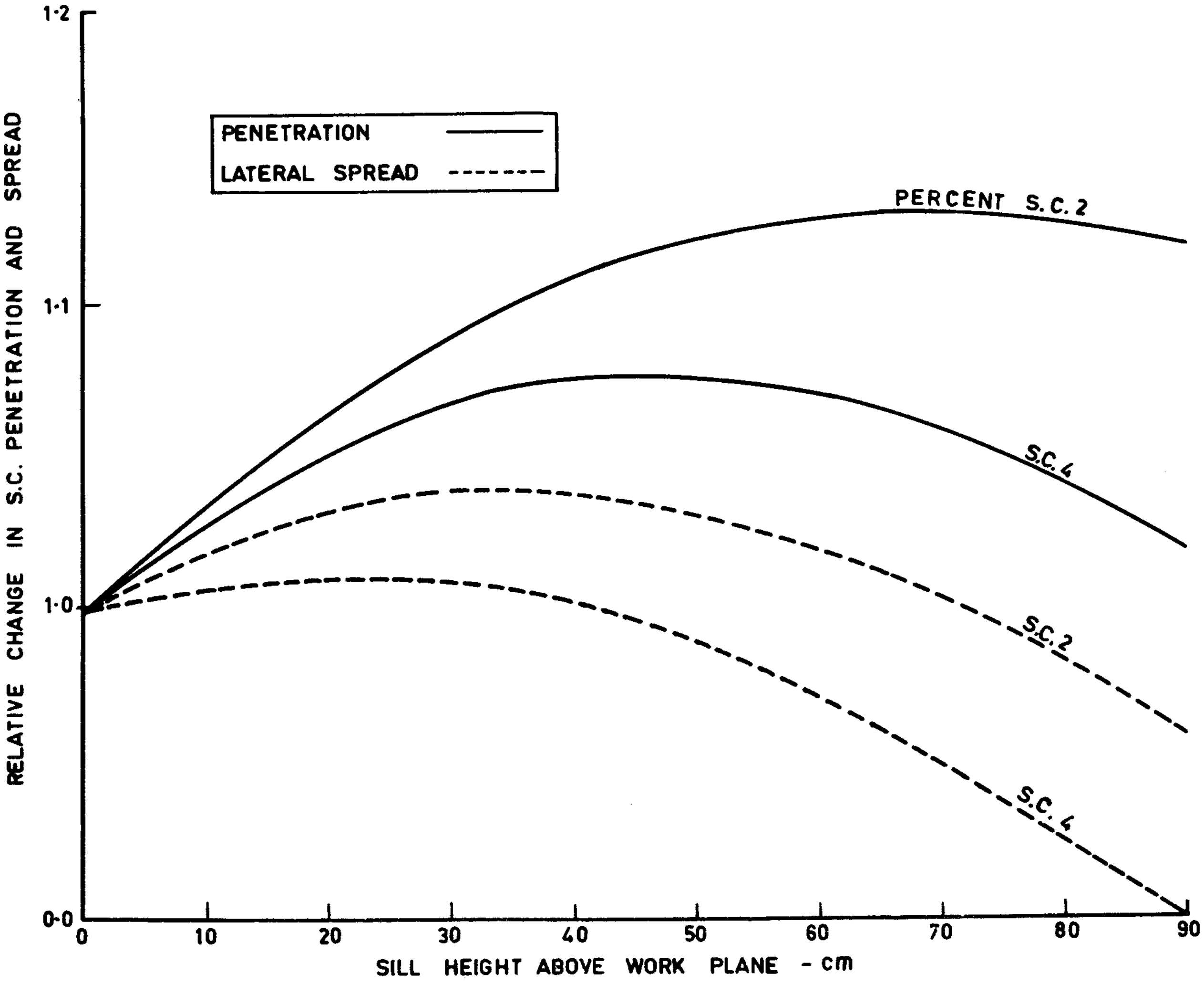


FIG. 13 VARIATION PENETRATION AND SPREAD OF SKY COMPONENT WITH SILL HEIGHT

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.

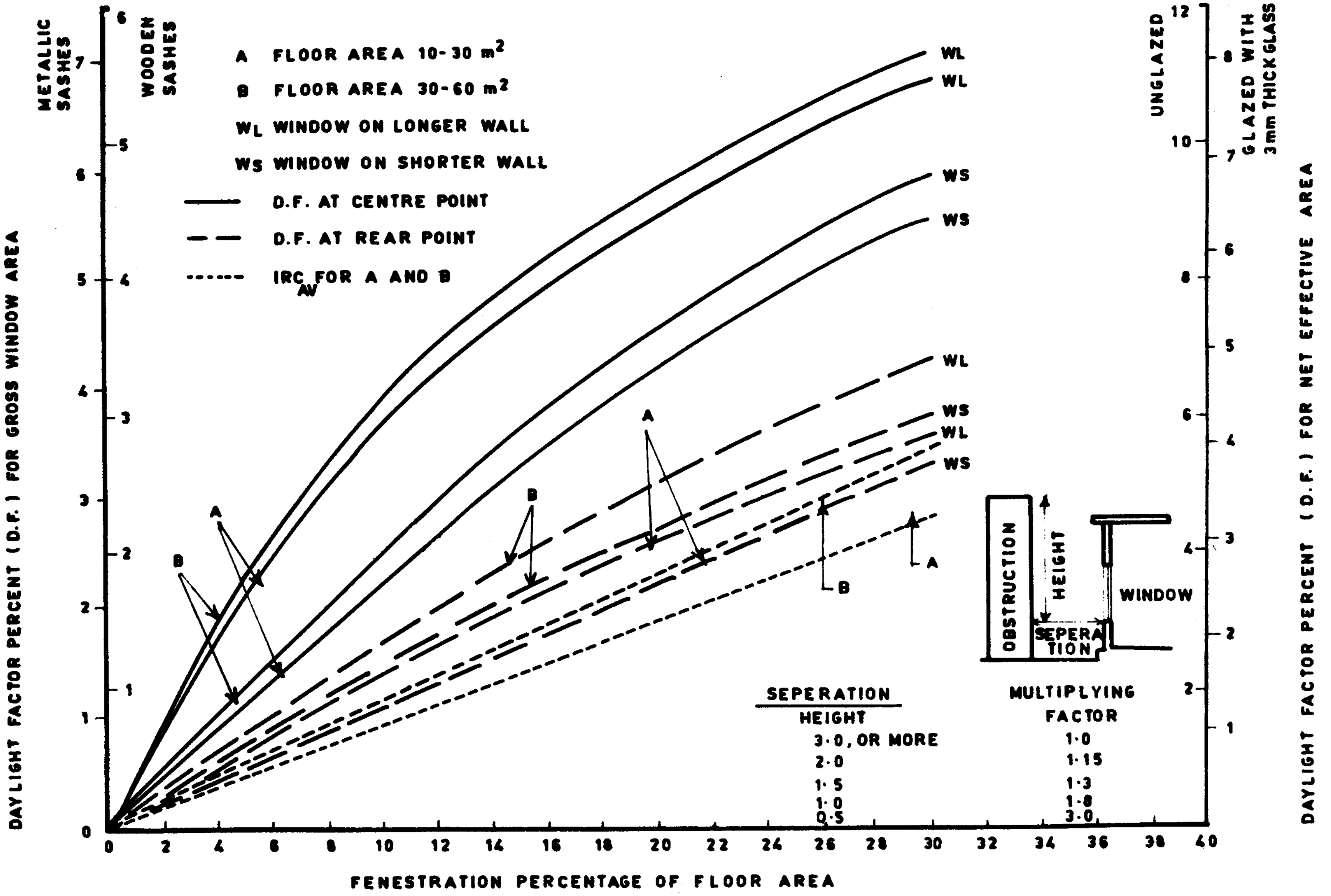


FIG. 14 DAYLIGHT FACTORS ON THE WORKING PLANE FOR A CENTRALLY LOCATED WINDOW

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:

$$\text{Required window area} = \frac{\text{Fenestration percent} \times \text{Floor area}}{100}$$

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:

$$(SC)_{ABCD} = (SC)_{NMDA} + (SC)_{NMCB} \qquad \ldots (1)$$

$$(SC)_{effective} = (SC)_{EDCF} = (SC)_{NMDE} + (SC)_{NMCF} \quad (2)$$

$$(SC)_{ABCD} = (SC)_{NMDE} + (SC)_{NMCF} - (SC)_{NLAE} - (SC)_{NLBF} \qquad \ldots (3)$$

$$(SC)_{ABCD} = (SC)_{NMCF} - (SC)_{NMDE} - (SC)_{NLBF} + (SC)_{NLAE} \qquad \ldots (4)$$

$$(SC)_{effective} = (SC)_{ABCD} - (SC)_{AEFB} \qquad \ldots (5)$$

$$(SC)_{effective} = (SC)_{ABCD} - (SC)_{AEFG} \qquad \ldots (6)$$

$$(SC)_{effective} = (SC)_{ABCD} \qquad \ldots (7)$$

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:

$$(SC)_\theta = (SC)_h \cos \theta + (SC)_v \sin \theta \qquad \ldots (8)$$

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:

$$\begin{aligned}(SC)_{ABCD} &= (SC)_{NMCF} - (SC)_{NMDE} - (SC)_{NLBF} + (SC)_{NLAE}\\ &= 5.709 - 2.441 - 0.878 + 0.403\\ &= 2.793\\ &= 2.79 \text{ percent}\end{aligned}$$

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:

$$\begin{aligned}(SC)_{\text{effective}} &= (SC)_{EDCF} = (SC)_{NMDE} + (SC)_{NMCF}\\ &= 0.859 + 0.859\\ &= 1.718\\ &= 1.72 \text{ percent}\end{aligned}$$

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 :

$$\begin{aligned}(SC)_{\text{effective}} &= (SC)_{ABCD} - (SC)_{AEFB}\\ &= 3.099 - 0.699\\ &= 2.4 \text{ percent}\end{aligned}$$

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.

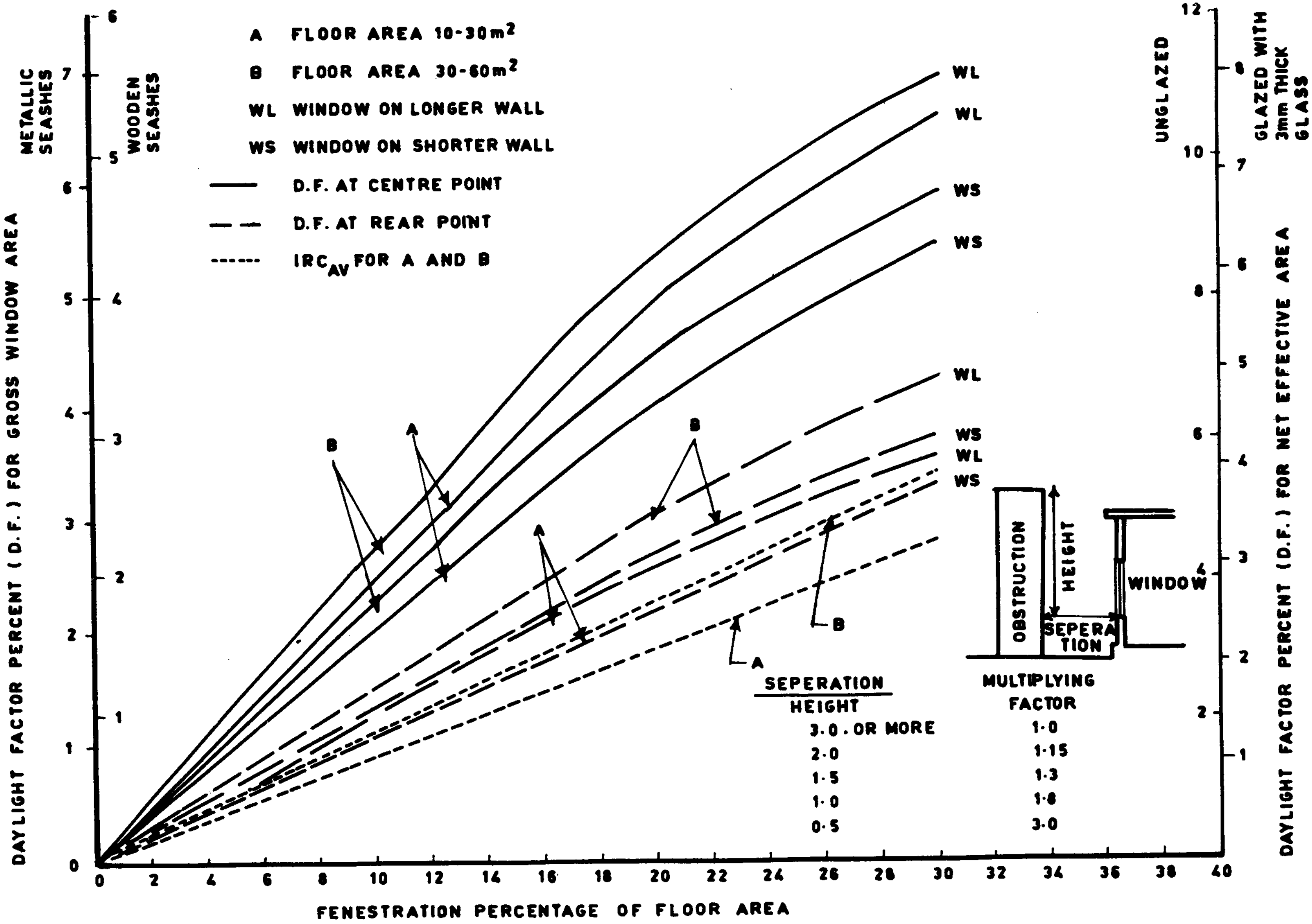
4.2.2.2 The contribution of daylight reflected by external obstruction is determined with the help of perspective projection of the obstruction on the window plane with respect to the given indoor point. Noting l/d and h/d values of the projected areas and using Table 13 or 14, depending upon the orientation 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.



SEPERATION HEIGHT	MULTIPLYING FACTOR
3·0 . OR MORE	1·0
2·0	1·15
1·5	1·3
1·0	1·8
0·5	3·0

FIG. 15 DAYLIGHT FACTORS ON THE WORKING PLANE FOR A CORNER LOCATED WINDOW

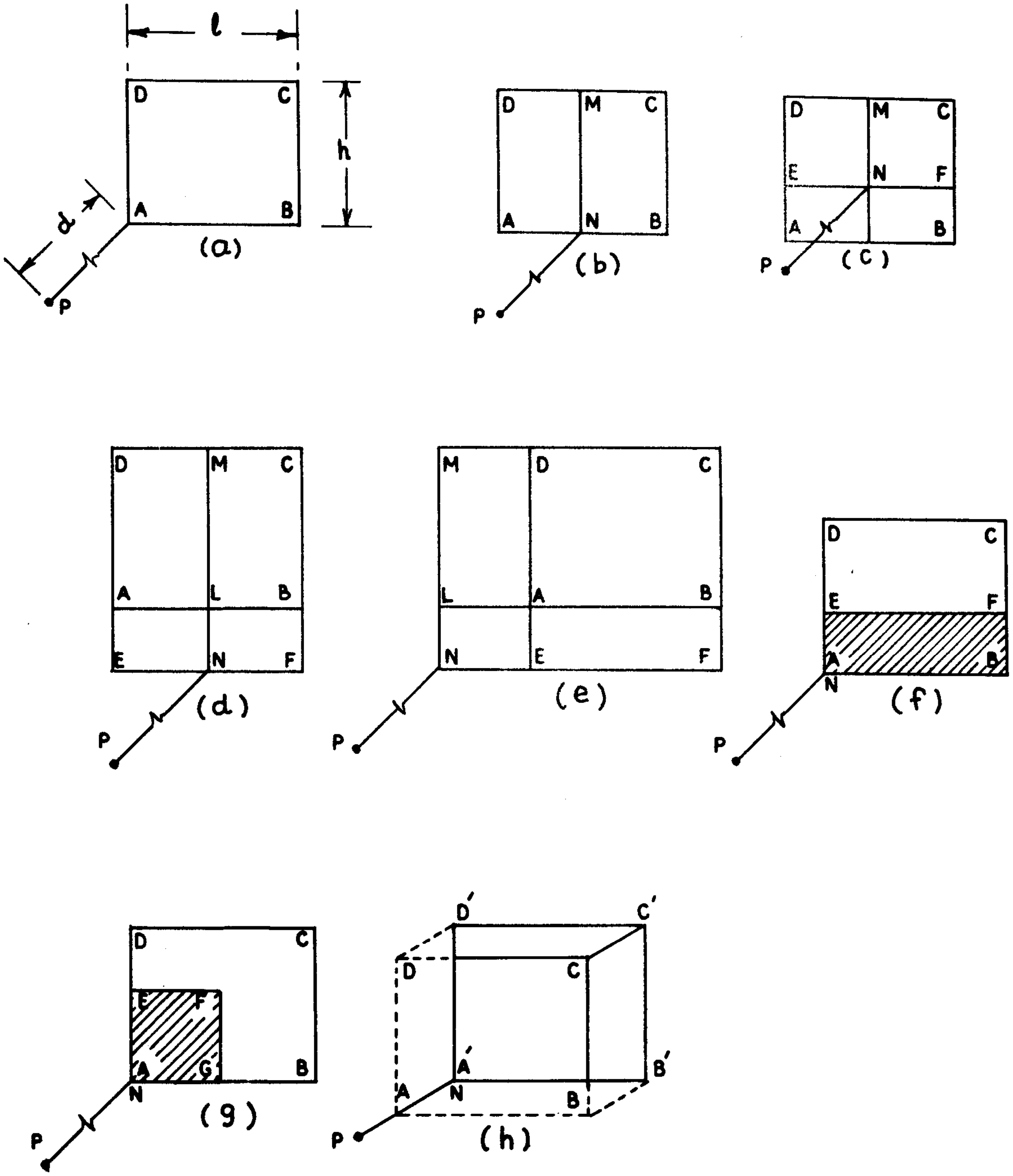


Fig. 16 Determination of Sky Component At a Given Point by Delineation of Rectangles on Window Wall Through the Projection of the Point

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.*

l/*D* *h*/*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)

l/d *h/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)

l/*d* *h*/*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.*

l/d *h/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)

l/d *h/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 REFLECTANCE (1)	SUNLIT SURFACE (2)	UNOBSTRUCTED NON-SUNLIT SURFACE (3)	NON-SUNLIT SURFACE WITH OPPOSITE OBSTRUCTIONS (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 = 5°

From Table 15, $\frac{1}{\text{BF}} = 0.43$

Therefore

$$\text{SF} = \text{SC} \times \frac{1}{\text{BF}} = 0.699 \times 0.43 = 0.30$$

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:

$$\text{IRC}_a = \frac{0.85\ W C R}{A(1-R)} \qquad \ldots (11)$$

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.

$$WCR = W\left[C_1 \times R_{fw} + C_2 \times R_{cw}\right] \quad \ldots (12)$$

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.

$$\mathrm{IRC} = \frac{0.85\,W}{A(1-R)}(C_1 R_{fw} + C_2 R_{cw}) \quad \ldots (13)$$

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

$$A = 2\ (5 \times 3 + 5 \times 3 + 3 \times 3)$$
$$= 2\ (15 + 15 + 9)$$
$$= 2 \times 39 = 78\ \mathrm{m}^2$$

$$R = \frac{15 \times 0.7 + 15 \times 0.3 + (48 - 2) \times 0.5 + 2 \times 0.15}{78}$$
$$= 0.491$$

$$\text{or } 1 - R = 0.509$$

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

$$R_{cw} = \frac{15 \times 0.7 + (5 \times 2 + 3 \times 2 + 5 \times 2) \times 0.5}{15 + 26}$$
$$= 0.573$$

$$R_{fw} = \frac{15 \times 0.3 + (5 \times 1 + 5 \times 1 + 3 \times 1) \times 0.5}{15 + 13}$$
$$= 0.393$$

$$\mathrm{IRC} = \frac{0.85\,W\,(78 R_{fw} + 10 R_{cw})}{A(1 - R)}$$
$$= \frac{0.85 \times 2\,(78 \times 0.393 + 10 \times 0.573)}{78 \times 0.509}$$
$$= 1.55 \text{ percent}$$

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

$$W = 1.8 \times 1.5 = 2.7\ \mathrm{m}^2$$
$$A = 78\ \mathrm{m}^2$$
$$R = 0.491$$
$$\text{or } (1 - R) = 0.509$$

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,

$$\text{IRC} = \frac{0.85 \times W(66.2\, R_{fw} + 10\, R_{cw})}{A\,(1 - R)}$$
$$= \frac{0.85 \times 2.7\ \ (66.2 \times 0.413 + 10 \times 0.587)}{78 \times 0.509}$$
$$= 1.92 \text{ percent.}$$

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. 21 A) 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 workplane) with its centre at the given point on the plane (*see* Fig. 21 B) 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

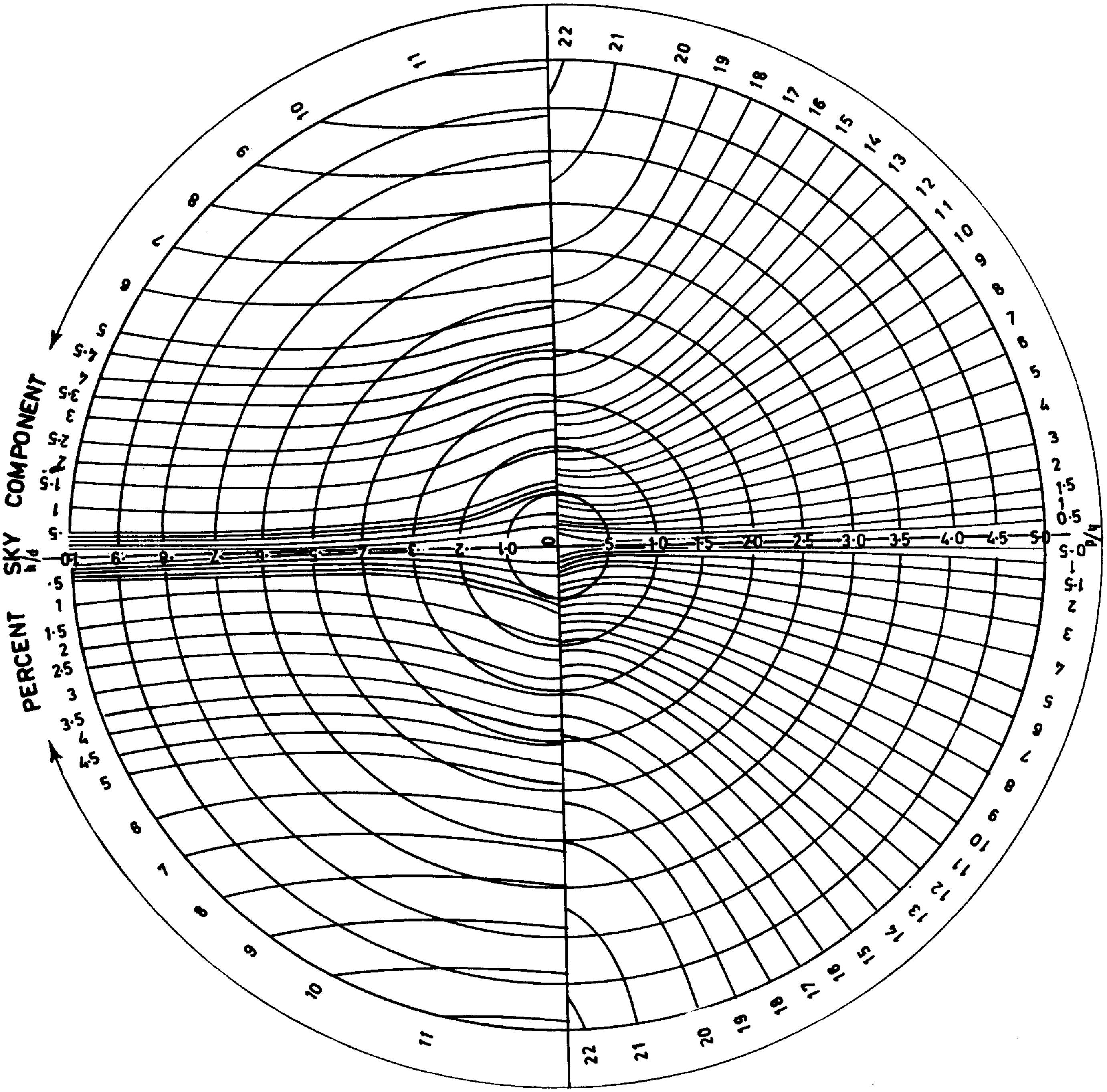


FIG. 17 SKY COMPONENT PROTRACTOR FOR A HORIZONTAL PLANE

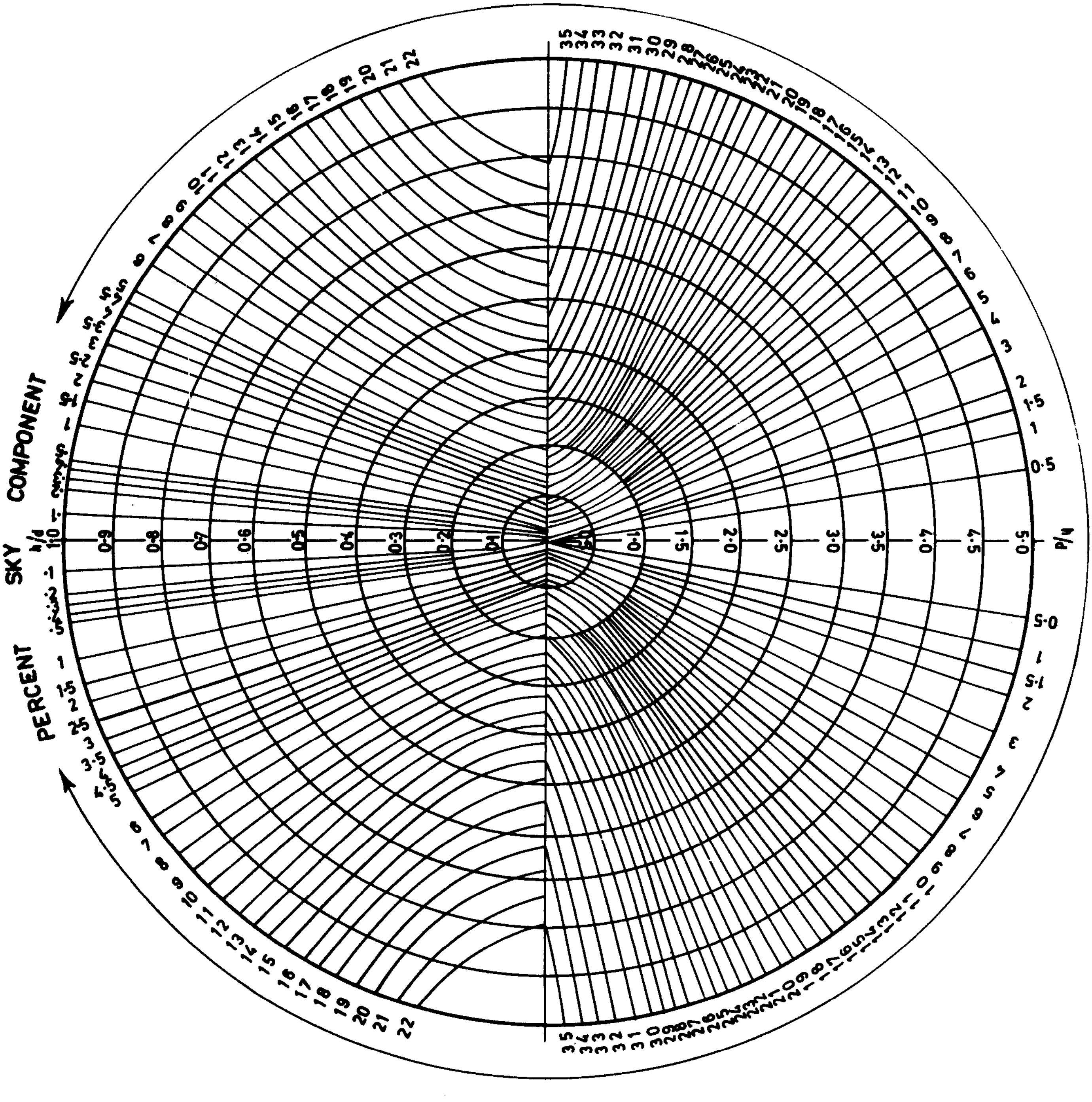


Fig. 18 Sky Component Protractor for a Vertical Plane Normal to Window Plane

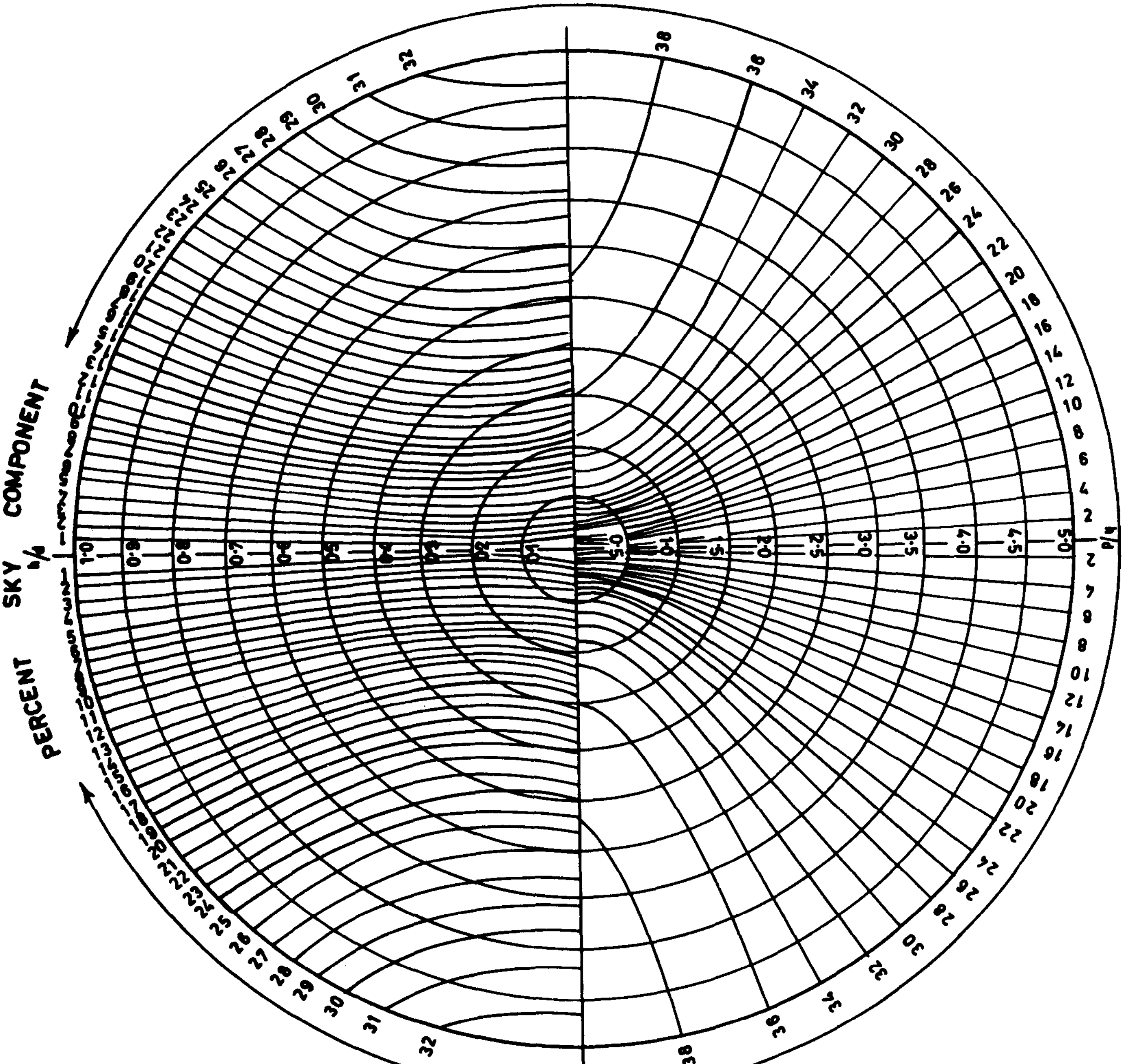


Fig. 19 Sky Component Protractor for a Vertical Plane Parallel to Window Plane

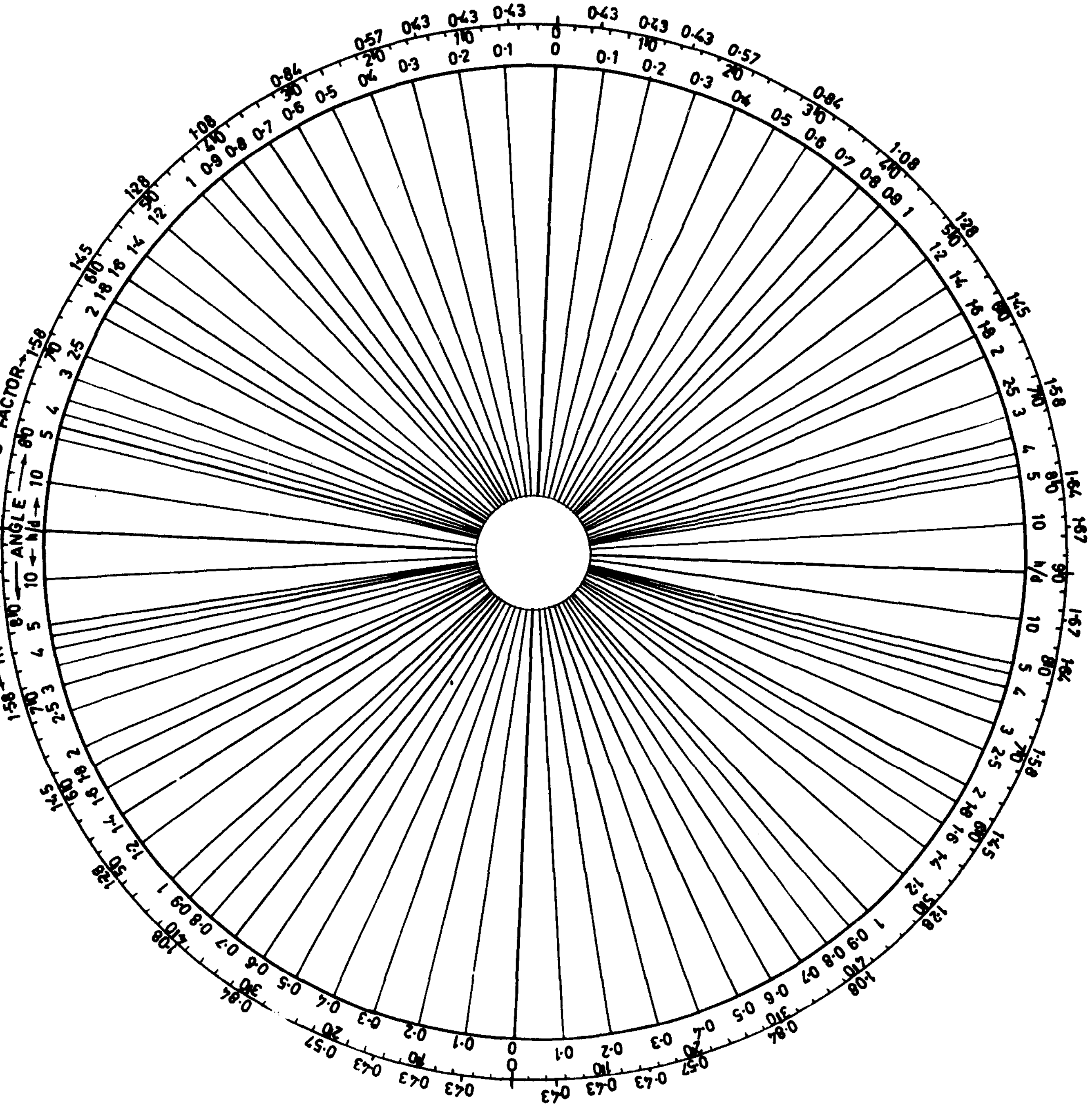


FIG. 20 AUXILIARY PROTRACTOR FOR DETERMINATION OF HEIGHT TO DISTANCE RATIO

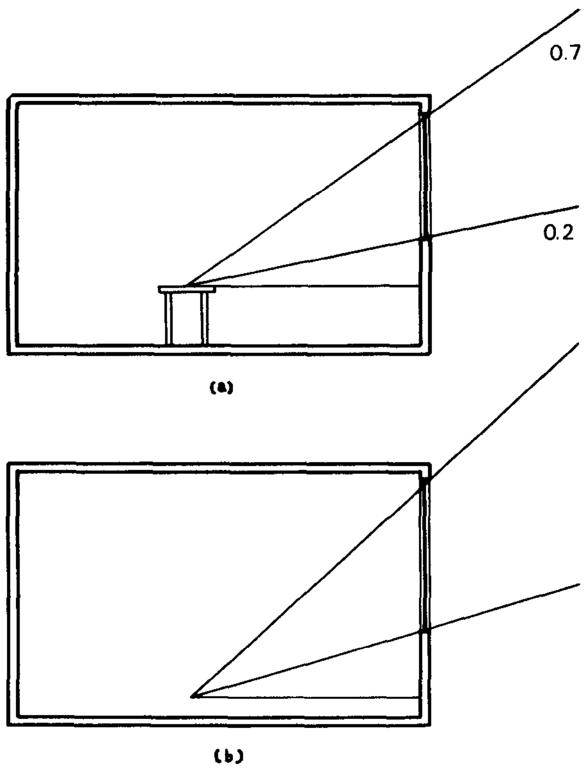


FIG. 21 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN OF A ROOM FOR A WINDOW WITHOUT LOUVRES (EXAMPLE 14)

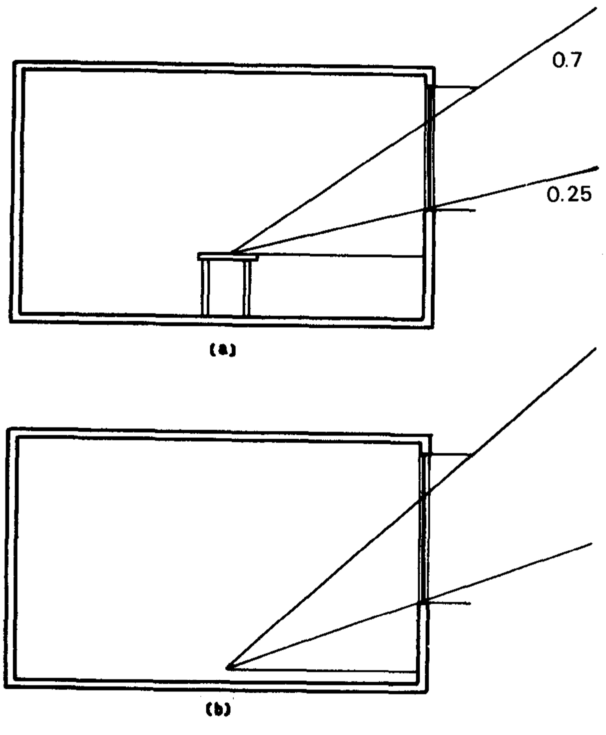


FIG. 22 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN OF A ROOM FOR A WINDOW WITH LOUVRES (EXAMPLE 15)

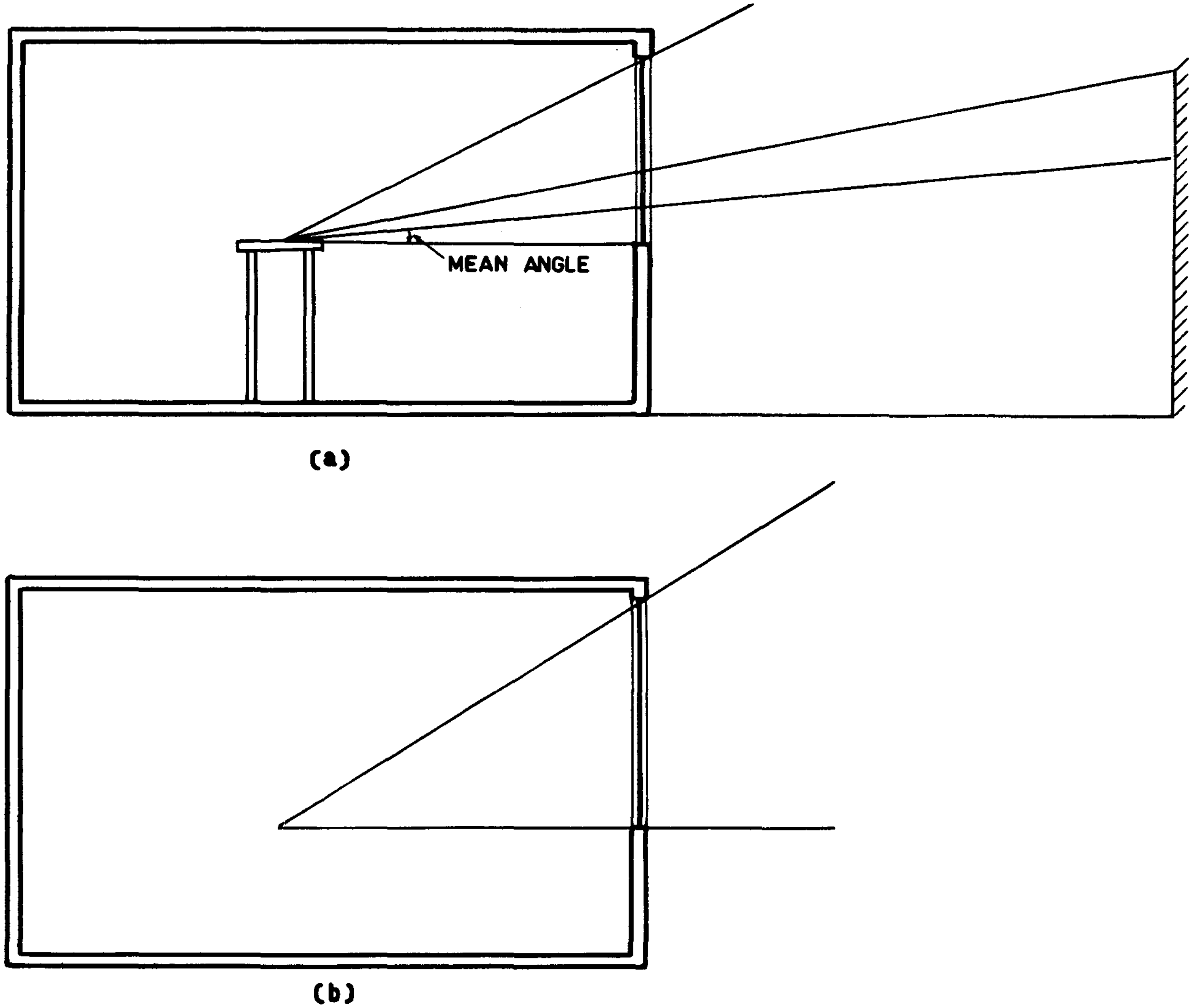


FIG. 23 ILLUSTRATION DEPICTING USE OF PROTRACTORS ON (a) SECTIONAL ELEVATION AND (b) PLAN IN PRESENCE OF EXTERNAL OBSTRUCTION (EXAMPLE 16)

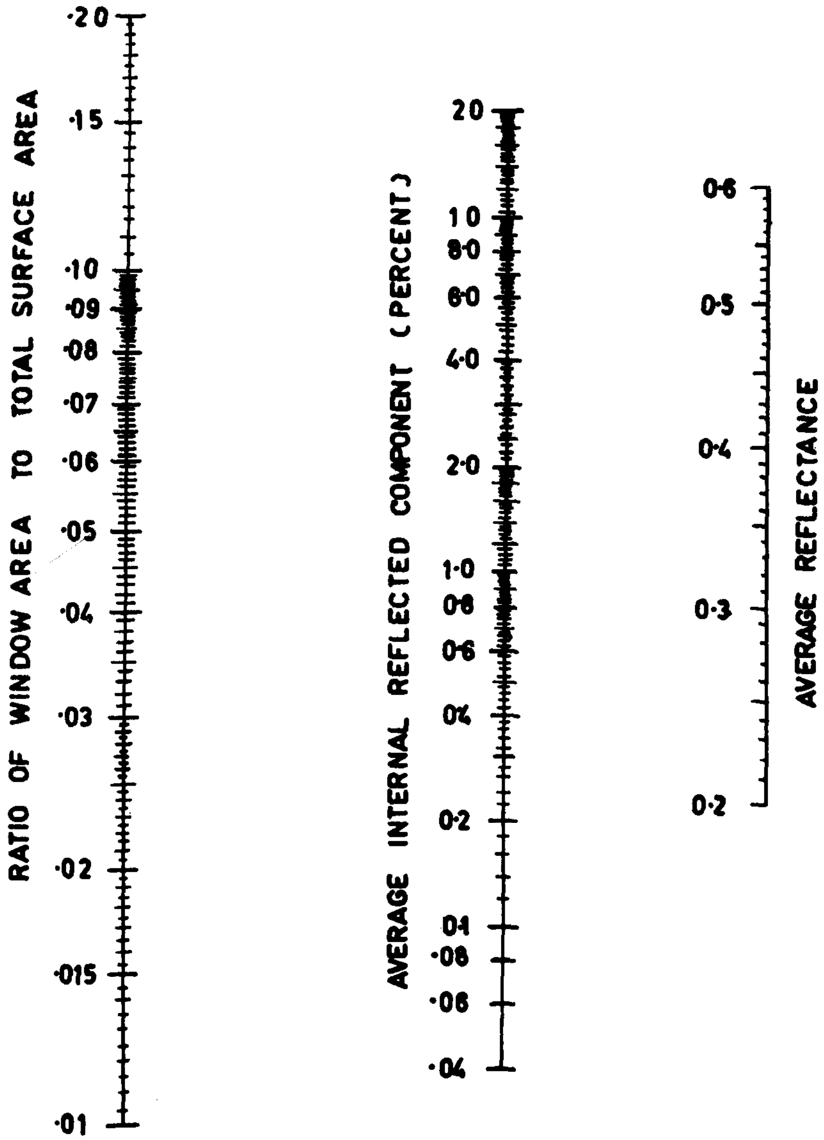


FIG. 24 NOMOGRAM FOR AVERAGE INTERNAL REFLECTED COMPONENT

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 × 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 × (− 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) × 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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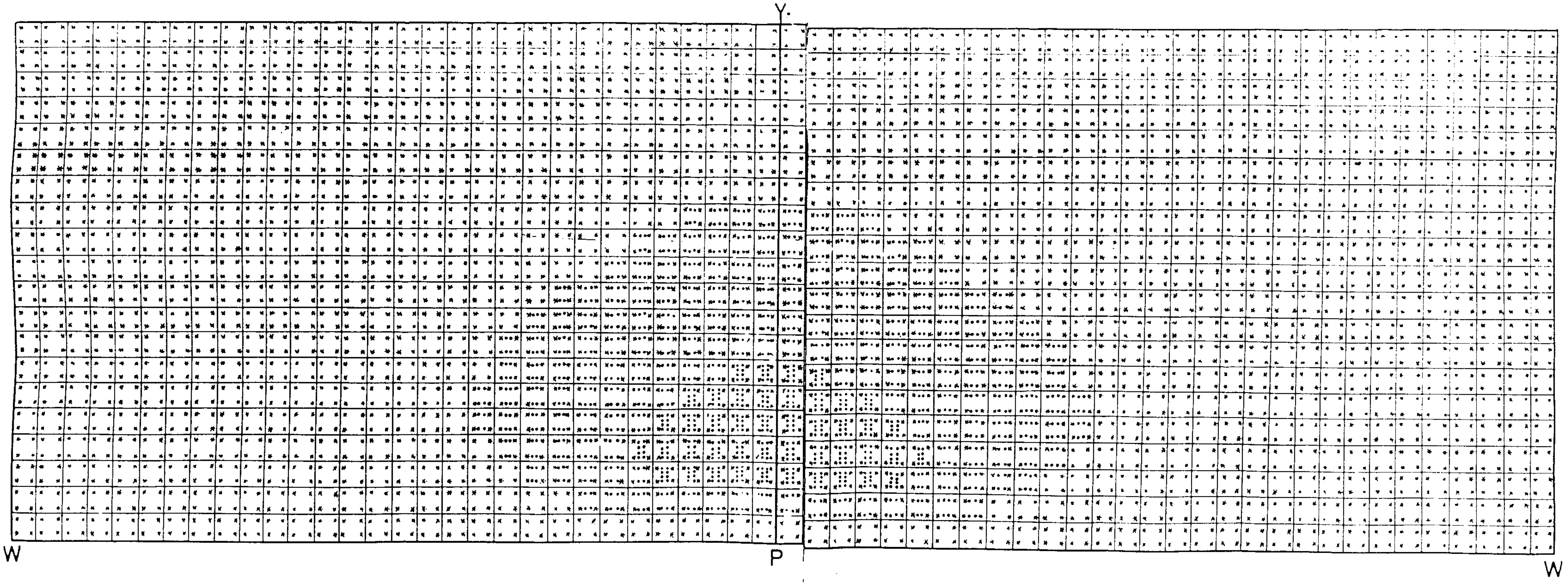

Fig. 28 Lux Grid for Daylighting Design of Side-lit Windows in Absence of External Obstructions

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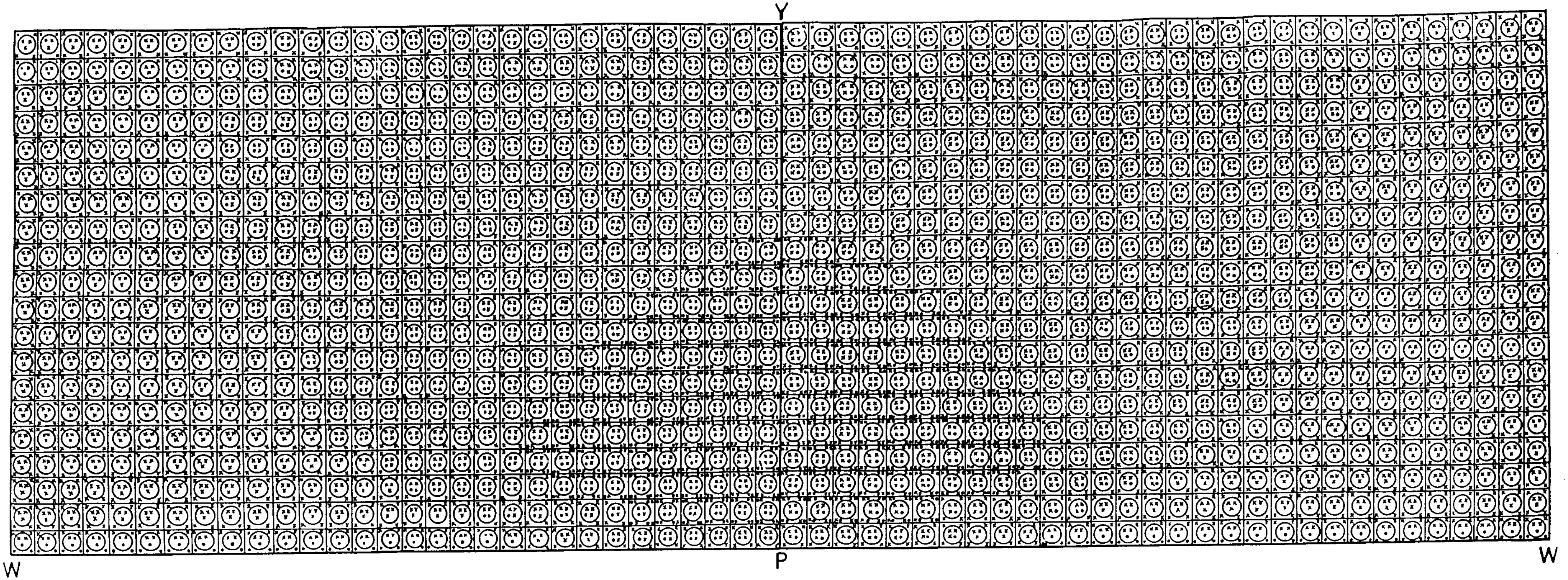


Fig. 26 Lux Grid II for Daylighting Design of Windows in Presence of External Obstruction

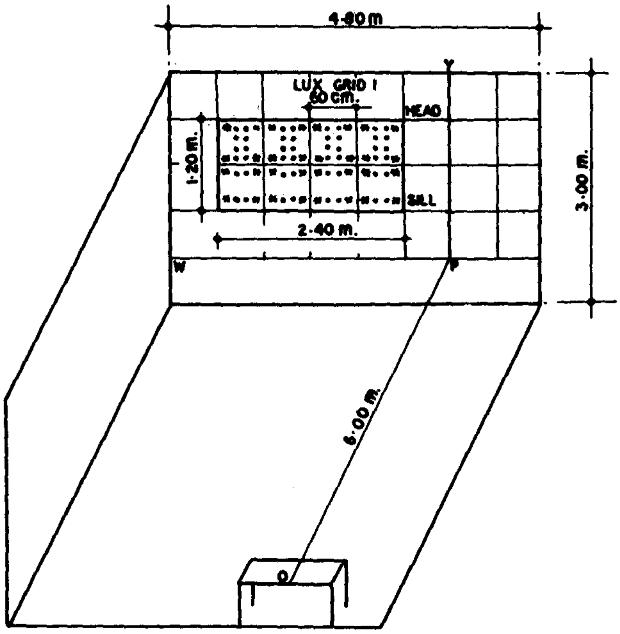


FIG. 27 ILLUSTRATION DEPICTING USE OF LUX GRID I FOR DETERMINATION OF DAYLIGHT ON THE WORKPLANE (EXAMPLE 19)

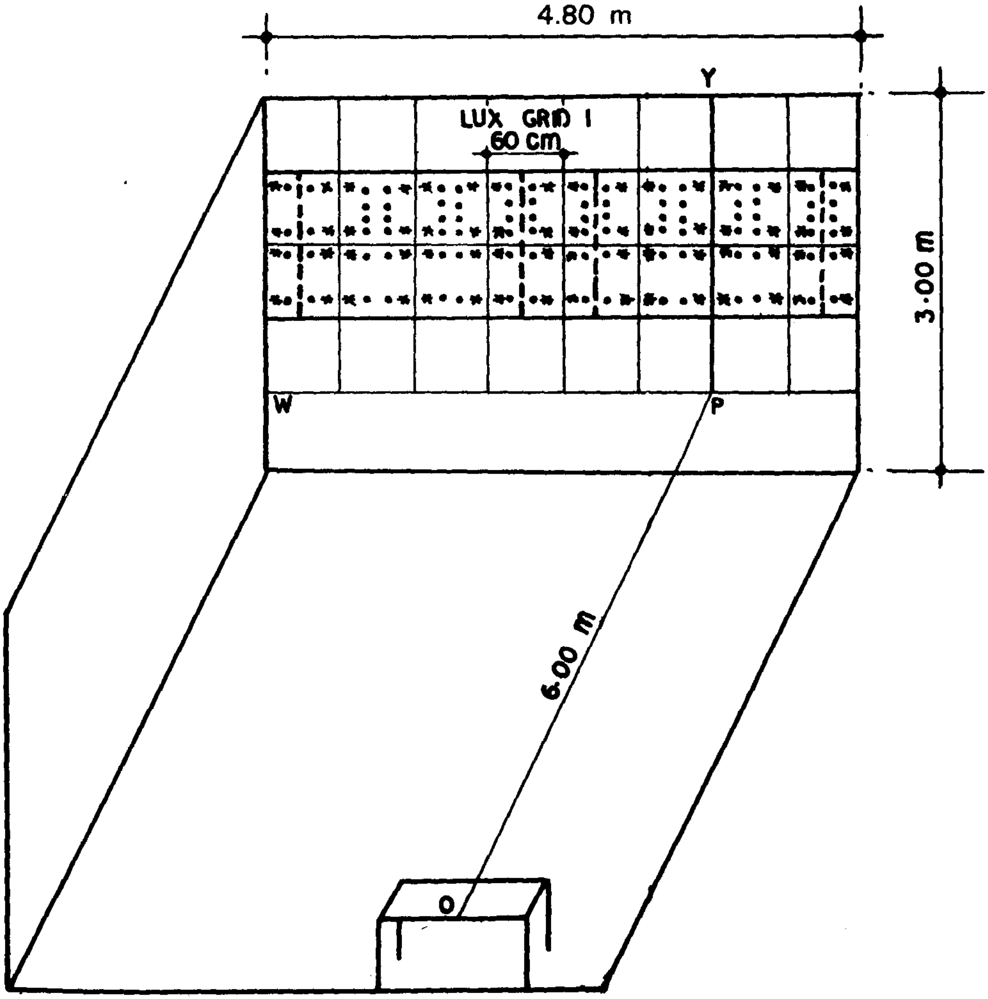


FIG. 28 ILLUSTRATION DEPICTING USE OF LUX GRADE II FOR DETERMINATION OF DAYLIGHT ON THE WORKING PLANE (EXAMPLE 20)

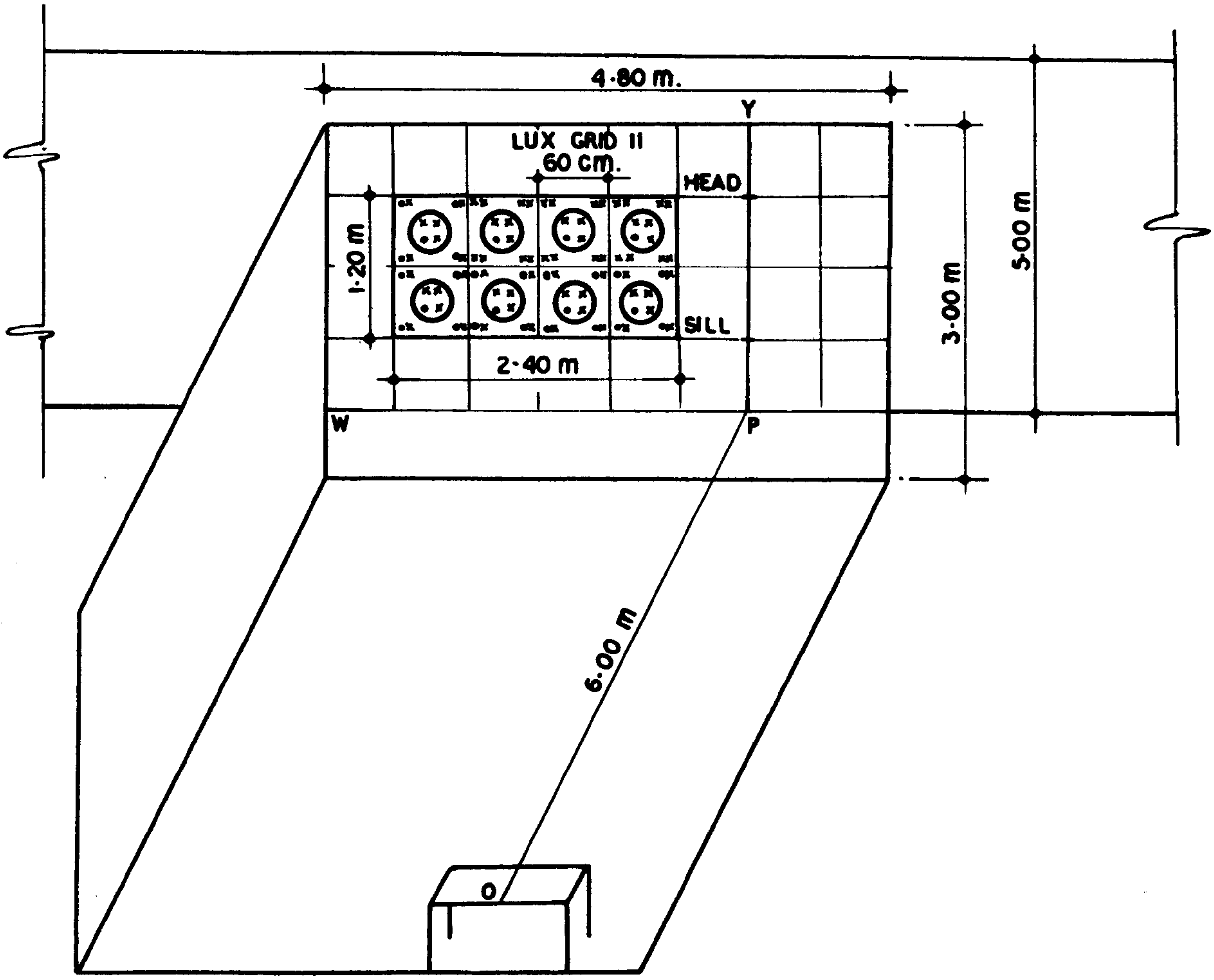


FIG. 29 ILLUSTRATION DEPICTING USE OF LUX GRID I FOR DAYLIGHTING DESign of WINDOWS (EXAMPLE 21)

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 m^2								
		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 m^2								
		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 $= 5 \times 3 = 15 \text{ m}^2$

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 $= 15 \times 10 = 150 \text{ m}^2$

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

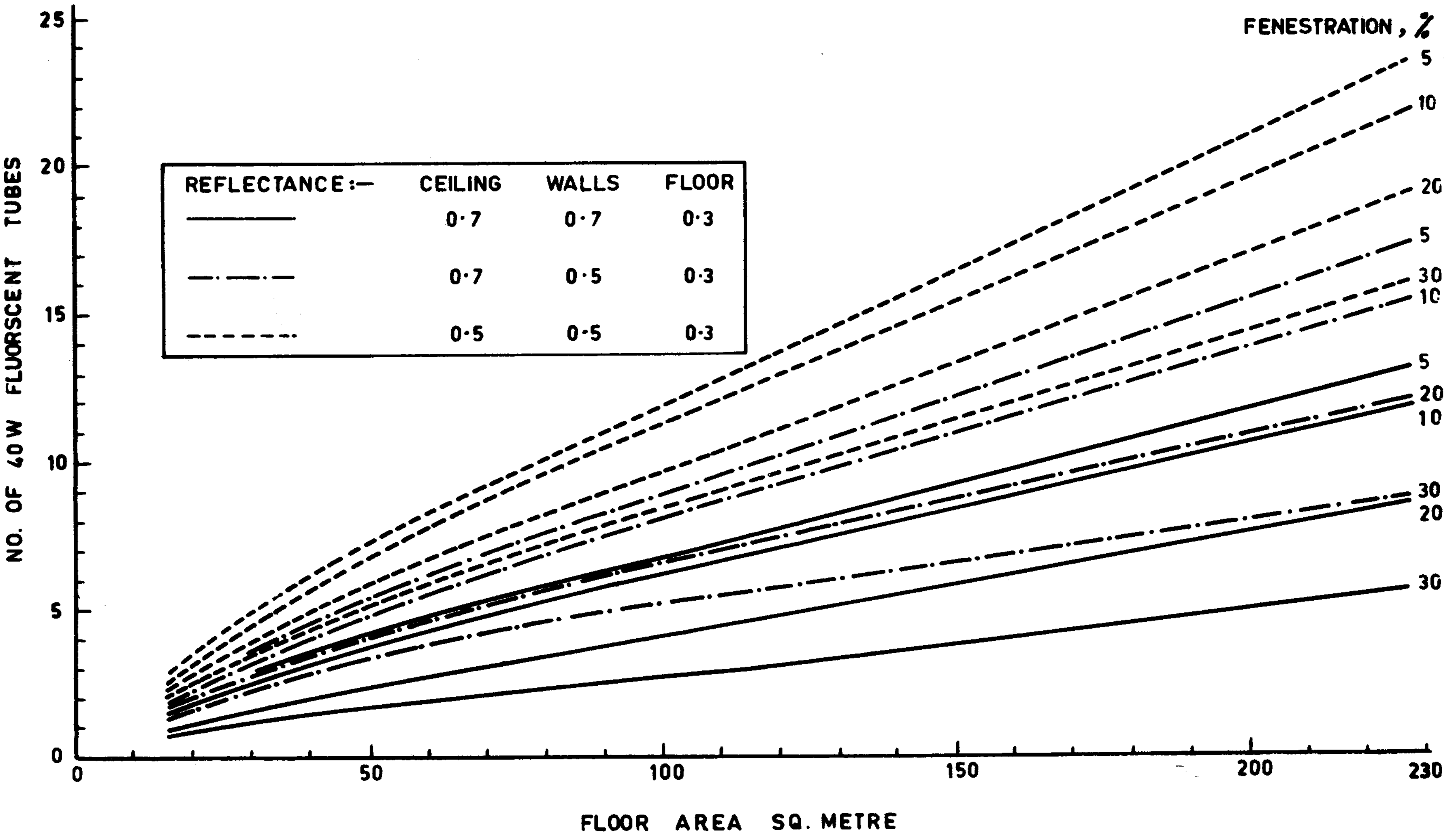


FIG. 30 DESIGN CURVES FOR DAYTIME SUPPLEMENTARY ARTIFICIAL LIGHTING FOR DIFFERENT ROOM SIZES AND WINDOW SIZES

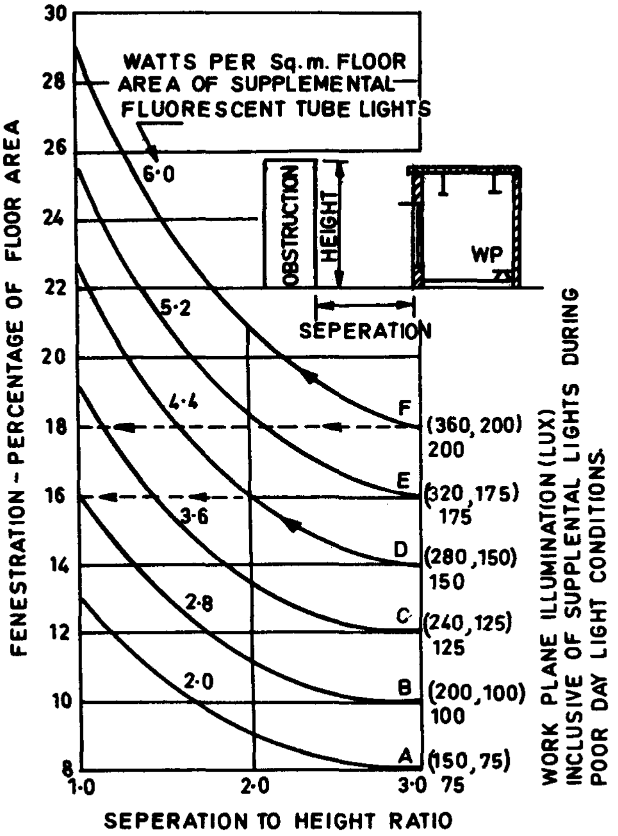


FIG. 31 NOMOGRAPH FOR DAYTIME SUPPLEMENTARY LIGHTING DESIGN

10 m and floor area between 30-50 m^2 have been assumed. For floor area beyond 50 m^2 and less than 30 m^2, the values of percent fenestration as well as wattage per m^2 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 m^2 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 m^2 and less than 30 m^2, the value of watts per m^2 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 m^2 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 m^2 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:

$$N_{\text{lamp}} \times \phi_{\text{lamp}} \times \mu \times d \quad \ldots(18)$$

or

$$N_{\text{luminaire}} \times \phi_{\text{luminaire}} \times \mu \times d \quad \ldots(19)$$

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.

$$\text{Therefore, } N_{\text{lamp}} = \frac{E \times A}{\mu \times d \times \phi_{\text{lamp}}} \quad \ldots(20)$$

or

$$N_{\text{luminaire}} = \frac{E \times A}{\mu \times d \times \phi_{\text{luminaire}}} \quad \ldots(21)$$

where

$\phi_{\text{lamp}}, \phi_{\text{luminaire}}$ = 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,

$$N_{\text{lamp}} = \frac{EA}{\mu\, d\, \Phi_{\text{lamp}}} = \frac{150 \times (5 \times 3)}{2\,440 \times 0.30 \times 0.70} = 4$$

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

$$N_{\text{lamp}} = \frac{EA}{\Phi_{\text{lamp}}\, \mu\, d}$$

$$= \frac{150 \times (15 \times 10)}{2\,440 \times 0.48 \times 0.70} = 27$$

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

$$N_{\text{lamp}} = \frac{EA}{\Phi_{\text{lamp}}\, \mu\, d} = \frac{300 \times (6 \times 5)}{2\,440 \times 0.43 \times 0.75} = 11$$

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 $H = 0.8 \times 2.4 = 1.92$ 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.

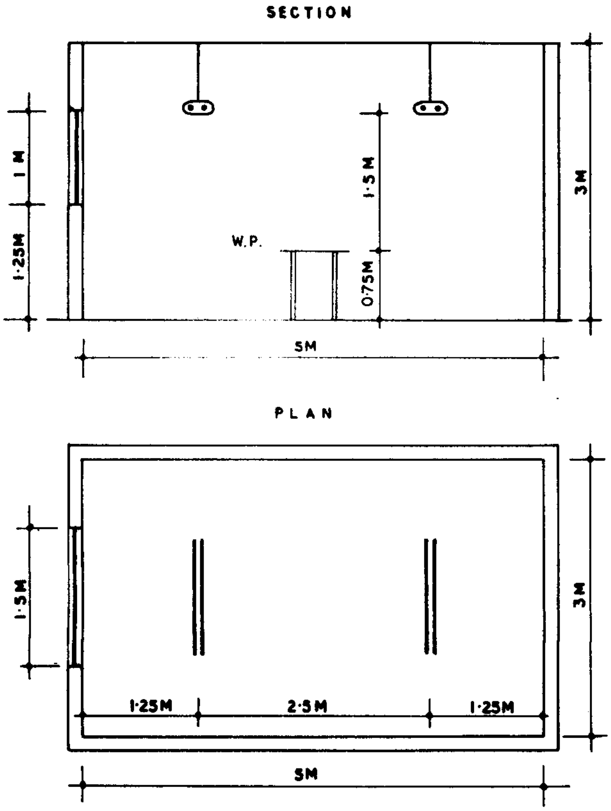


FIG. 32 DISTRIBUTION OF TWIN LAMP LUMINAIRES ON SECTION AND PLAN (EXAMPLE 26)

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

$$N_{\text{lamp}} = \frac{EA}{\Phi_{\text{lamp}}\,\mu\,d} = \frac{300 \times (6 \times 5)}{2\,440 \times 0.53 \times 0.70} = 10$$

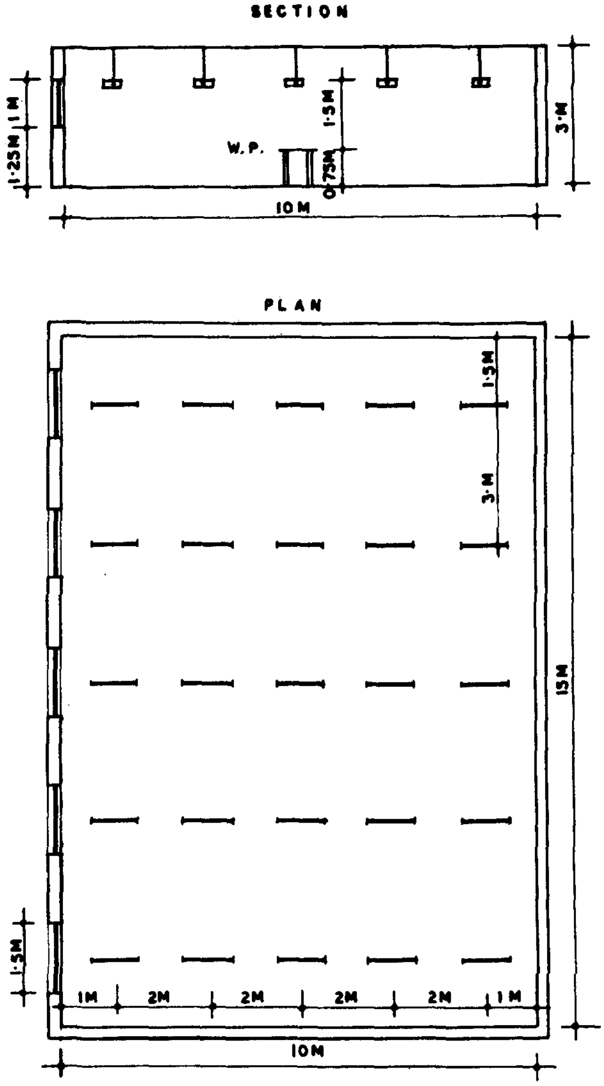


Fig. 33 Distribution of Single Lamp Luminaires on Section and Plan (Example 27)

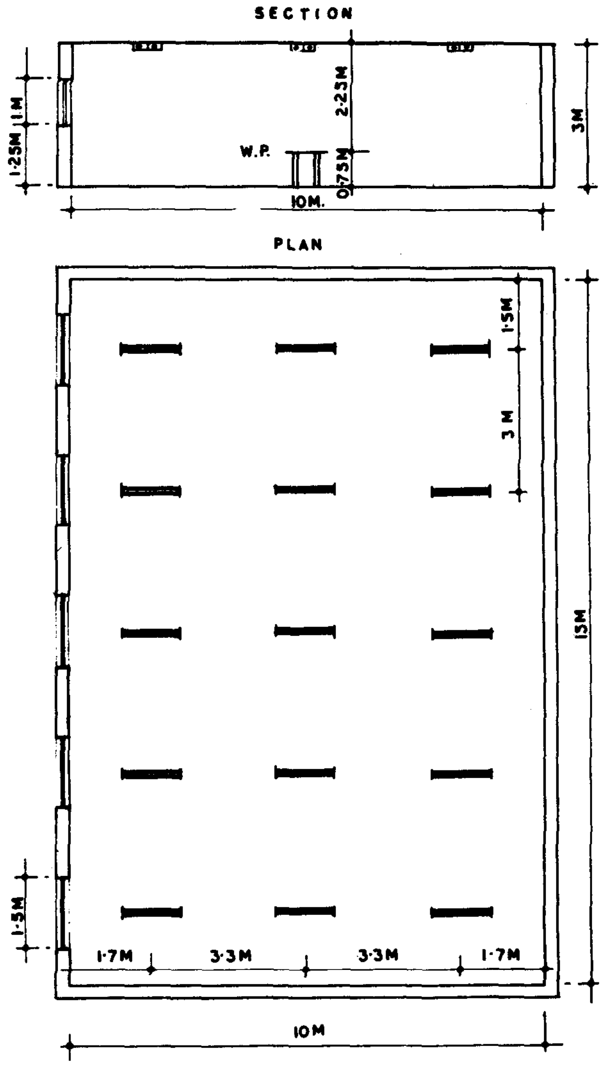


Fig. 34 Distribution of Twin Lamp Luminaires on Sfction and Plan (Example 27)

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

$$= \frac{A}{r^2}$$

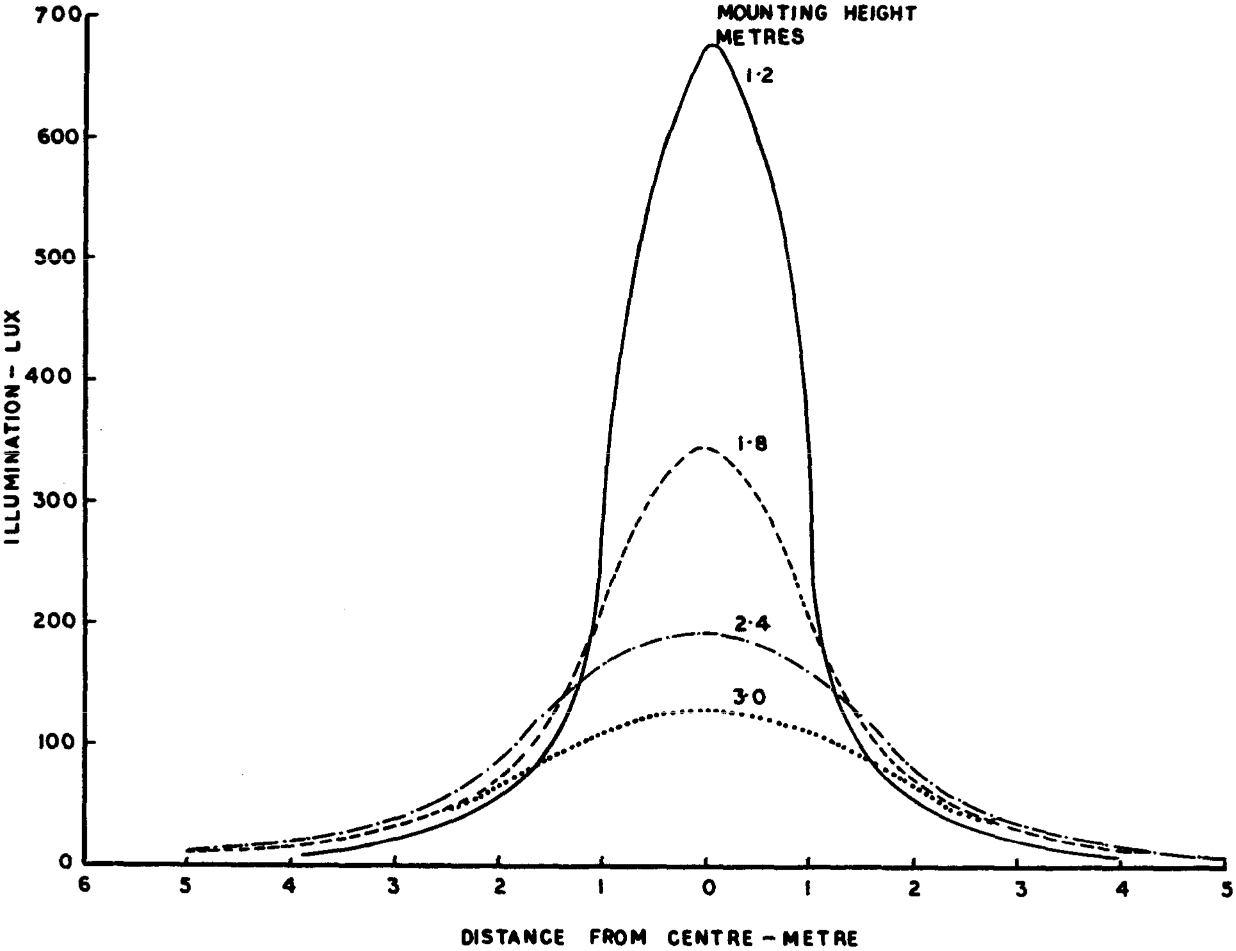


FIG. 35 DISTRIBUTION OF DIRECT ILLUMINATION ON A WORKPLANE DUE TO TWIN 40 W FLUORESCENT TUBE

$$= \frac{\pi\,(0.05)^2}{(2^2 + 1^2)}$$

$$= 0.001\ 57 \text{ steradians.}$$

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 cm²) at 0°; that is, as seen from vertically beneath the fitting.

ii) *BZ 9 to BZ 10* : The maximum orthogonally projected luminous area (in cm²) 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

$Y = 18.3 \text{ m} = 10\ H$

$X = 7.4 \text{ m} = 4\ H$

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

$$\left.\begin{array}{ll} \text{Downward flux } (F) = 2\,100 & : +1.9 \\ \text{Area } (A) = 4\,516 \text{ cm}^2 & : -6.8 \\ \text{Height } (H) = 1.8 \text{ m} & : -0.6 \end{array}\right\} -5.5 \quad \text{From Table 11}$$

Algebraic sum − 3.8

The glare index is then 24.2 − 3.8 = 20.4.

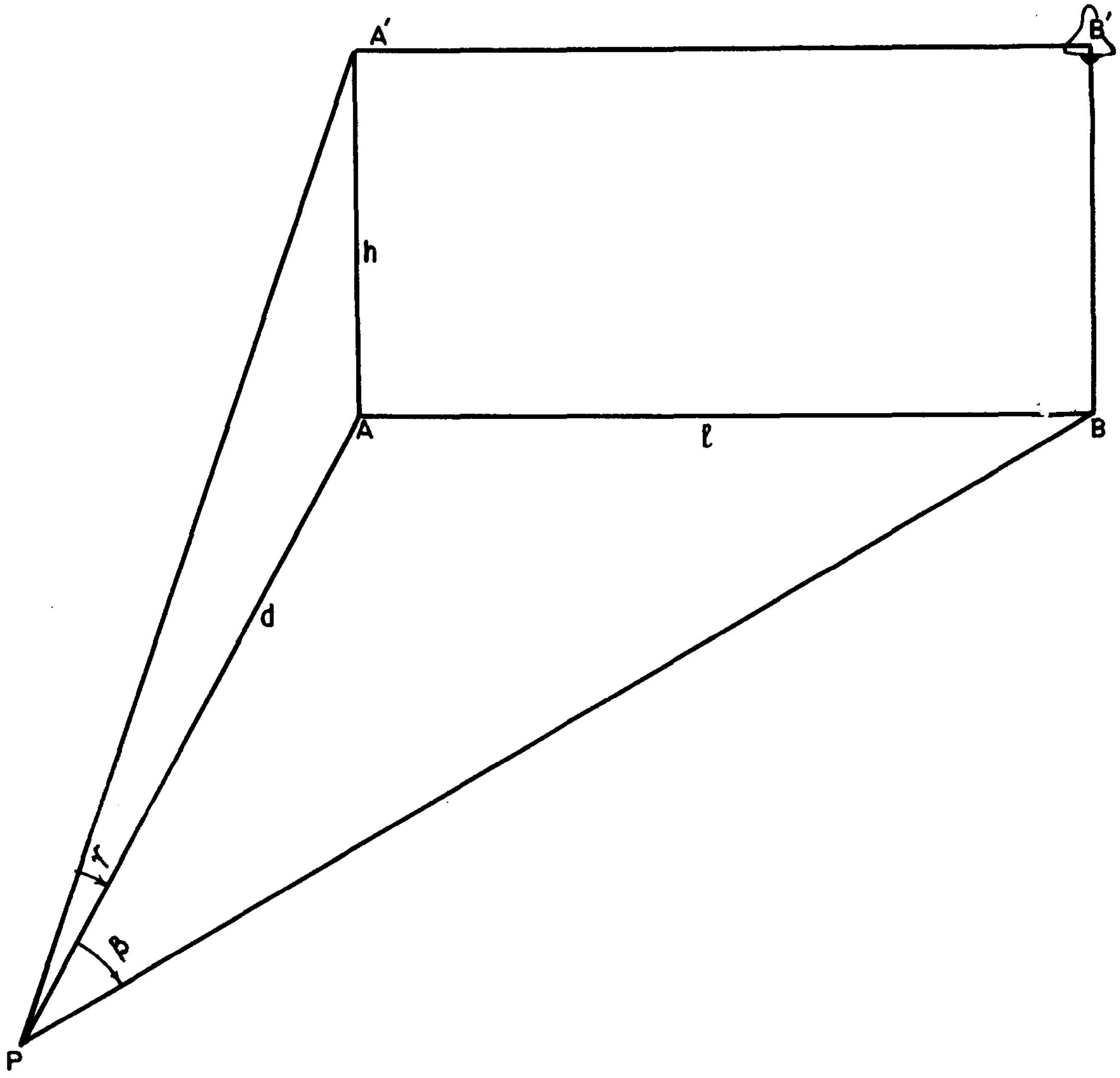
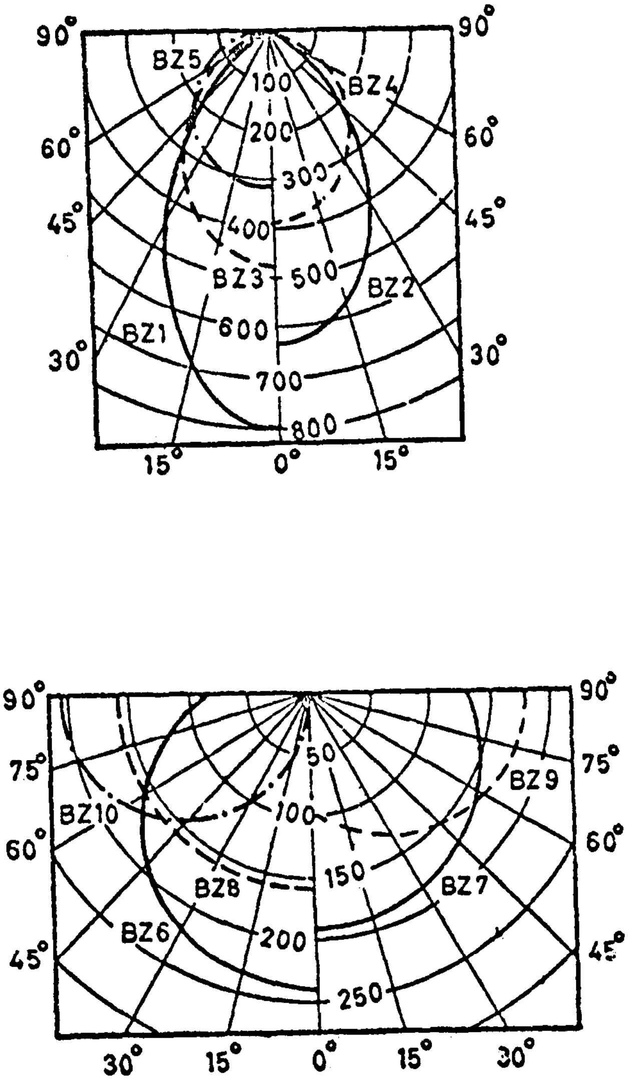


FIG. 36 ANGULAR DISPLACEMENT OF THE SOURCE FROM THE DIRECTION OF VIEWING

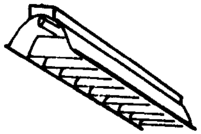
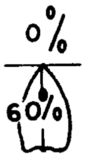
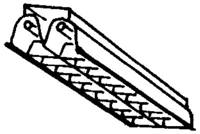
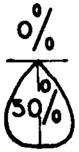


BZ 1 $I \propto \cos^4\theta$
BZ 2 $I \propto \cos^3\theta$
BZ 3 $I \propto \cos^2\theta$
BZ 4 $I \propto \cos^{1.5}\theta$
BZ 5 $I \propto \cos\theta$
BZ 6 $I \propto (1+2\cos\theta)$
BZ 7 $I \propto (2+\cos\theta)$
BZ 8 I·Constant
BZ 9 $I \propto (1+\mathrm{SIN}\theta)$
BZ 10 $I \propto \mathrm{SIN}\theta$

FIG. 37 POLAR CURVES IN THE BZ CLASSIFICATION

TABLE 22 COEFFICIENTS OF UTILIZATION FOR TYPICAL LUMINAIRES WITH SUGGESTED MAXIMUM SPACING RATIOS AND MAINTENANCE FACTORS

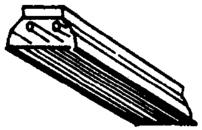
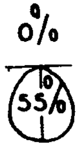
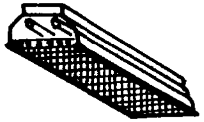
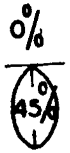
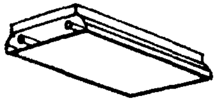
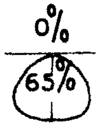
(*Clause* 6.2.5)

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.*

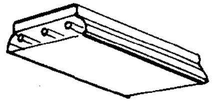
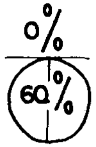
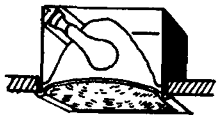
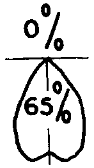
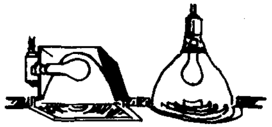
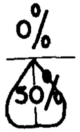
(*Clause* 6.2.5)

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 Troffer Glass, Plastic or 30° Louver 	 	0.9 *H*	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
			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
			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
			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 Troffer with 45° Metal Louver 	 	0.6 *H*	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		
			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	
			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	
			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 Troffer with Prismatic Lens 	 	0.9 *H*	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		
			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	
			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	
			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.*

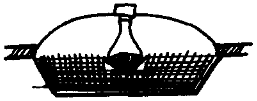
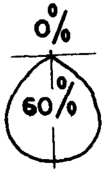
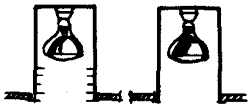
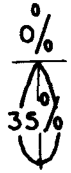
(*Clause* 6.2.5)

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 or Louver			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		
			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.*

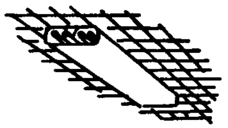
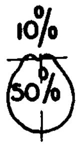
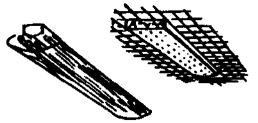
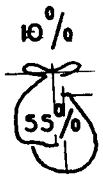
(*Clause* 6.2.5)

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.*

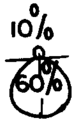
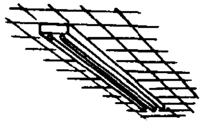
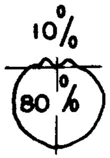
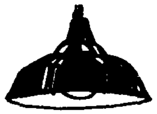
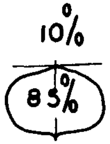
(*Clause* 6.2.5)

Luminaire	Flux 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)
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.*

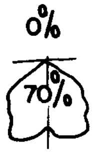
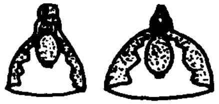
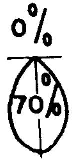
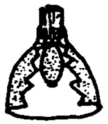
(*Clause* 6.2.5)

LUMINAIRE	FLUX 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)
Diffusing Sides and Prismatic Bottom 		1.1 *H*	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	
			1.5	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 		1.0 *H*	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	
			1.5	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 		1.0 *H*	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
			1.5	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.*

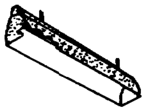
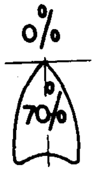
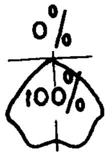
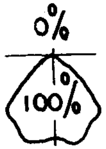
(*Clause* 6.2.5)

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 With Incandescent Lamp 	 	1.0 *H*	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		
			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	
			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	
			1.5	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 Aluminium or Glass Medium Distribution High Bay (Ventilated) 	 	0.9 *H*	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
			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
			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		
			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
			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 Porcelain Enameled Wide Distribution High Bay (Ventilated) 	 	1.0 *H*	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
			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
			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		
			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
			1.5	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.*

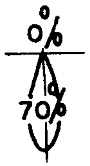
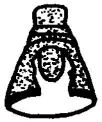
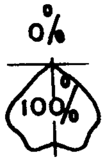
(*Clause* 6.2.5)

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 		1.0 *H*	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
			1.5	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) 		1.0 *H*	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
			1.5	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) 		1.0 *H*	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
			1.5	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.*

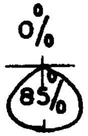
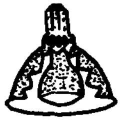
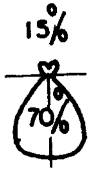
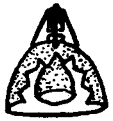
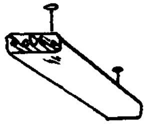
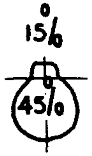
(*Clause* 6.2.5)

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.*

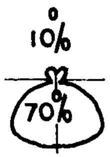
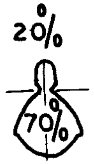
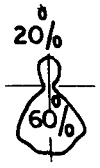
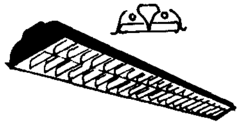
(*Clause* 6.2.5)

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	1 0000 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.*

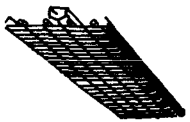
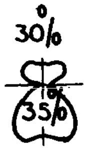
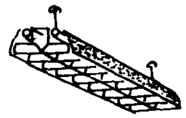
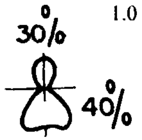
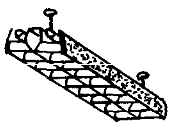
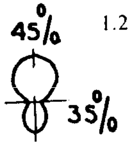
(*Clause* 6.2.5)

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			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
		1.0 *H*	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			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
		1.0 *H*	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			0.6	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
		0.9 *H*	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.*

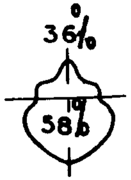
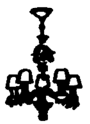
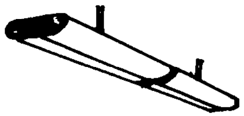
(*Clause* 6.2.5)

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.*

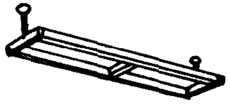
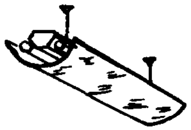
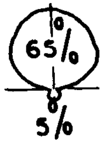
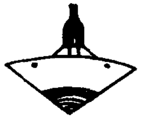
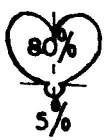
(*Clause* 6.2.5)

LUMINAIRE	FLUX DISTRIBUTION	MAX. SPACING	SURFACE REFLECTANCE													MAINTENANCE FACTOR	
			Floor	0.1			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)
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
	 36% 58%	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
	 35% 23%	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
	 60% 15%	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.*

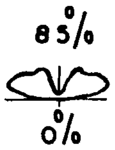
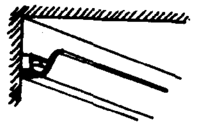
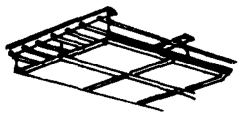
(*Clause* 6.2.5)

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 	 	1.2 *H*	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
			1.5	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 	 	1.2 *H*	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
			1.5	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 	 	1.2 *H*	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
			1.5	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.*

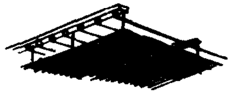
(*Clause* 6.2.5)

LUMINAIRE	FLUX 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)
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 to 40 cm below ceiling	0.8	0.15	0.12	0.10	0.13	0.10	0.08	0.09	0.07	0.06				Good 0.70	
			1.0	0.18	0.15	0.12	0.16	0.18	0.10	0.10	0.09	0.07					
			1.25	0.22	0.18	0.16	0.20	0.16	0.14	0.13	0.11	0.10				Medium 0.60	
			1.5	0.25	0.21	0.19	0.21	0.19	0.17	0.15	0.13	0.11					
			2.0	0.29	0.26	0.22	0.25	0.22	0.20	0.17	0.15	0.14				Poor 0.50	
			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 (White) Extended Area System			0.6	0.19	0.16	0.15	Ceiling cavity reflectance 75%										
			0.8	0.23	0.20	0.19	Louvre surface reflectance 75%									Good	0.70
			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)

d *h*	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′ 100.000	27° 71.400	45° 35.400	56° 17.100	68° 8.980	68° 5.192	71° 3.208	74° 2.112	76° 1.420	78° 1.020	79° 0.760	80° 0.568	81° 0.452	81° 0.360	82° 0.280	82° 0.232	83° 0.19
1.5	0°0′ 44.440	18° 38.000	34° 25.600	45° 15.732	53° 9.600	59° 6.088	63° 4.000	67° 2.720	69° 1.908	72° 1.424	73° 1.056	75° 0.820	76° 0.644	77° 0.504	78° 0.400	79° 0.336	80° 0.28
2.0	0°0′ 25.000	14° 22.828	27° 17.888	37° 12.800	45° 8.840	51° 0.996	56° 4.264	60° 3.056	63° 2.236	66° 1.676	68° 1.280	70° 0.996	72° 0.792	73° 0.636	74° 0.520	75° 0.428	76° 0.36
2.5	0°0′ 16.000	11° 15.084	22° 12.808	31° 10.088	39° 7.616	45° 5.656	50° 4.200	54° 3.140	58° 2.380	61° 1.832	63° 1.432	66° 1.132	67° 0.912	69° 0.740	70° 0.608	72° 0.504	73° 0.42
3.0	0°0′ 11.112	9° 10.692	18° 9.488	27° 7.948	34° 6.400	40° 5.040	45° 3.928	49° 3.064	53° 2.400	56° 1.896	59° 1.512	61° 1.220	63° 0.996	66° 0.820	67° 0.680	68° 0.568	69° 0.48
3.5	0°0′ 8.164	8° 7.920	16° 7.256	23° 6.340	30° 5.344	36° 4.400	41° 3.572	45° 2.888	49° 2.332	52° 1.892	55° 1.540	58° 1.264	60° 1.044	62° 0.872	63° 0.732	65° 0.616	66° 0.52
4.0	0°0′ 6.252	7° 6.108	14° 5.708	21° 5.132	27° 4.472	32° 3.812	37° 3.200	41° 2.688	45° 2.208	48° 1.832	51° 1.524	54° 1.272	56° 1.068	58° 0.900	60° 0.764	62° 0.652	63° 0.56
4.5	0°0′ 4.940	6° 4.848	13° 4.592	18° 4.216	24° 3.772	29° 3.300	34° 2.844	38° 2.428	42° 2.060	45° 1.748	48° 1.480	51° 1.256	53° 1.068	55° 0.912	57° 0.784	59° 0.672	61° 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.*

d *h*	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*×*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*×*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														
2*H*	2*H*	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
	3*H*	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
	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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
4*H*	2*H*	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
	3*H*	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
	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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
8*H*	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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
12*H*	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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 Walls Floor		70 50 14	70 30 14	50 50 14	50 30 14	30 30 14	70 50 14	70 30 14	50 50 14	50 30 14	30 30 14	70 50 14	70 30 14	50 50 14	50 30 14	30 30 14		
Room Dimension *X*×*Y*		Initial Glare Indices															Endwise	Crosswise
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×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	28·7	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 Walls Floor		70 50 14	70 30 14	50 50 14	50 30 14	30 30 14	70 50 14	70 30 14	50 50 14	50 30 14	30 30 14	70 50 14	70 30 14	50 50 14	50 30 14	30 30 14		
Room Dimension *X*×*Y*		Initial Glare Indices															End-wise	Cross-wise
2*H*	2*H*	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
	3*H*	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
	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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
4*H*	2*H*	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
	3*H*	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
	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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
8*H*	4*H*	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
	6*H*	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
	3*H*	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
	12*H*	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
12*H*	4*H*	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
	6*H*	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
	8*H*	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
	12*H*	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*×*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 m^2 have been assumed. For floor area beyond 50 m^2 and less than 30 m^2, 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) cm²	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 m² and greater than 50 m², 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/m^2 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/m^2
70	2.0
100	2.8
125	3.6
150	4.4
175	5.2
200	6.0

NOTE — These values of watts per m^2 should be multiplied by 1.15 and 0.85 for floor area less than 30 m^2 and greater than 50 m^2 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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