DAYLIGHTING IN ARCHITECTURAL DESIGN

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by

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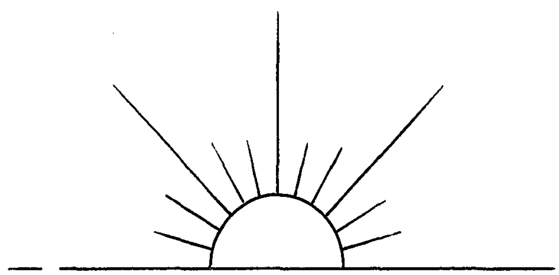

In the beginning, God said

" Let there be light. "

ABSTRACT

Daylight design in architecture is used to provide adequate lighting to the interior and to exclude unwanted light from the room. Since human beings established their shelters with a lighting opening, they have been continuously searching for better methods to obtain suitable natural lighting in the living.

In this thesis, the necessary definitions of lighting and brief methods for calculating daylight are described in Parts I and II. Considerations of daylight control from several important view points, the quantity and quality of daylight, daylight and visual comfort, orientation of buildings for daylight,daylight design in town planning and in various buildings for different purposes, such as school, hospital and house, are set forth in the last part.

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PREFACE

Although daylighting and architectural design have been studied for a long time architectural research into daylighting has increased rapidly in recent years. Daylight has been used in buildings because it is free. Today it is still free but constructing and maintaining window openings is expensive. In North America, especially, where electrical lighting is economical and widely available, natural lighting has become a luxury which provides its users with a better working environment and more enjoyable living conditions.

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INTRODUCTION

Architectural daylighting forms part of architectural physics and deals with natural light in buildings. Its purpose is to meet every requirement for good visual work and healthy environments by providing optimum illumination in a room.

In practice, improving the utilization of the interminable natural light would save millions of amps of electricity.

However, the most important criteria for providing natural lighting in buildings is not limited to economic questions. Lighting is important for human physiological and sanitary well-being because man has been used to living in an environment of natural lighting. Besides this, sunlight has an important effect on the human psychological state.

The effect of natural light on the form of buildings is also very important. In many buildings planning, elevations, interior decoration and colour selection are dependent on the availability of natural light. These factors have all provided the field of architectural lighting with the impetus responsible for its recent development.

Some people think that natural light is free while we are using it in our buildings. Actually, we spend a great amount of money erecting a light opening and maintaining it. The expense depends on window size, shape of the opening, method of construction of the light opening, the type of climate in the region and also the main purpose of the building.

The importance of economic and health factors of natural lighting depend on the level of illumination in the room, the modes of lighting used, the window construction and colour of the glass. In each case, if we wish to obtain reasonable lighting, we should consider the climate, the use of the rooms and the speciality of visual work.

In factories, suitable design of lighting is an efficient method not only to increase the productivity, but also to improve the quality of production. It may also reduce the ratio of waste products and decrease the frequency of occupation sickness.

In domestic and public buildings, adequate lighting can improve the visual and health conditions, so that it protects the human being.

In conclusion, if we wish to design adequate natural lighting for buildings, we ought to plan the most suitable design for the openings by calculating the illumination and arranging the openings or windows to coincide with the requirements of the lighting standard.

PART I

ARCHITECTURAL DAYLIGHTING IN GENERAL

Section A History of Architectural Daylight

Man likes natural light and he desires to have it in the house at all times. Light is as important as water and air for human health. In primitive period, man lived in the trees receiving air and sun-light. After he came down from the trees in order to escape the wild beasts, numbing cold, enervating heat, drenching rains and bitter winds, he went into a cave — a dark enviroment. Then, he emerged to a hut. Caves and huts were windowless and gloomy. There was no material at hand to keep the weather out and let light in at the same time. However, being a light-loving animal, man innovated a means by which to admit light. He brought light into his home through the doorway at first, and then from the smoke outlet of the roof. It was the beginning of that centuries - long struggle for lighting.

Later on, the primitive householder built a small " window " in the wall; he modified his door to a hatch or half-door arrangement, by which he gained a certain amount of illumination and protection against the weather at the same time.

These first " window ", wall or roof openings, were constructed without covering or were covered by opaque materials, such as wood, woven thatch, rushes, leaves or stone sheets, which then they were covered with animal skins or cloth, and as a result, light was kept from the room. Gradually, these materials were supplanted by translucent stone, such as gypsum, or translucent sheets of marble, or by sheets, mica, or alabaster, or parchment, oiled paper or oiled linen. (A-1)

Eventually, glass was discovered, probably in the second millennium before the time of Christ. With its discovery man had an increasingly efficient means of admitting light to his home. The Romans were likely the first people to use glass for windows. They learned the manufacture of glass from the Egyptians when Egypt became a province of their empire. However, they exploited glass chiefly for decorative purposes; and its development was not sufficient to displace stone, cloth, or shells entirely as a window covering because glass was deemed mysterious and it was produced in extreme secret. At that time glass was a precious item that only the rich and powerful could use. During the early Middle Ages, the church began to use glass for windows in a host of edifices. Clear glass was combined with small pieces of coloured glass to admit coloured light thereby producing a holy, religious environment. But the use of glass for domestic homes was still economically impossible and far away. In the latter years of the sixteenth century, when glass became economically available and common, it began to be extensively used for domestic windows. (A-1, A-2)

However, it was only a temporary victory in the ancient struggle for natural lighting, and the proper evolution of natural lighting was limited and bound by the window tax which lasted from 1695 to 1851 in Europe. In nineteenth century, it also was restricted by the deliberate rejection of its technical possibilities by the architects and their spurious interest in styles. Since the late Victorian era, a growing appreciation of the scientific principles of admitting daylight to buildings has gradually influenced architectural design. After the eighteenth century architects have been free to use as much daylight as possible. (A-2)

Daylight in architectural design was investigated systematically only in the last century. Architects and engineers researched different ways of providing adequate illumination. They found some methods to calculate daylight. After the Second World War, the investigation of daylight in England and America became very progressive. (A-3)

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Section B Significance of Daylighting in Architectural Design

B.1 Definitions and units of illumination

Light is a form of energy radiating from a luminous body. Daylight design in architecture involves the physics of natural radiant energy. According to the various wave lengths, radiation may be divided into three kinds : a) The wave lengths from 0.001 to 0.00038 mm known as ultra-violet radiation ; b) The wave lengths from 0.00038 to 0.00077 mm termed visible radiation and c) The wave lengths from 0.00077 to 0.34 mm known as infra-red radiation (see Fig. 1-1). The visible radiation, which affects the optic nerves thereby producing the sensation of sight, is known as light. (B-1, B-2)

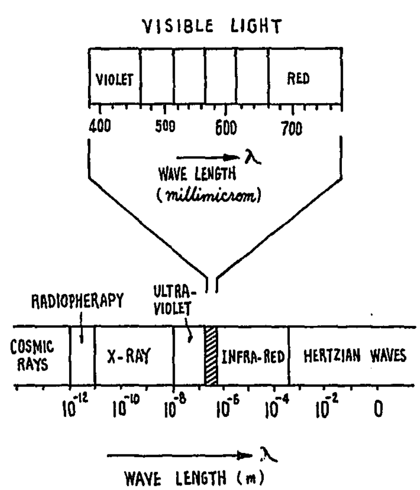


Fig. 1-1 Spectrum of radiant energy of sun

RADIANT FLUX (F) is the time rate of radiant energy in any part of the spectrum. There is monochromatic radiant flux which is formed by the radiation of one wave-length and polychromatic radiant flux that is formed by several monochromatic radiant fluxs of various wave-lengths. Natural light-source radiates the polychromatic radiant fluxs with the property of continuous spectrum. The polychromatic radiant flux of daylight is combined by monochromatic radiant fluxs to innumberable wave-lengths with continuous change. (B-2, B-3)

LUMINOUS FLUX (F) is the time rate of flow of light. It is also a measure of the efficiency of the radiator. Radiant flux within the limits of 4,000 to 7,600 angstroms (400 to 760 millimicrons) is simply luminous flux. The unit of luminous flux is LUMEN (lm). " It is equal to the luminous flux through a unit solid angle (steradian) from a uniform point source of 1 candle, or the luminous flux received on a unit surface all points of which are unit distance from a uniform point source of 1 candle. " (B-1, B-3)

In the English system, the unit surface is 1 square foot (sq.ft.), and the unit distance is 1 foot (ft.). In the metric system, when the unit surface is 1 square meter (sq.m), the unit distance is 1 meter (m). When the area is 1 square centimeter (sq.cm.) the unit distance is 1 centimeter (cm.). Because the element of time is ordinarly omitted, the lumen may be considered as the unit quantity of light.

Under the coagulative temperature condition of platinum, the value of luminous flux which radiates from absolute black substance of

5305×10^{-10} sq. m is 1 lumen. The value of lumen can be obtained in the following manner : in a bright summer day the luminous flux to ground surface per square centimeter is 1 lumen; but it is about 10 lumens when the sunlight shines directly. (B-4)

INTENSITY (I) is the solid angular flux density in a given direction.

It is flux divided by the solid angle over which the flux is distributed. Its unit is the CANDLE (c) $I = \frac{dF}{dw}$ (B-3, B-4)

ILLUMINATION (E) is the density of the luminous flux on a surface, hence it is flux divided by the area over which the flux is distributed. $E = \frac{dF}{dS}$

The unit of illumination is FOOT-CANDLE (ft-c). Foot-candle is the illumination produced on or at a surface all points of which are at a distance of 1 foot from a uniform point source of 1 candle. It is also the illumination produced by spreading 1 lumen uniformly over an area 1 foot square. In the metric system the illumination is measured in units of lux. (B-3, B-4)

BRIGHTNESS (B) is the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. Our eyes are sensible to the amount of brightness.

FOOT-LAMBERT (ft-l) is the unit of brightness. It is a perfectly diffusing surface emitting or reflecting light at the rate of 1 lumen per square foot. (B-2, B-3)

B.2 Luminous properties of a substance

The luminous properties of any substance such as building materials are denoted by the following properties :

a. Variations in the reflection, absorption, transmission and refraction by the material on which the luminous flux falls.

b. Changes in the distribution of radiant flux with wavelength as a result of the interactions of the material and the incident radiant flux.

c. The distribution of reflective and transmissive luminous fluxes in a room.

The reflectance of substance can be denoted by the reflection factor (P). It is equal to the ratio of the light reflected (Fp) by a body to the incident light (Fi).

$$P = \frac{Fp}{Fi}$$

The property of absorption of a substance can be decided by the absorption factor (α) which is equal to the ratio of the light ($F\alpha$) absorbed by a body to the incident light (Fi).

$$\alpha = \frac{Ft}{Fi}$$

The transmissive property can be appraised by the transmission factor (t). It is equal to the ratio of the light (Ft) transmitted by a body to the incident light (Fi).

$$t = \frac{Ft}{Fi}$$

(B-2, B-3)

B.3 Sun and sky as sources of light

The sun is the original source of daylight. It shines directly and indirectly on both the exterior and interior of the building. The sun produces a strong and powerful flux of radiant energy. Part of this light flux known as sunlight reaches the earth's surface after passing directly through the atmosphere. The rest of the radiant energy is diffused by multiple reflection as it passes through the atmosphere and produces a diffuse light. The quantity of daylight received by a given building is continually changing, because the source of light, the sun, is constantly changing its position relative to the building. (B-5)

In Canada and Northern United States and many other parts of the world we cannot rely on the direct light of the sun as our basic illuminant. Here we only see the sun for about 1/3 of our waking hours, and then only in rooms which are orientated to the sunlight. We therefore have to plan our daylighting on the basis that the sky is our source of light. (B-6)

In order to understand some of the simplier problems of daylighting illumination we assume the whole sky appears to be a uniform hemisphere. It follows that as the sun gets higher in the heavens the sky will be brighter. In actual fact, the blue sky is usually brighter near the horizon, and darkest at a point perpendicular to the sun, whereas the overcast sky is brightest at the zenith, and only 1/3 as bright at the horizon. Fig. 1-2 shows the brightness distribution of C.I.E. Standard Overcast Sky expressed as a relation between the average brightness (luminance) and the angle of altitude.

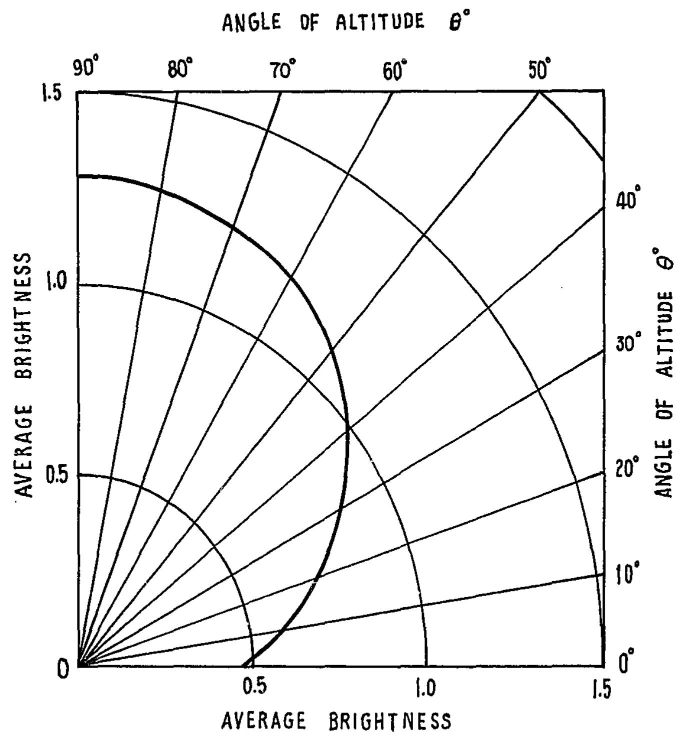


Fig. 1-2 The relation between the average brightness (luminance) and the angle of altitude

Now the amount of useful daylight at any point within a room is directly proportional to the area of sky that can be seen from that point through the lighting opening. If no sky is visible from a point in the room, the daylight at that point is not sufficient for any normal purpose. (B-6)

The proportions of the natural light coming from the sun and from the sky vary greatly. When the sun is at low elevations at noon with a clear sky as much as 1/6 of the light may come from the sky and 5/6 from direct sunlight. At observatories high in the mountains on very clear days it has been found that as little as 1/10 of the light which reaches the earth comes from the sky and 9/10 comes directly from the sun. (B-7)

Thin clouds increase the amount of diffused light and decrease the amount of direct light, thus varying the ratio. Sunlit cumulus clouds are much brighter than a clear blue sky even if the latter be hazy. The amount of light received from such a sky may be as much as 1/3 to 2/5 of the total light received from the sky and sun together when the sun is visible. When the sky is completely overcast with white clouds the light received from the clouds may equal that received from the sun. Light from a clear blue sky does not vary greatly in intensity during a considerable portion of the day (see Fig. 1-3). (B-8)

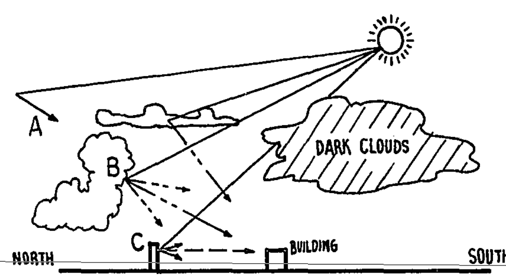
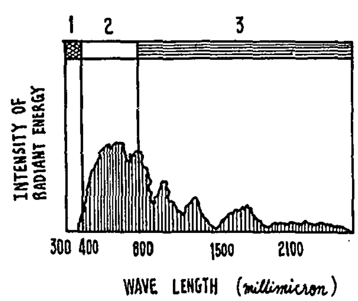


Fig. 1-3 Aspects of Brightness
Reflected light from clouds (B) is brighter than from a clear sky (A). A white wall (C), even if it stands in the shade, is a more powerful reflector than sky (A)

B.4 Direct and diffuse light

B.4.1 Direct sunlight

The sun, which is effectively a large radiator with a black body temperature about 6000° C, transfers a lot of radiant energy to the universe. The amount of the energy which reaches the surface of the earth is only 0.5×10^{-9} of the sun's output. Fig. 1-4 shows that the distribution of radiant energy at the earth's surface as a function of wavelength is very non-uniform. The maximum energy is between the wave-length from 380 to 770 millimicron in the visible part of the spectrum. Visible radiation constitutes 52% of the total solar radiant energy. (B-8, B-9)

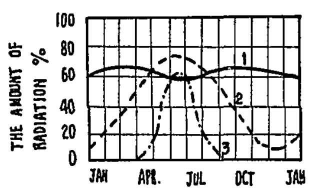


1, ultraviolet
2, visible portion
3, infra-red

Fig.1-4 The distribution of solar radiant energy on the earth.

The solar coefficient denotes the amount of solar radiation which is received from each sq.cm on the surface perpendicular to the radiant energy flux in a minute. Its unit of measure is the calore. The standard of measurement in America is 1,938 $^{cal}/cm^2$ min = 0.135 $^{watt}/cm^2$. In Europe it is 1,895 $^{cal}/cm^2$ min = 0.132 $^{watt}/cm^2$. Using this value, we can obtain the amount of radiation on a given unit surface for a day, night, month or year, because the amount of solar radiation is determined by the latitude of that region. Since light can be diffused and absorbed by the molecules of water vapour and dust particles floating in the air, the atmospheric state (transparency) affects the exterior illumination and radiation. In the sky above cities and industrial regions, the air contains more floating dust and smoke particles which reduce the natural illumination and solar radiation. (B-9)

The annual amount of solar radiation received at different latitudes can be denoted by a curve in Fig. 1-5. This curve is based on the value 0.75 for the atmospheric transparency coefficient. At the equator the quantity of solar radiation received at the surface of the earth per day remains relatively constant. This results from the very small variations in daylength which occur throughout the year. At the



1 —— at Equator
2 ---- at the North latitude 45°
3 -·-·- at North Pole

Fig. 1-5 The distribution of the solar radiation in the year.

North Pole the amount of solar radiation is concentrated in six months of the year between April and September. In the region north of latitude 45°N, the daily amount of radiation exceeds the amount received at Equator between May and August. Practically, however, this ratio can be changed by the clouds in the sky.

The composition of solar spectrum also varies for direct radiation. Fig. 1-6 shows the relation between the composition of solar spectrum and sky cover. (B-8, B-9)

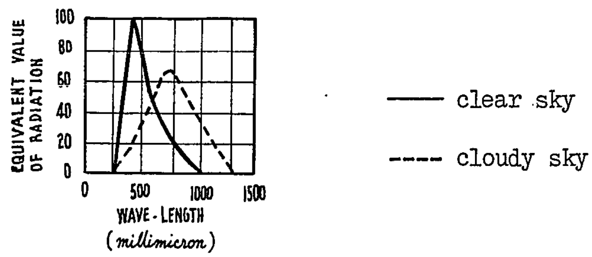


Fig. 1-6 The composition of the spectrum of solar radiation.

The ratio of the diffusing radiation and direct radiation in a year relates to the solar angle of height and the transparency of atmosphere. Under clear sky, this ratio ranges from 6 to 27%. Under cloudy sky, even if there is not much cloud cover this value may increase to 65% or more. Now we may find the value of external illumination using the solar radiant references. Fig. 1-7 shows that the efficiency of illumination is related to the angle of solar elevation. (B-10)

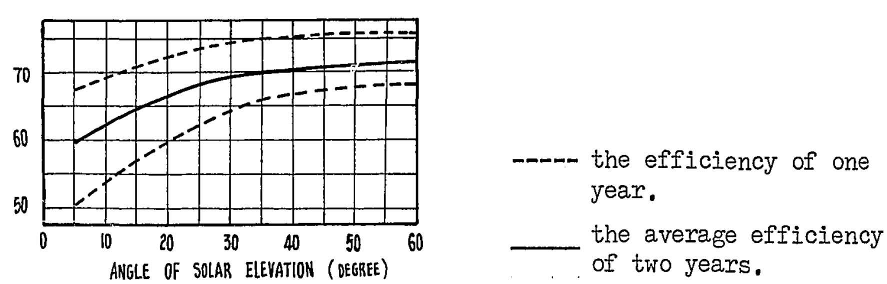


Fig. 1-7 The efficiency of illumination relates.

B.4.2 Diffused skylight

Diffused skylight results from the multiple reflection of sunlight by small molecules of water vapour and dust floating in the atmosphere. Therefore, both the quantity and type of clouds in the atmosphere have a large effect on the diffusing illumination. (B-9)

The various kinds of cloud are determined by their shape and composition. They are divided into high clouds composed of ice crystals and low clouds formed from water vapour.

The quantity of cloud is measured visually by specifying the number of tenths of the sky covered by cloud. Eleven classes of cloud quantity exist ranging from 0 for a clear sky to 10 for overcast conditions.

The value of illumination may be affected by various cloud types. Under high clouds, the level of illumination may be increasing to 70,000 lux as the solar angle of height is very high. Under low clouds, the illumination decreases to such a low value that one has to use artificial light in daytime. The illumination of diffusing skylight on a sunny day is not exceeding 20,000 lux. (B-8, B-10)

The atmospheric transparency and covering material of ground surface has an important effect on the illumination. Table I-1 lists the reflective coefficients of several surfaces. We may rely on these values in computations of the quantities of illumination available in various designs. (B-11, B-12)

Table I-1 The reflective coefficient of ground surfaces covered with various materials

Type of ground surface	Coefficient of reflection
covering with :	
snow	0.8 - 0.7
light colour gypsum board	0.4 - 0.3
white sands	0.3 - 0.2
smooth ground	0.3 - 0.07
yellow sands	0.2 - 0.15
asphalt	0.12- 0.1
green grass	0.1 - 0.06

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PART II

CALCULATION OF DAYLIGHT

Section A Daylight Calculation According to the Meteorological Conditions

The most important aspect of daylight calculation and design results from the variable nature of the source. The results of calculation are depend on external conditions, which vary with the time of day, the date in the year, and with the weather.

In America it is usual to consider two types of weather conditions : (1) an overcast sky and (2) a clear sky with or without sunlight. In Europe and particularly the British Isles the former condition is so common that it is necessary to base daylighting techniques on the provision of minimum standards of lighting - under overcast conditions alone. This fact constitutes the basic difference in American and British approaches. With clear sky conditions it is possible and practical to work with actual values of illumination that will vary considerably with orientation, location, and season. Where overcast skies are more common, over small changes in latitude, it is practical to think of the light admitted as a percentage of the total light available from the hemisphere of the sky while ignoring orientation and location. (A-1)

In order to cover the wide range of climatic conditions calculations must cover :

(1) clear sky conditions with sunlight and

(2) overcast sky conditions

The clear sky conditions will be dealt with first using American methods, and then overcast sky conditions will be handled by British methods of calculation.

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A-1 Lighting in Architectural Design by Derek Phillips, McGraw-Hill Book Company, New York, 1964. P. 233.

Section B The American Method of Computing Daylight

B.1 Clear sky with sunlight

B.1.1 Brief description of method

This method is described in a report " Predicting Daylight as Interior Illumination " by J. W. Griffith at Southern Methodist University, Dallas, Texas. By using this method, the total illumination on the window is determined first, and from this, by means of prepared table, the illumination on the working plane is found. The tables provide coefficients of utilization on a similar basis to the Lumen Method used for interior lighting calculations. (B-1)

B.1.2 The illumination on the window

The illumination on the window is made up of the following item :

a) Illumination on the window from the Sky — The window illumination will also contain a sunlight component when the room is orientated toward the sun. (Fig. 2-1 & 2-2)

Since the brightness of the sky varies with the time of day and year and the position of the sun (altitude and azimuth) in relation to the window, to determine the illumination from the sky we must :

1. Find the solar altitude and azimuth for the particular location by referring to Table II-1 ,

2. Use these figures to find the illumination on a vertical surface (E_V) from Fig. 2-5 or 2-6 for a given building orientation.

3. In the case of direct sunlight falling on the window, the illumination is found from Table II-2.

Illumination from sun on window (E_S)

$$= E \times \cos \phi \times \cos \theta$$

where E = illumination (in foot candles) perpendicular to sun's ray.

ϕ = azimuth angle from normal

θ = altitude angle from normal

4. Total illumination on window from sky (E sky)

$$E\ sky = E_V + E_S$$

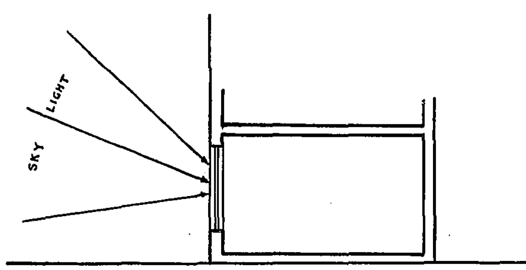


Fig. 2-1 Illumination from Sky on the window.

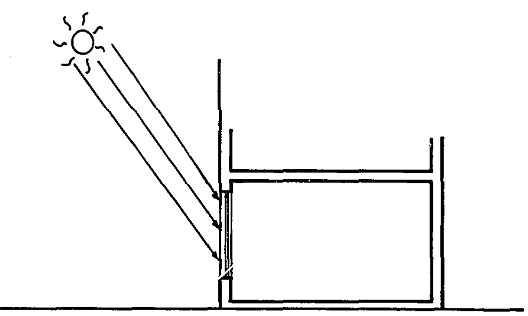


Fig. 2-2 Illumination from direct sunlight on the window.

b) The Illumination on the window Reflected from the Ground

1. Reflection from the ground of the sky illumination (Fig. 2-3) :

In order to determine the reflection from the ground of the sky illumination, we use the formula :

Illumination on window due to reflection of sky illumination from the ground (E_{r1})

$$= 0.5 \ (E_{g1} \times P_g)$$

where E_{g1} = illumination on ground (horizontal surface) from clear sky —— from Fig. 2-5 and 2-6

P_g = reflection factor of ground —— from Table II-3

2. Reflection from the ground of sunlight (Fig. 2-4):

In order to determine the reflection from the ground of sunlight, we use the formula :

Illumination on window due to reflection of sunlight from the ground (E_{r2})

$$= 0.5 \ (E_{g2} \times P_g)$$

where E_{g2} = illumination on the ground from sunlight —— the value for horizontal planes in Table II-2.

3. The total illumination reflected from the ground

$$E \text{ ground} = E_{r1} + E_{r2} \qquad (B\text{-}2)$$

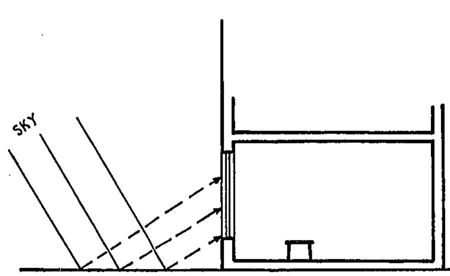


Fig. 2-3 Reflection from the ground of the sky illumination.

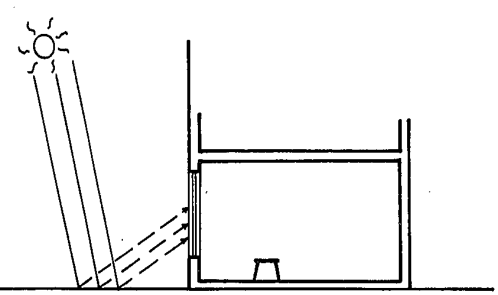
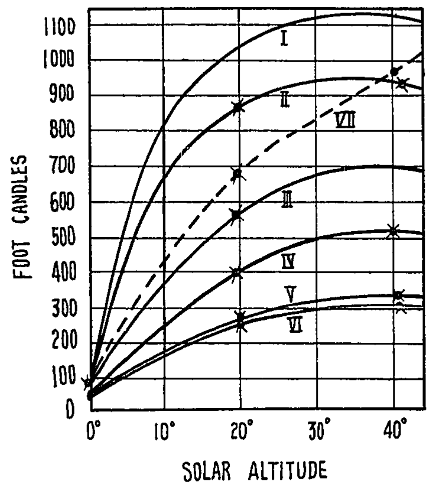


Fig. 2-4 Reflection from the ground of sunlight.

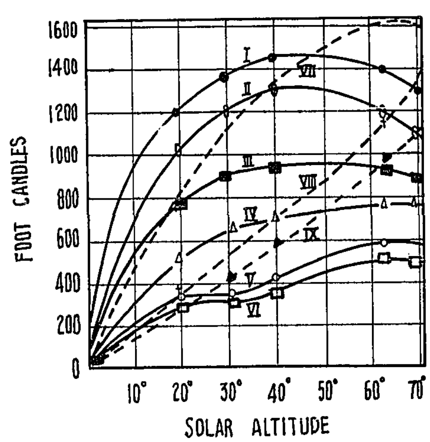
Table II-1 Solar Altitude and Azimuth for Different Latitudes

Latitude		Date	Solar time						
			A.M.—6	7	8	9	10	11	Noon
			P.M.—6	5	4	3	2	1	
			Angle, deg						
30°N	Altitude	June 21	12	24	37	50	63	75	83
		Mar, Sept 21		13	26	38	49	57	60
		Dec 21			12	21	29	35	37
	Azimuth	June 21	111	104	99	92	84	67	0
		Mar, Sept 21	90	83	74	64	49	28	0
		Dec 21		60	54	44	32	17	0
34°N	Altitude	June 21	13	25	37	50	62	74	79
		Mar, Sept 21		12	25	36	46	53	56
		Dec 21			9	18	26	31	33
	Azimuth	June 21	110	103	95	90	78	58	0
		Mar, Sept 21	90	82	72	61	46	26	0
		Dec 21			54	43	30	16	0
38°N	Altitude	June 21	14	26	37	49	61	71	75
		Mar, Sept 21		12	23	34	43	50	52
		Dec 21			7	16	23	27	28
	Azimuth	June 21	109	101	90	83	70	46	0
		Mar, Sept 21	90	81	71	58	43	24	0
		Dec 21			54	43	30	16	0
42°N	Altitude	June 21	16	26	38	49	60	68	71
		Mar, Sept 21		11	22	32	40	46	48
		Dec 21			4	13	19	23	25
	Azimuth	June 21	108	99	89	78	63	39	0
		Mar, Sept 21	90	80	69	56	41	22	0
		Dec 21			53	42	29	14	0
46°N	Altitude	June 21	17	27	37	48	57	65	67
		Mar, Sept 21		10	20	30	37	42	44
		Dec 21			2	10	15	20	21
	Azimuth	June 21	107	97	88	74	58	34	0
		Mar, Sept 21	90	79	67	54	39	21	0
		Dec 21			52	41	28	14	0
48°N	Altitude	June 21	17	27	37	47	56	63	65
		Mar, Sept 21		10	20	29	36	40	42
		Dec 21			1	8	14	17	19
	Azimuth	June 21	106	95	85	72	55	31	0
		Mar, Sept 21	90	79	67	53	38	20	0
		Dec 21			52	41	28	14	0



Curve I - clear sky, vertical surface facing 0° azimuth from sun;
Curve II - clear sky, vertical surface facing 45° azimuth from sun;
Curve III - clear sky, vertical surface facing 70° azimuth from sun;
Curve IV - clear sky, vertical surface facing 90° azimuth from sun;
Curve V - clear sky, vertical surface facing 135° azimuth from sun;
Curve VI - clear sky, vertical surface facing 180° azimuth from sun;
Curve VII - clear sky, horizontal surface.
(Courtesy I.E.S. Handbook)

Fig. 2-5 Curves of winter skylight illumination on different surfaces.



Curve I - clear sky, vertical surface facing 0° azimuth from sun;
Curve II - clear sky, vertical surface facing 45° azimuth from sun;
Curve III - clear sky, vertical surface facing 70° azimuth from sun;
Curve IV - clear sky, vertical surface facing 90° azimuth from sun;
Curve V - clear sky, vertical surface facing 135° azimuth from sun;
Curve VI - clear sky, vertical surface facing 180° azimuth from sun;
Curve VII - clear sky, horizontal surface;
Curve VIII - cloudy sky, horizontal surface (Note: double the intensity scale);
Curve IX - cloudy sky, vertical surface.
(Courtesy I.E.S. Handbook.)

Fig. 2-6 Curves of summer skylight illumination on different surfaces.

Table II-2 Average Solar Illumination

Latitude	Plane	December 21			March, Sept. 21			June 21		
		8 A.M. 4 P.M.	10 A.M. 2 P.M.	Noon	8 A.M. 4 P.M.	10 A.M. 2 P.M.	Noon	8 A.M. 4 P.M.	10 A.M. 2 P.M.	Noon
		Illumination, ft-c								
30°N	Perp.†	4,200	7,000	7,700	6,400	8,300	8,600	7,700	8,600	8,900
	Horiz.‡	700	3,400	4,400	2,600	5,900	7,000	4,600	7,200	8,500
34°N	Perp.	3,100	6,500	7,100	6,300	8,100	8,400	7,600	8,600	8,900
	Horiz.	400	2,700	3,700	2,400	5,600	6,700	4,600	7,100	8,400
38°N	Perp.	2,500	6,000	6,900	6,100	8,000	8,300	7,600	8,500	8,900
	Horiz.	200	2,000	3,000	2,100	5,400	6,200	4,600	7,000	8,300
42°N	Perp.	2,000	5,500	6,400	6,000	7,800	8,200	7,600	8,400	8,800
	Horiz.	100	1,600	2,700	2,000	4,800	5,800	4,600	6,800	7,900
46°N	Perp.	500	4,500	5,800	5,800	7,600	8,100	7,600	8,100	8,800
	Horiz.		1,000	1,800	1,800	4,400	5,500	4,600	6,700	7,400

+ Perpendicular to the sun's rays.
‡ Tangent to the earth's surface.

Table II-3 Reflectances of Building Materials and Outside Surfaces

Material	Reflectance per cent
Asphalt (free from dirt)	7
Bluestone, sandstone	18
Brick :	
light buff	48
dark buff	40
dark red glazed	30
Cement	27
Concrete	55
Earth (moist cultivated)	7
Granite	40
Granolite pavement	17
Grass (dark green)	6
Gravel	13
Macadam	18
Marble (white)	45
Paint (white)	
new	75
old	55
Slate (dark clay)	8
Snow	
new	74
old	64
Vegetation (mean)	25

From I.E.S. Handbook, Fig. 9.47.

B.1.3 Working plane illumination

This is used to determine the interior illumination from the illumination on the window. Figs.2-7 and 2-8 show the working plane illumination from the sky and ground. The formulas used are :

a) Working plane illumination from the sky (E_{w1})

$$= E_{sky} \times A \times C \times K_c \times K_{1-w}$$

where E_{sky} = illumination from the sky.

A = area of window transmitting light

C = coefficient of utilization for sky; it varies with different room lengths and different controls on the windows (Table II-4, II-6 or II-8)

K_c = factor for ceiling height (Table II-9, II-11 or II-13)

K_{1-w} = factor for length and width of room; only applies where horizontal louvers are in use (Table II-14)

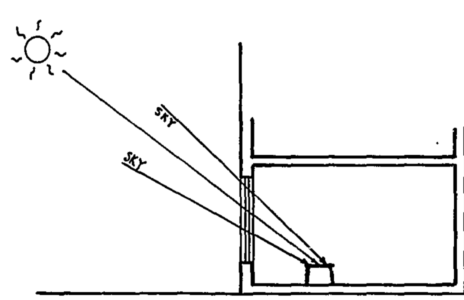


Fig.2-7 Working plane illumination from the sky.

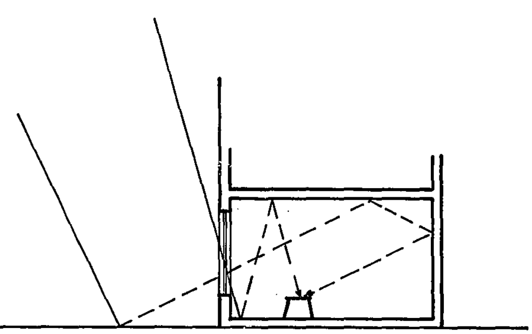


Fig.2-8 Working plane illumination from the ground.

b) Working plane illumination from the ground (E_{w2})

$$= E_g \times A \times C \times K_c \times K_{1-w}$$

where E_g = area of window transmitting light

C = coefficient of utilization for the ground (Table II-5 or II-6)

K_c = factor for ceiling height (Table II-10 or Table II-12)

K_{1-w} = factor for length and width of room ; only applies where horizontal louvers are in use (Table II-15)

In the tables, the dimensions of rooms should be read as follows :

1. Room width — Dimension of rooms measured between window and the rear wall. For bilaterally lit rooms, it is the distance from window wall to window wall.

2. Room length – Dimension between walls at right angles to window.

c) The total working plane illumination

$$E_w = E_{w1} + E_{w2} \qquad \text{(B-3)}$$

The major disadvantage of applying this method in Canada results from our scarcity of reliable records of sky brightness. It is possible to use the figures for sky brightness contained in the tables, appropriate for United States conditions, and to compare the relative efficiency of different building designs without being too concerned about absolute values.

Similar tables and data are available for use with overcast skies, but as techniques for calculation with overcast skies have reached an advanced stage in Europe where this condition is more usual, the methods of calculation described will be those developed in Britain.

Table II-4 Coefficients of Utilization (C) for Clear Sky with No Control on Window*

Position	Width, ft	Length					
		20 ft		30 ft		40 ft	
		Wall reflectance					
		70%	30%	70%	30%	70%	30%
Max	20	0.0185	0.0156	0.0129	0.0111	0.0099	0.0088
	30	0.0183	0.0156	0.0123	0.0108	0.0088	0.0083
	40	0.0180	0.0151	0.0118	0.0107	0.0086	0.0082
Mid	20	0.0138	0.0094	0.0090	0.0071	0.0075	0.0060
	30	0.0074	0.0049	0.0056	0.0039	0.0041	0.0033
	40	0.0047	0.0029	0.0036	0.0025	0.0026	0.0021
Min	20	0.0095	0.0054	0.0071	0.0044	0.0060	0.0039
	30	0.0049	0.0025	0.0042	0.0021	0.0029	0.0019
	40	0.0028	0.0013	0.0024	0.0012	0.0019	0.0011

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-5 Coefficients of Utilization (C) for Uniform Ground with No Control on the Window*

Position	Width, ft	Length					
		20 ft		30 ft		40 ft	
		Wall reflectance					
		70%	30%	70%	30%	70%	30%
Max	20	0.0132	0.0101	0.0092	0.0079	0.0073	0.0064
	30	0.0127	0.0101	0.0088	0.0079	0.0069	0.0063
	40	0.0123	0.0101	0.0084	0.0077	0.0065	0.0062
Mid	20	0.0115	0.0081	0.0085	0.0064	0.0066	0.0054
	30	0.0075	0.0051	0.0056	0.0043	0.0045	0.0037
	40	0.0050	0.0033	0.0040	0.0030	0.0038	0.0023
Min	20	0.0095	0.0064	0.0074	0.0049	0.0060	0.0040
	30	0.0046	0.0023	0.0037	0.0021	0.0030	0.0019
	40	0.0026	0.0016	0.0023	0.0011	0.0020	0.0010

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-6 **Coefficients of Utilization (*C*) Based on Horizontal Louver Adjustment with Sun and Sky as Source***

Sun angle, deg	Position	Louver angle: 30 deg, Wall reflectance 70%	30 deg, 30%	45 deg, 70%	45 deg, 30%	60 deg, 70%	60 deg, 30%
15	Max	0.0687	0.0554	0.0426	0.0346	0.0218	0.0162
	Mid	0.0488	0.0341	0.0371	0.0218	0.0195	0.0110
	Min	0.0376	0.0228	0.0276	0.0156	0.0142	0.0078
30	Max	0.0630	0.0500	0.0394	0.0312	0.0208	0.0156
	Mid	0.0462	0.0324	0.0337	0.0216	0.0176	0.0110
	Min	0.0342	0.0204	0.0250	0.0143	0.0130	0.0071
45	Max	0.0553	0.0434	0.0345	0.0274	0.0198	0.0141
	Mid	0.0416	0.0301	0.0304	0.0211	0.0158	0.0105
	Min	0.0308	0.0182	0.0225	0.0127	0.0117	0.0064
60	Max	0.0464	0.0362	0.0313	0.0236	0.0190	0.0135
	Mid	0.0370	0.0264	0.0270	0.0185	0.0140	0.0092
	Min	0.0274	0.0159	0.0199	0.0111	0.0104	0.0056

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-7 **Coefficients of Utilization (*C*) Based on Horizontal Louver Adjustment with Uniform Ground as Source***

Position	Louver angle: 30 deg, Wall reflectance 70%	30 deg, 30%	45 deg, 70%	45 deg, 30%	60 deg, 70%	60 deg, 30%
Max	0.150	0.108	0.141	0.102	0.087	0.063
Mid	0.141	0.094	0.118	0.077	0.067	0.043
Min	0.124	0.072	0.096	0.056	0.049	0.028

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-8 **Coefficients of Utilization (C) for a Uniform Sky (or a Window with a Diffusing Blind)***

Position	Width, ft	Length: 20 ft, Wall reflectance 70%	20 ft, 30%	30 ft, 70%	30 ft, 30%	40 ft, 70%	40 ft, 30%
Max	20	0.0222	0.0195	0.0157	0.0137	0.0115	0.0108
	30	0.0217	0.0193	0.0149	0.0136	0.0108	0.0104
	40	0 0213	0.0191	0.0145	0.0135	0.0106	0.0102
Mid	20	0.0152	0.0110	0.0099	0.0083	0.0080	0.0069
	30	0.0070	0.0054	0.0060	0.0043	0.0040	0.0037
	40	0.0046	0.0030	0.0035	0.0025	0.0026	0.0022
Min	20	0.0097	0.0059	0.0072	0.0047	0.0057	0.0042
	30	0.0042	0.0023	0.0038	0.0021	0.0026	0.0018
	40	0.0024	0.0012	0.0020	0.0011	0.0016	0.0010

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-9 **Factors for Ceiling Heights (K_c) for Clear Sky with No Control on the Window***

Position	Width, ft	Ceiling height: 8 ft, Wall reflectance 70%	8 ft, 30%	10 ft, 70%	10 ft, 30%	12 ft, 70%	12 ft, 30%	14 ft, 70%	14 ft, 30%
Max	20	0.145	0.155	0.129	0.132	0.111	0.111	0.101	0.098
	30	0.141	0.149	0.125	0.130	0.111	0.111	0.095	0.101
	40	0.157	0.157	0.135	0.134	0.111	0.111	0.096	0.099
Mid	20	0.110	0.128	0.116	0.126	0.111	0.111	0.103	0.108
	30	0.106	0.125	0.110	0.129	0.111	0.111	0.112	0.120
	40	0.117	0.118	0.122	0.118	0.111	0.111	0.123	0.122
Min	20	0.105	0.129	0.112	0.130	0.111	0.111	0.111	0.116
	30	0.099	0.144	0.107	0.126	0.111	0.111	0.107	0.124
	40	0.119	0.116	0.130	0.118	0.111	0.111	0.120	0.118

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-10 **Factors for Ceiling Height (K_c) for Uniform Ground with No Control on Window***

Position	Width, ft	Ceiling height 8 ft, Wall reflectance 70%	8 ft, 30%	10 ft, 70%	10 ft, 30%	12 ft, 70%	12 ft, 30%	14 ft, 70%	14 ft, 30%
Max	20	0.124	0.206	0.140	0.135	0.111	0.111	0.091	0.086
	30	0.182	0.188	0.140	0.143	0.111	0.111	0.092	0.088
	40	0.124	0.182	0.140	0.142	0.111	0.111	0.094	0.088
Mid	20	0.123	0.145	0.122	0.129	0.111	0.111	0.100	0.095
	30	0.097	0.104	0.107	0.112	0.111	0.111	0.111	0.105
	40	0.079	0.079	0.100	0.106	0.111	0.111	0.118	0.118
Min	20	0.099	0.108	0.110	0.114	0.111	0.111	0.107	0.104
	30	0.082	0.082	0.098	0.105	0.111	0.111	0.121	0.116
	40	0.070	0.066	0.095	0.099	0.111	0.111	0.125	0.132

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-11 **Factors for Ceiling Heights (K_c) with Sun and Sky as Source—Control at Window***

Position	Width, ft	Ceiling height 8 ft, Wall reflectance 70%	8 ft, 30%	10 ft, 70%	10 ft, 30%	12 ft, 70%	12 ft, 30%	14 ft, 70%	14 ft, 30%
Max		0.154	0.170	0.129	0.131	0.107	0.112	0.091	0.091
Mid	20	0.100	0.106	0.101	0.106	0.099	0.102	0.091	0.091
	30	0.074	0.080	0.086	0.090	0.091	0.093	0.091	0.091
	40	0.070	0.074	0.079	0.084	0.088	0.091	0.091	0.091
Min	20	0.080	0.080	0.091	0.091	0.093	0.093	0.091	0.091
	30	0.068	0.068	0.079	0.079	0.087	0.087	0.091	0.091
	40	0.064	0.064	0.076	0.076	0.084	0.084	0.091	0.091

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-12 **Factors for Ceiling Heights (K_c) with Uniform Ground as Source— Control at Window***

Position	Width, ft	Ceiling height 8 ft, Wall reflectance 70%	8 ft, 30%	10 ft, 70%	10 ft, 30%	12 ft, 70%	12 ft, 30%	14 ft, 70%	14 ft, 30%
Max		0.174	0.200	0.142	0.157	0.117	0.123	0.091	0.091
Mid	20	0.104	0.116	0.110	0.121	0.106	0.112	0.091	0.091
	30	0.074	0.082	0.092	0.099	0.099	0.106	0.091	0.091
	40	0.058	0.062	0.079	0.083	0.092	0.096	0.091	0.091
Min	20	0.078	0.082	0.093	0.097	0.099	0.102	0.091	0.091
	30	0.058	0.060	0.074	0.076	0.090	0.092	0.091	0.091
	40	0.052	0.056	0.070	0.071	0.086	0.087	0.091	0.091

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-13 **Factors for Ceiling Height (K_c) for Uniform Sky (or a Window with a Diffusing Blind)***

Position	Width, ft	Ceiling height 8 ft, Wall reflectance 70%	8 ft, 30%	10 ft, 70%	10 ft, 30%	12 ft, 70%	12 ft, 30%	14 ft, 70%	14 ft, 30%
Max	20	0.145	0.154	0.123	0.128	0.111	0.111	0.099	0.096
	30	0.141	0.151	0.126	0.128	0.111	0.111	0.095	0.096
	40	0.159	0.157	0.137	0.127	0.111	0.111	0.097	0.096
Mid	20	0.101	0.116	0.115	0.125	0.111	0.111	0.101	0.110
	30	0.095	0.113	0.105	0.122	0.111	0.111	0.110	0.122
	40	0.011	0.105	0.124	0.1[illegible]	0.111	0.111	0.130	0.124
Min	20	0.097	0.111	0.107	0.121	0.111	0.111	0.112	0.119
	30	0.096	0.125	0.103	0.117	0.111	0.111	0.115	0.125
	40	0.111	0.105	0.125	0.111	0.111	0.111	0.133	0.124

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-14 **Factors for Length and Width of Room (K_{l-w}) with Sun and Sky as Source—Horizontal Louvers at Window***

Position	Length, ft	Width 20 ft, Wall reflectance 70%	Width 20 ft, Wall reflectance 30%	Width 30 ft, Wall reflectance 70%	Width 30 ft, Wall reflectance 30%	Width 40 ft, Wall reflectance 70%	Width 40 ft, Wall reflectance 30%
Max	20	0.0500	0.0500	0.0470	0.0480	0.0455	0.0475
	30	0.0353	0.0357	0.0330	0.0350	0.0323	0.0343
	40	0.0268	0.0285	0.0250	0.0280	0.0243	0.0275
Mid	20	0.0500	0.0500	0.0335	0.0305	0.0195	0.0190
	30	0.0376	0.0370	0.0250	0.0257	0.0173	0.0167
	40	0.0288	0.0328	0.0198	0.0230	0.0125	0.0148
Min	20	0.0500	0.0500	0.0265	0.0210	0.0125	0.0099
	30	0.0380	0.0410	0.0200	0.0183	0.0120	0.0097
	40	0.0288	0.0368	0.0170	0.0175	0.0108	0.0090

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

Table II-15 **Factors for Length and Width of Room (K_{l-w}) with Uniform Ground as Source—Horizontal Louvers at Window***

Position	Length, ft	Width 20 ft, Wall reflectance 70%	Width 20 ft, Wall reflectance 30%	Width 30 ft, Wall reflectance 70%	Width 30 ft, Wall reflectance 30%	Width 40 ft, Wall reflectance 70%	Width 40 ft, Wall reflectance 30%
Max	20	0.0500	0.0500	0.0475	0.0485	0.0455	0.0490
	30	0.0353	0.0383	0.0333	0.0390	0.0323	0.0383
	40	0.0273	0.0313	0.0260	0.0303	0.0250	0.0310
Mid	20	0.0500	0.0500	0.0330	0.0320	0.0215	0.0210
	30	0.0373	0.0413	0.0247	0.0277	0.0173	0.0200
	40	0.0288	0.0343	0.0195	0.0243	0.0138	0.0163
Min	20	0.0500	0.0500	0.0235	0.0205	0.0115	0.0097
	30	0.0387	0.0437	0.0193	0.0190	0.0107	0.0096
	40	0.0295	0.0358	0.0153	0.0173	0.0088	0.0087

* Ceiling reflectance is 80 per cent, floor reflectance is 30 per cent. The maximum position is 5 ft from the window; mid position is in the center of the room, and the minimum position is 5 ft from the rear wall.

B.2 Overcast sky

The brightness distribution of an overcast sky is not uniform. It is normally lightest at the zenith and darkest at the horizon and is generally not affected by the position of the sun. A formula for overcast conditions was given by Moon and Spencer, (B-4) based on observations made in the United States as follows :

$$B\theta = B\phi \left(\frac{1 + 2\sin\theta}{3}\right)$$

where $B\theta$ = laminance of the sky at altitude θ

$B\phi$ = laminance of the sky at the zenith

Under overcast skies the brightness at the horizon is approximately 1/3 that at the zenith and 1/2 the average sky brightness. (B-4)

In calculations for overcast skies the brightness does not vary with the azimuth position of the sun and, while the light received from high altitude angles is more intense than that received at low angles, the orientation of the building does not have to be taken into account. (B-5)

R E F E R E N C E

B-1 Predicting Daylight as Interior Illumination by J. W. Griffith, A report of work carried out at Southern Methodist University, Dallas, Texas, for the Libbey-Owens-Ford Glass Co. of Toledo, Ohio, Completed. 1958.

B-2 Lighting in Architectural Design by Derek Phillips McGraw-Hill Book Co., New York, 1964. P. 238.

B-3 Lighting in Architectural Design by Derek Phillips, McGraw-Hill Book Co., New York, 1964. P. 241.

B-4 Illumination from a Non-Uniform Sky, by P. Moon and D. E. Spencer, Illuminating Engineering, Vol. 37. P. 707-726.

B-5 Lighting in Architectural Design by Derek Phillips, McGraw-Hill Book Co., New York, 1964. P. 248.

Section C The British Method for Computing Daylight

C.1 The Daylight Factor —— Definition

A more comprehensive concept of daylight illumination in an interior can be expressed either in absolute terms such as an illumination value in lumens per square feet or as a percentage of the total daylight illumination available from the whole unobstructed sky, that is, a DAYLIGHT FACTOR. It gives a more useful measure of the interior lighting in all regions; dry tropical, cloudy and humid climates and regions of high latiudes, where latitude, climate, and industrial haze result in widely variable daylight. (C-1)

The Daylight Factor is defined as " The ratio of the daylight illumination at a point on a given plane due to the light received directly or indirectly from a sky with an assumed or a known luminance distribution, to the illumination on a horizontal plane due to an obstructed hemisphere of the sky (excluding sunlight), expressed as a percentage. " (C-2) For example, if the daylight factor is 5 per cent at a location in the interior of a building when the exterior illumination is 1,000 ft-c then the interior illumination at this point will be :

$$(5/100) \times 1000 = 50 \text{ ft-c} \quad (C-3, C-4)$$

The percentage visible through a window is usually surprisingly small, and can be as low as 1/5 of 1 per cent, before becoming quite inadequate for normal purpose, but slightly higher percentages are required for critical tasks, such as reading or writing. (C-5)

To determine the daylight factor for a room being used for a specific purpose, it is only necessary to decide on the minimum exterior illumination level and the required internal illumination level. For example, if the required illumination level is 20 ft-c then the required daylight factor would be :

(20/500) x 100 = 4 per cent.

In such a case a 4 per cent daylight factor must be provided at the worst lit position in the room at all times when artificial light would not normally be used. In America and Great Britain, 500 ft-c is considered to be the normal level of the minimum exterior illumination, which results from a sky of average brightness of 500 ft-l. Other general minimum daylight levels are : 300 ft-c in Holland, Germany, and Swi+zerland, and 500 ft-c in Italy. (C-6)

C.2 The Calculation of Daylight Factor

The illumination at any point in an interior is made up of light direct from the overcast sky, by reflection from external surfaces, and by interreflection from walls, ceiling, and floor shown as Fig. 2-9. The Daylight Factor at a point in a room can be considered as the summation of :

a) The Sky Component (S.C.) which is the light coming from the sky through the window directly on to the point without reflection in route.

b) The External Reflected Component (E.R.C.), which is the light coming directly to the point through the window, but after reflection off external surfaces.

c) The Internal Reflected Component (I.R.C.), which is the light reaching the point only after reflection from the various surfaces in the room. (C-7)

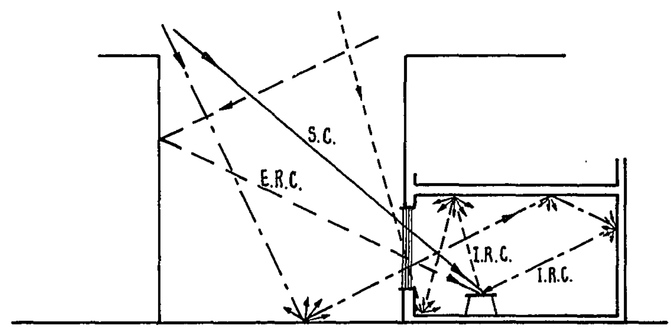


Fig. 2-9 Components of the daylight factor:
S.C. = sky component;
E.R.C.= external reflected component;
I.R.C.= internal reflected component.

C.2.1 Calculation of Direct Daylight —— Sky Component

The sky component of daylight factor can be determined by many various methods depending upon the references being considered. It may be obtained by formulas, Daylight Tables, Daylight Protractors and Diagrams, and Graphical Methods.

C.2.1.1 The Formula Method

The sky component can be found by the following formula :

Sky Component = S.F. x T x K

where T = transmission factor for clean glazing material —— from Table II-16

K = the sky brightness ratio —— from Table II-17

S.F. = sky factor

Table II-16 Normal Incidence Light Transmission Da+a for Glass

Glass type	Transmission range, per cent
Clear vision :	
Window, plate, tempered plate	90-92
Heat absorbing	40-75
Glare reducing	$12\frac{1}{2}$-68
Glass block	81-85
Double glazing units	81-85
Wired glass	72-84
Obscuring :	
Hammered frosted heat absorbing	36-58
Hammered heat absorbing	53-63
Frosted glass	63-76
Patterned glass	52-92
Double glazing units	56-76
Patterned sand blasted glass	36-77
Decorative glass block	70-80
Light directing — light-diffusing glass block	20-50

The sky factor is the illumination at a point in a room received directly from a sky of uniform brightness through an unglazed aperture, expressed as a percentage of the illumination occurring simultaneously out of doors from the whole sky. (C-7)

There are many methods to determine the sky factor. The available methods may be divided into four types : (1) graphic methods, (2) tabular methods, (3) protractor methods, and (4) diagram methods. Each method has a complete and detailed description in " Lighting in Architectural Design " of D. Phillips and " Daylighting " of R.G. Hopkinson.

For instance Graphic Methods, protractor methods and diagram methods are illustrated in the page 250 to 255 in " Lighting in Architectural Design " while Tabular methods are illustrated in the page 88 to 110 of "Daylight".

Table II-17 Values of Sky Brightness Ratio (K) for Overcast Sky

Average angle of altitude of patch of visible sky, deg.	K
5	0.50
10	0.58
20	0.72
30	0.86
40	0.98
42	1.00
45	1.04
50	1.09
60	1.17
70	1.24
80	1.27
85	1.28

Another simple formula giving the approximate average sky component for a large factory with distributed top lighting (roof lighting) can simply derived and shown by :

$$\text{Average Sky Component} = \frac{\text{Glazing Area}}{\text{Floor Area}} \; n \; 100\%$$

where n is a coefficient of utilization determined by the transmission of the glazing, the degree of dirtying, the obstruction by glazing bars, and the slope of the glazing. See Table II-18. (C-8)

Table II-18 Values of coefficient of utilization

Type of roof glazing	n
Horizontal	0.3
Shed, 30^{o} slope	0.3
North-light, 60^{o} slope	0.2
Asymmetric monitor	0.2
Vertical monitor	0.15

C.2.1.2 Daylight Tables Methods

By using daylight tables the B.R.S. SIMPLIFIED DAYLIGHT TABLES are the fastest means to obtain the components of Daylight Factors, because they are simpler than the National Physical Laboratory Graded Daylight Factor Tables and Rivero's Tables. Tables II-19, II-20 give the value of sky component directly for a reference point. The details for using these tables is described in H.G. Hopkinson's " Daylighting ". The Fig. 2-10 is an example. (C-9)

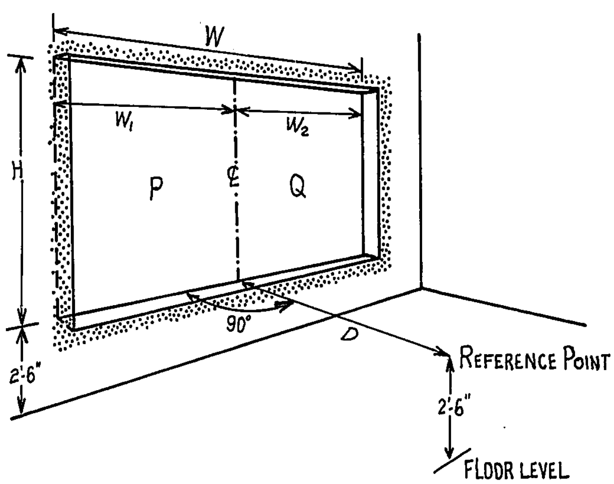


Fig. 2-10 The operation of the B.R.S. Simplified Table.

Table II-19

SKY COMPONENTS (C.I.E. STANDARD OVERCAST SKY) FOR VERTICAL GLAZED RECTANGULAR WINDOWS

Ratio H/D = Height of Window Head above Working Plane : Distance from Window																					Angle of Obstruction
∞	1·3	2·5	3·7	4·9	5·9	6·9	7·7	8·4	9·0	9·6	10·7	11·6	12·2	12·6	13·0	13·7	14·2	14·6	14·9	15·0	90°
5·0	1·2	2·4	3·7	4·8	5·9	6·8	7·6	8·3	8·8	9·4	10·5	11·1	11·7	12·3	12·7	13·3	13·7	14·0	14·1	14·2	79°
4·0	1·2	2·4	3·6	4·7	5·8	6·7	7·4	8·2	8·7	9·2	10·3	10·9	11·4	12·0	12·4	12·9	13·3	13·5	13·6	13·7	76°
3·5	1·2	2·4	3·6	4·6	5·7	6·6	7·3	8·0	8·5	9·0	10·1	10·6	11·1	11·8	12·2	12·6	12·9	13·2	13·2	13·3	74°
3·0	1·2	2·3	3·5	4·5	5·5	6·4	7·1	7·8	8·2	8·7	9·8	10·2	10·7	11·3	11·7	12·0	12·4	12·5	12·6	12·7	72°
2·8	1·1	2·3	3·4	4·5	5·4	6·3	7·0	7·6	8·1	8·6	9·6	10·0	10·5	11·1	11·4	11·7	12·0	12·2	12·3	12·3	70°
2·6	1·1	2·2	3·4	4·4	5·3	6·2	6·8	7·5	7·9	8·4	9·3	9·8	10·2	10·8	11·1	11·4	11·7	11·8	11·9	11·9	69°
2·4	1·1	2·2	3·3	4·3	5·2	6·0	6·6	7·3	7·7	8·1	9·1	9·5	10·0	10·4	10·7	11·0	11·2	11·3	11·4	11·5	67°
2·2	1·1	2·1	3·2	4·1	5·0	5·8	6·4	7·0	7·4	7·9	8·7	9·1	9·6	10·0	10·2	10·5	10·7	10·8	10·9	10·9	66°
2·0	1·0	2·0	3·1	4·0	4·8	5·6	6·2	6·7	7·1	7·5	8·3	8·7	9·1	9·5	9·7	9·9	10·0	10·1	10·2	10·3	63°
1·9	1·0	2·0	3·0	3·9	4·7	5·4	6·0	6·5	6·9	7·3	8·1	8·5	8·8	9·2	9·4	9·6	9·7	9·8	9·9	9·9	62°
1·8	0·97	1·9	2·9	3·8	4·6	5·3	5·8	6·3	6·7	7·1	7·8	8·2	8·5	8·8	9·0	9·2	9·3	9·4	9·5	9·5	61°
1·7	0·94	1·9	2·8	3·6	4·4	5·1	5·6	6·1	6·5	6·8	7·5	7·8	8·2	8·5	8·6	8·8	8·9	9·0	9·1	9·1	60°
1·6	0·90	1·8	2·7	3·5	4·2	4·9	5·4	5·8	6·2	6·5	7·2	7·5	7·8	8·1	8·2	8·4	8·5	8·6	8·6	8·6	58°
1·5	0·86	1·7	2·6	3·3	4·0	4·6	5·1	5·6	5·9	6·2	6·8	7·1	7·4	7·6	7·8	7·9	8·0	8·0	8·1	8·1	56°
1·4	0·82	1·6	2·4	3·2	3·8	4·4	4·8	5·2	5·6	5·9	6·4	6·7	7·0	7·2	7·3	7·4	7·5	7·5	7·6	7·6	54°
1·3	0·77	1·5	2·3	2·9	3·6	4·1	4·5	4·9	5·2	5·5	5·9	6·2	6·4	6·6	6·7	6·8	6·9	6·9	6·9	7·0	52°
1·2	0·71	1·4	2·1	2·7	3·3	3·8	4·2	4·5	4·8	5·0	5·4	5·7	5·9	6·0	6·1	6·2	6·2	6·3	6·3	6·3	50°
1·1	0·65	1·3	1·9	2·5	3·0	3·4	3·8	4·1	4·3	4·6	4·9	5·1	5·3	5·4	5·4	5·5	5·6	5·6	5·7	5·7	48°
1·0	0·57	1·1	1·7	2·2	2·6	3·0	3·3	3·6	3·8	4·0	4·3	4·5	4·6	4·7	4·7	4·8	4·8	4·9	5·0	5·0	45°
0·9	0·50	0·99	1·5	1·9	2·2	2·6	2·8	3·1	3·3	3·4	3·7	3·8	3·9	4·0	4·0	4·0	4·1	4·1	4·2	4·2	42°
0·8	0·42	0·83	1·2	1·6	1·9	2·2	2·4	2·6	2·7	2·9	3·1	3·2	3·3	3·3	3·3	3·3	3·4	3·4	3·4	3·4	39°
0·7	0·33	0·68	0·97	1·3	1·5	1·7	1·9	2·1	2·2	2·3	2·5	2·5	2·6	2·6	2·6	2·6	2·7	2·7	2·8	2·8	35°
0·6	0·24	0·53	0·74	0·98	1·2	1·3	1·5	1·6	1·7	1·8	1·9	1·9	2·0	2·0	2·0	2·1	2·1	2·1	2·1	2·1	31°
0·5	0·16	0·39	0·52	0·70	0·82	0·97	1·0	1·10	1·2	1·3	1·4	1·4	1·4	1·4	1·5	1·5	1·5	1·5	1·5	1·5	27°
0·4	0·10	0·25	0·34	0·45	0·54	0·62	0·70	0·75	0·82	0·89	0·92	0·95	0·95	0·96	0·96	0·97	0·97	0·97	0·98	0·98	22°
0·3	0·06	0·14	0·18	0·26	0·30	0·34	0·38	0·42	0·44	0·47	0·49	0·50	0·50	0·51	0·51	0·52	0·52	0·52	0·53	0·53	17°
0·2	0·03	0·06	0·09	0·11	0·12	0·14	0·16	0·20	0·21	0·21	0·22	0·22	0·22	0·22	0·23	0·23	0·23	0·23	0·24	0·24	11°
0·1	0·01	0·02	0·02	0·03	0·03	0·04	0·04	0·05	0·05	0·05	0·06	0·06	0·06	0·06	0·07	0·07	0·07	0·07	0·08	0·08	6°
0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·2	1·4	1·6	1·8	2·0	2·5	3·0	4·0	6·0	∞	0°

Ratio W/D = Width of Window to one Side of Normal : Distance from Window

Table II-20

SKY COMPONENTS (UNIFORM SKY) FOR VERTICAL GLAZED RECTANGULAR WINDOWS

Ratio H/D = Height of Window Head above Working Plane : Distance from Window																					Angle of Obstruction
∞	1·3	2·6	3·9	5·0	6·1	7·0	7·9	8·8	9·5	10·1	11·2	12·0	12·7	13·2	13·6	14·3	14·7	15·0	15·3	15·8	90°
5·0	1·3	2·6	3·8	5·0	6·0	7·0	7·9	8·7	9·4	10·0	11·0	11·7	12·3	12·7	13·1	13·7	14·0	14·3	14·6	15·1	79°
4·0	1·2	2·6	3·7	4·9	5·9	6·9	7·8	8·5	9·2	9·8	10·8	11·5	12·1	12·6	12·9	13·5	13·7	14·0	14·2	14·6	76°
3·5	1·2	2·6	3·7	4·9	5·8	6·8	7·6	8·4	9·1	9·6	10·7	11·4	12·0	12·4	12·7	13·3	13·5	13·7	14·0	14·2	74°
3·0	1·2	2·5	3·6	4·8	5·7	6·7	7·4	8·2	8·9	9·4	10·4	11·1	11·7	12·1	12·4	12·9	13·1	13·3	13·5	13·7	72°
2·8	1·2	2·5	3·5	4·7	5·7	6·6	7·3	8·1	8·8	9·3	10·3	11·0	11·5	11·9	12·2	12·7	12·9	13·1	13·2	13·4	70°
2·6	1·2	2·4	3·5	4·6	5·6	6·5	7·2	7·9	8·6	9·1	10·1	10·8	11·3	11·6	12·0	12·4	12·6	12·8	12·9	13·1	69°
2·4	1·1	2·4	3·4	4·5	5·4	6·3	7·0	7·7	8·4	8·9	9·9	10·5	11·0	11·4	11·7	12·1	12·3	12·4	12·6	12·7	67°
2·2	1·1	2·3	3·3	4·4	5·3	6·1	6·8	7·5	8·2	8·6	9·6	10·2	10·6	11·0	11·3	11·7	11·9	12·0	12·1	12·2	66°
2·0	1·1	2·3	3·2	4·2	5·1	5·9	6·6	7·2	7·8	8·3	9·2	9·7	10·2	10·5	10·7	11·1	11·3	11·4	11·5	11·6	63°
1·9	1·0	2·2	3·1	4·1	5·0	5·7	6·4	7·0	7·6	8·0	9·0	9·4	9·9	10·2	10·4	10·8	11·0	11·1	11·2	11·2	62°
1·8	1·0	2·2	3·0	4·0	4·8	5·6	6·2	6·8	7·4	7·8	8·7	9·2	9·6	9·9	10·1	10·4	10·6	10·7	10·8	10·8	61°
1·7	0·99	2·1	3·0	3·9	4·7	5·4	6·0	6·6	7·1	7·5	8·4	8·8	9·2	9·5	9·7	10·0	10·2	10·3	10·4	10·4	60°
1·6	0·97	2·0	2·9	3·8	4·5	5·2	5·8	6·4	6·9	7·3	8·1	8·5	8·8	9·1	9·3	9·6	9·8	9·9	10·0	10·0	58°
1·5	0·94	2·0	2·8	3·6	4·4	5·0	5·6	6·1	6·6	7·0	7·8	8·1	8·5	8·7	8·9	9·2	9·4	9·4	9·5	9·6	56°
1·4	0·91	1·9	2·7	3·5	4·2	4·8	5·3	5·9	6·3	6·7	7·4	7·7	8·0	8·3	8·5	8·7	8·8	8·9	9·0	9·1	54°
1·3	0·87	1·8	2·5	3·3	4·0	4·6	5·0	5·6	5·9	6·3	7·0	7·3	7·5	7·8	7·9	8·1	8·3	8·4	8·4	8·5	52°
1·2	0·82	1·7	2·4	3·1	3·8	4·3	4·8	5·2	5·6	5·9	6·6	6·8	7·0	7·2	7·4	7·6	7·7	7·8	7·8	7·9	50°
1·1	0·77	1·6	2·2	2·9	3·5	4·0	4·5	4·9	5·2	5·5	6·0	6·2	6·5	6·7	6·8	6·9	7·0	7·1	7·2	7·2	48°
1·0	0·72	1·5	2·1	2·7	3·2	3·7	4·1	4·5	4·8	5·0	5·5	5·7	5·9	6·0	6·2	6·2	6·3	6·4	6·5	6·5	45°
0·9	0·65	1·4	1·9	2·4	2·9	3·4	3·7	4·0	4·3	4·5	4·9	5·1	5·2	5·4	5·5	5·5	5·6	5·6	5·7	5·7	42°
0·8	0·57	1·2	1·6	2·1	2·6	3·0	3·3	3·6	3·8	4·0	4·2	4·4	4·6	4·7	4·7	4·8	4·8	4·9	4·9	4·9	39°
0·7	0·50	1·0	1·4	1·8	2·2	2·5	2·8	3·0	3·2	3·3	3·6	3·7	3·8	3·9	3·9	4·0	4·0	4·0	4·0	4·0	35°
0·6	0·40	0·83	1·1	1·5	1·8	2·1	2·3	2·4	2·6	2·7	2·8	2·9	3·0	3·1	3·1	3·1	3·2	3·2	3·2	3·2	31°
0·5	0·30	0·63	0·86	1·2	1·4	1·6	1·7	1·8	1·9	2·0	2·0	2·1	2·2	2·2	2·3	2·3	2·3	2·4	2·4	2·4	27°
0·4	0·21	0·43	0·59	0·80	0·94	1·1	1·2	1·2	1·3	1·4	1·4	1·5	1·5	1·6	1·6	1·6	1·6	1·6	1·7	1·7	22°
0·3	0·13	0·25	0·33	0·46	0·54	0·64	0·68	0·73	0·78	0·82	0·84	0·86	0·88	0·90	0·92	0·93	0·94	0·95	0·96	0·97	17°
0·2	0·05	0·11	0·16	0·22	0·27	0·31	0·34	0·36	0·38	0·40	0·42	0·44	0·45	0·46	0·46	0·47	0·47	0·47	0·48	0·48	11°
0·1	0·01	0·02	0·04	0·07	0·09	0·11	0·12	0·13	0·14	0·14	0·15	0·15	0·16	0·16	0·16	0·17	0·17	0·17	0·18	0·18	6°
0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0	1·2	1·4	1·6	1·8	2·0	2·5	3·0	4·0	6·0	∞	0°

Ratio W/D = Width of Window to one Side of Normal : Distance from Window

C.2.1.3 Daylight Protractors Method

Daylight Protractors are very valuable to architects when plans and sections of the building are being prepared. It is a quick method for obtaining results from drawings but they can only be used where all external obstructions are horizontal, or where they can be approximated by a horizontal line.

A series of protractors has been developed by the Building Research Station in Great Britain. Different sets of Protractors apply to a sky of uniform luminance and for the C.I.E. Standard Overcast Sky. Each set of Protractors consists of 5 pairs as follows :

1 - 2 For vertically glazing windows

3 - 4 For horizontally glazing windows

5 - 6 For glazed apertures sloping at 30° to horizontal

7 - 8 For glazed apertures sloping at 60° to horizontal

9 - 10 For unglazed apertures

(this pair can be used to determine the sky factor from a uniform sky)

The detailed description and examples in using the Protractors (Fig. 2-11) were illustrated in chapter six of Daylighting and page 252 - 253 of Lighting in Architectural Design. (C-10, C-11)

C.2.1.4 Daylight Diagrams and Graphical Methods

There are many various diagrams and graphical methods for the calculation of direct daylight. The most adventageous and widely used is devised by P.J. and J.M. Waldram, known as the Waldram Diagram shown

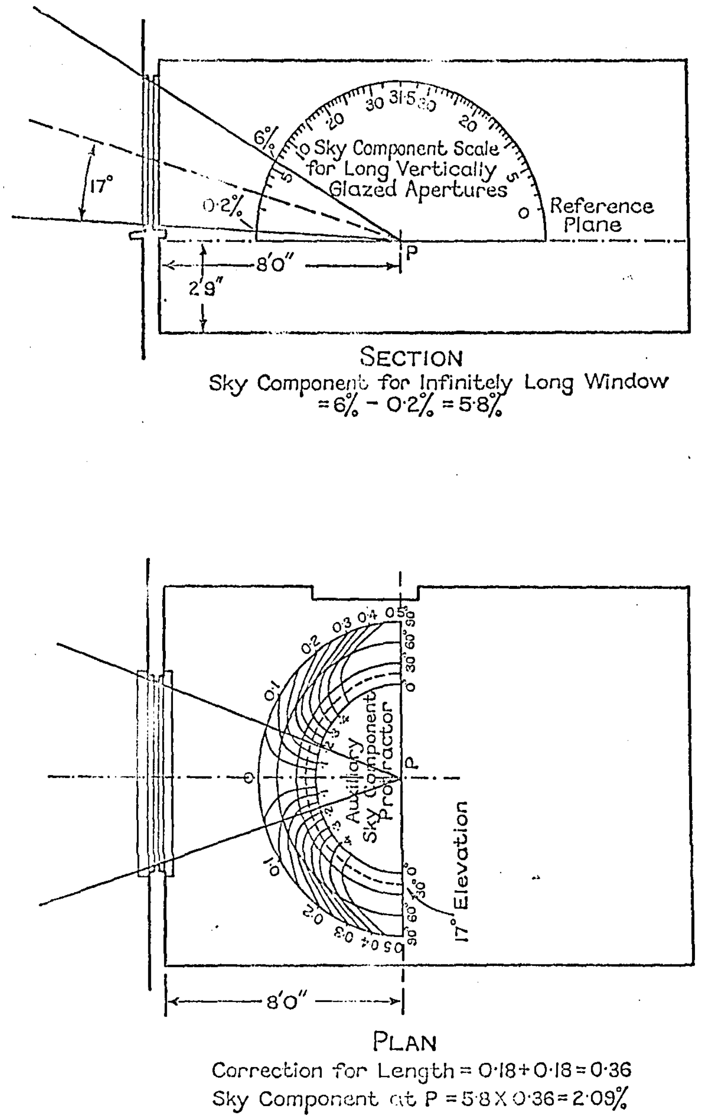


Fig. 2-11 Use of sky component protractors for vertically glazed windows.

as Fig. 2-12. It gives high accuracy and is particulary useful where the visible sky is irregular in shape due to building obstractions. The diagram is used in the final stages of design to give an accurate assessment of the sky component when details of the siting of the building and design of the windows are known. The detailed description and operation of the method are presented in the ' Daylighting ' page 175-183.

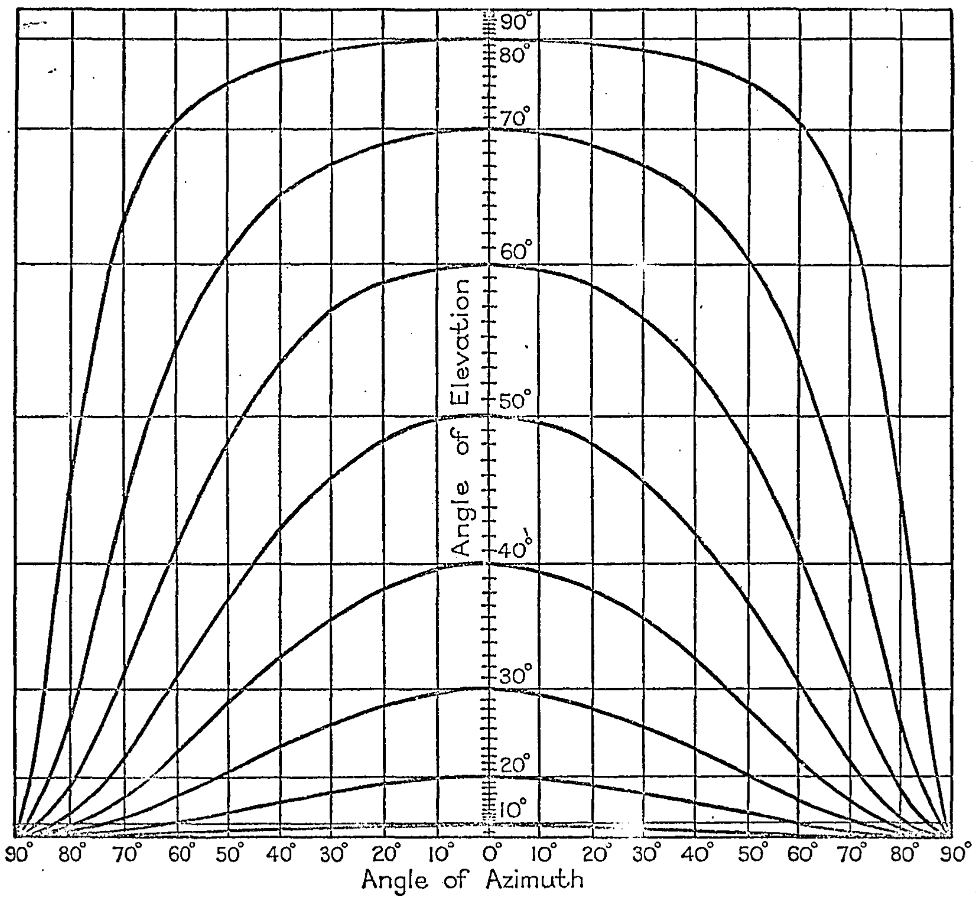


Fig. 2-12 Waldram Diagram for unglazed apertures and C.I.E. Overcast Sky luminance distribution (i.e. sky components on a horizontal reference plane).

C.2.2 Calculation of Reflected Daylight

The direct light from the sky which reaches the reference point in a building is supplemented by light reflected from both exterior and interior surfaces. The light reflected directly to the reference point from exterior surfaces is called the EXTERNALLY REFLECTED COMPONENT (E.R.C.), shown in Fig. 2-3. In heavily built-up areas, this light may comprise a large proportion of the total available internal light. The light reflected to the reference point from internal surfaces is called the INTERNALLY REFLECTED COMPONENT (I.R.C.).

C.2.2.1 Determination of the E.R.C.

The E.R.C. can be determined by the same methods used to determine the sky factor and the sky component. The basic formula is as follow :

E.R.C. = sky factor of uniform patch of sky x L x T

$$\text{where } L = \frac{\text{Brightness of obstruction}}{\text{Average brightness of sky}}$$

T = Transmission factor for clean glazing meterial (From Table II-16)

(C-12)

The E.R.C. may be determined easily by using of the B.R.S. Daylight Protractors as shown in Fig. 2-13.

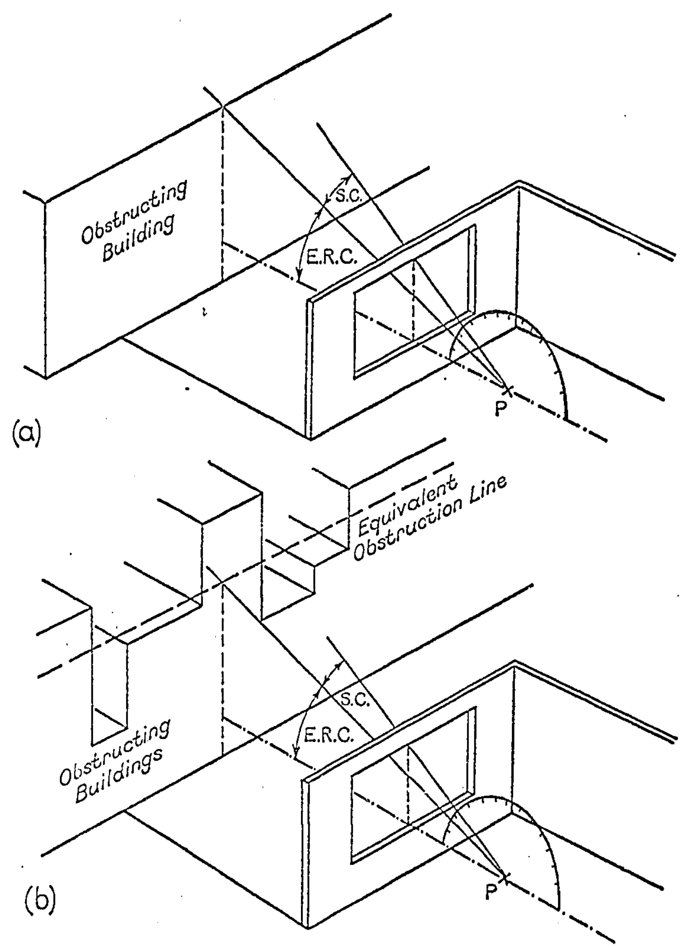


Fig. 2-13 Determination of the externally reflected component with the B.R.S. Daylight Protractors and the use of the 'equivalent obstruction line'.

C.2.2.2 Determination of the I.R.C.

The internally reflected component is most easily calculated by flux transfer methods based on the theory of the integrating sphere. In order to avoid lengthy calculations, the B.R.S. Nomograms have been derived. Figs. 2-14, 2-15 and 2-16 show three nomograms which can be used to obtain

(I) the average internal reflected component for side-lit rooms.

(II) the minimum internal reflected component for side-lit rooms.

and (III) the average internal reflected component from rooflights.

The procedures for using Nomogram I and II are as follows :

1. Determine the value of A and find the appropriate point on Scale A.

$$A = \frac{\text{Window area}}{\text{total surface area of room}}$$

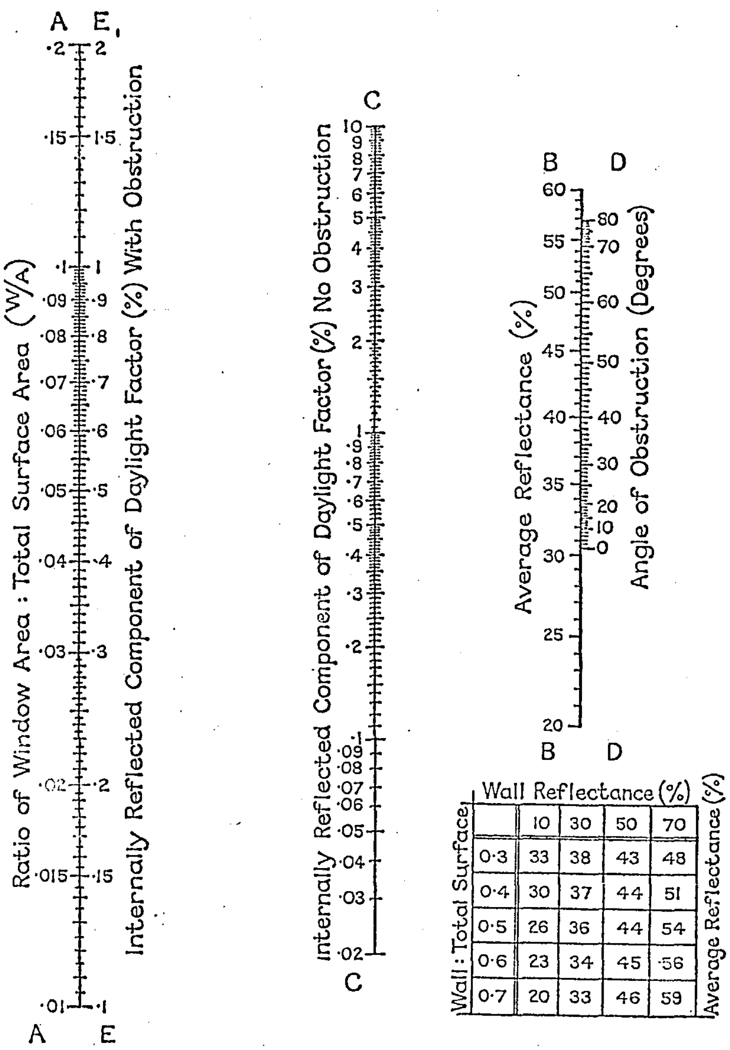
2. Determine the value of B and find the appropriate point on Scale B.

   B = average reflection factor of all room surfaces (From Table II-21)

3. Join points A and B to give a point on Scale C. The point where the line intersects Scale C is the value of the unobstructed internal reflection factor.

4. Mark the angle of the obstruction above the center of the window (Fig. 2-17) on Scale D.

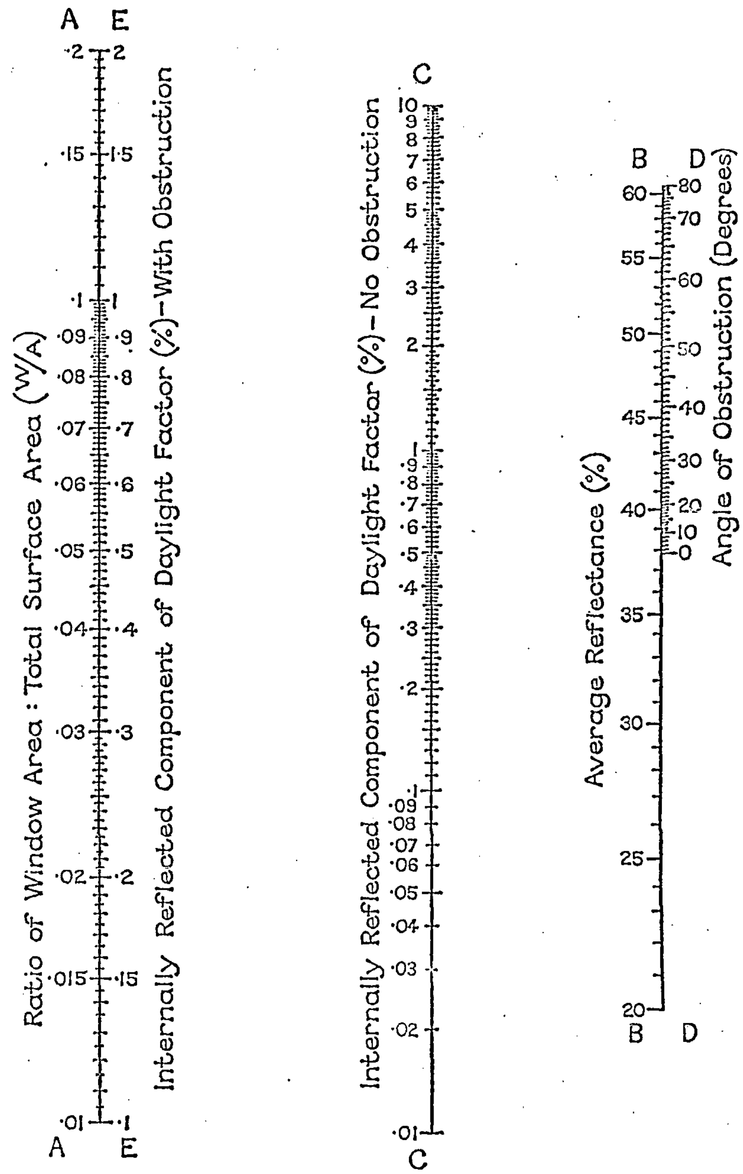
5. Join points C and D, continuing the line to give a point on Scale E. The value on Scale E is the true internal reflected component.



Wall : Total Surface	10	30	50	70
0·3	33	38	43	48
0·4	30	37	44	51
0·5	26	36	44	54
0·6	23	34	45	56
0·7	20	33	46	59

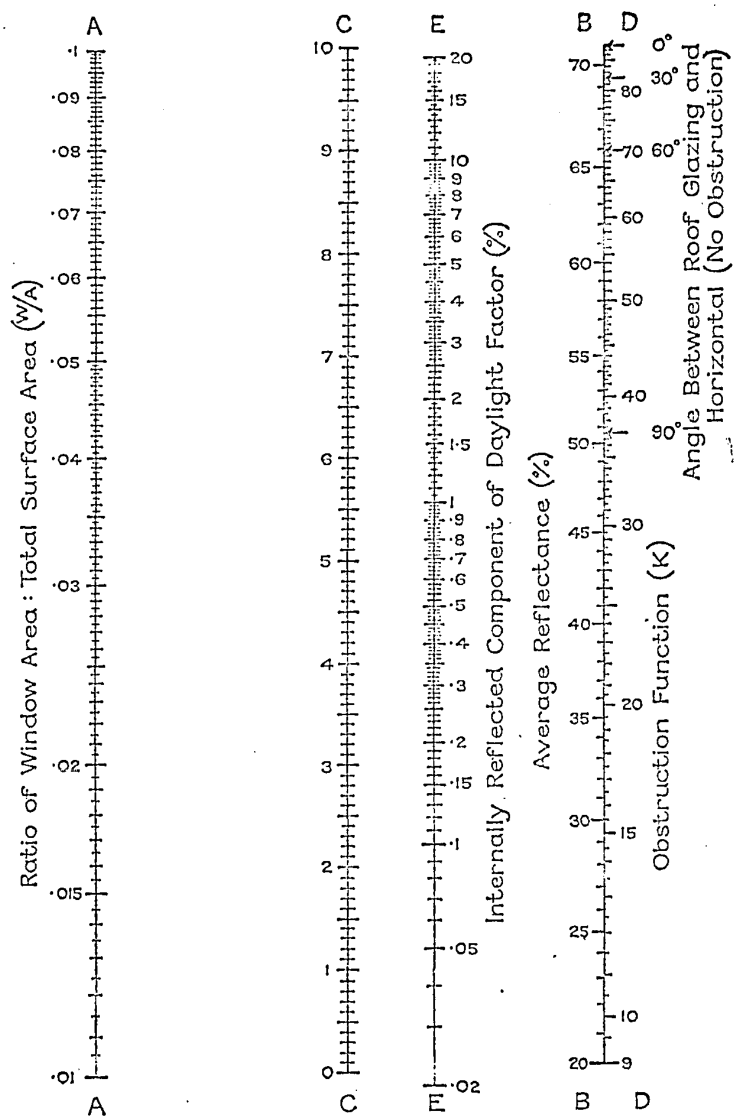
NOMOGRAM I

Fig. 2-14 Nomogram for the calculation of the average internally reflected component of daylight factor in side-lit rooms.



NOMOGRAM II

Fig. 2-15 Nomogram for the calculation of the minimum internally reflected component of daylight factor in side-lit rooms.



NOMOGRAM III

Fig. 2-16 Nomogram for the calculation of the average internally reflected component of daylight factor in top-lit rooms.

The procedure for using Nomogram III is as follows :

1. Determine the value of A by the relation :

$$A = \frac{\text{window area}}{\text{total surface area of room}}$$

This value is marked on Scale A.

2. Determine the value of B where

B = average reflection factor.

This value is marked on Scale B.

3. Join points A and B to give point on Scale C.

4. Find angle of obstruction at center of rooflight.

5. Using Tables II-22, II-23, II-24 or II-25 (according to the angle of slope of the glazing) determine the obstruction factor. Mark the obstruction factor on Scale D.

6. Join points D and C and where they intercept on Scale E gives the internal reflected component. (C-13)

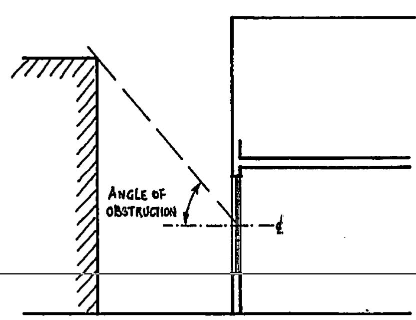


Fig. 2-17 Altitude of obstruction above the center of a window.

Table II-21 Average Reflection Factors

Proportion †	Wall reflection factor, per cent			
	10	30	50	70
0.3	33	38	43	48
0.4	30	37	44	51
0.5	26	36	44	54
0.6	23	34	45	56
0.7	20	33	46	59

* These factors are valid only when the ceiling reflectance is 70 per cent, the floor reflectance is 15 per cent, and A is 0.05.

† The proportion is the wall area divided by the total surface area.

Table II-22 **Obstruction Factors for Vertically Glazed Rooflights (overcast sky conditions)***

Angle of obstruction, deg	*K*
0 (no obstruction)	37
10	34
20	30
30	26
40	21
50	16
60	12
70	10
80	9

* The angle of obstruction is measured from the center of the window in degrees above the horizontal.

Table II-23 **Obstruction Factors for Rooflights Sloping at 30 deg to the Horizontal***

Angle of obstruction facing the rooflight, deg	Angle of obstruction behind the rooflight, deg					
	0–30	40	50	60	70	80
0	82	82	81	79	74	69
10	81	80	80	77	73	67
20	78	78	77	74	70	64
30	74	73	72	70	66	60
40	68	68	67	64	60	54
50	61	61	60	58	53	48
60	54	54	53	50	46	40
70	46	45	45	42	38	32
80	37	37	36	33	29	23

* The angle of obstruction is measured from the center of the window in degrees above the horizontal.

Table II-24 **Obstruction Factors for Rooflights Sloping at 60 deg to the Horizontal***

Angle of construction facing the rooflight, deg	Angle of obstruction behind the rooflight, deg		
	0–60	70	80
0	70	70	68
10	65	65	64
20	59	59	58
30	52	52	51
40	44	44	43
50	36	36	34
60	28	28	26
70	21	21	20
80	16	16	15

* The angle of obstruction is measured from the center of the window in degrees above the horizontal.

Table II-25 **Obstruction Factors for Horizontal Rooflights***

Angle of obstruction on one side of rooflight, deg	Angle of obstruction on second side of rooflight, deg								
	0	10	20	30	40	50	60	70	80
0	88	87	87	85	82	78	72	65	57
10	87	87	87	85	82	77	71	64	56
20	87	87	86	85	82	77	71	64	56
30	85	85	85	83	80	75	69	62	54
40	82	82	82	80	77	72	66	59	51
50	78	77	77	75	72	68	62	54	47
60	72	71	71	69	66	62	56	48	41
70	65	64	64	62	59	54	48	41	33
80	57	56	56	54	51	47	41	33	25

* The angle of obstruction is measured from the center of the window in degrees above the horizontal.

A simpler, quicker method for determining the I.R.C. involves the use of the I.R.C. simplified tables (Table II-26, II-27) where the internally reflected component can be read directly after we make certain assumptions. Table II-26 gives the minimum I.R.C. values. They can be changed to average values by use of conversion factor at the bottom of the Table. (C-14)

Table II-26 INTERNALLY REFLECTED COMPONENT OF DAYLIGHT FACTOR

(Minimum I.R.C.—percent)

Ratio— Actual glass area to floor area	*Actual glass area (% of floor area)*	*Floor reflectance (%)* 10				20				40			
		Wall reflectance (%) 20	40	60	80	20	40	60	80	20	40	60	80
1:50	2	—	—	0·1	0·2	—	0·1	0·1	0·2	—	0·1	0·2	0·2
1:20	5	0·1	0·1	0·2	0·4	0·1	0·2	0·3	0·5	0·1	0·2	0·4	0·6
1:14	7	0·1	0·2	0·3	0·5	0·1	0·2	0·4	0·6	0·2	0·3	0·6	0·8
1:10	10	0·1	0·2	0·4	0·7	0·2	0·3	0·6	0·9	0·3	0·5	0·8	1·2
1:6·7	15	0·2	0·4	0·6	1·0	0·2	0·5	0·8	1·3	0·4	0·7	1·1	1·7
1:5	20	0·2	0·5	0·8	1·4	0·3	0·6	1·1	1·7	0·5	0·9	1·5	2·3
1:4	25	0·3	0·6	1·0	1·7	0·4	0·8	1·3	2·0	0·6	1·1	1·8	2·8
1:3·3	30	0·3	0·7	1·2	2·0	0·5	0·9	1·5	2·4	0·8	1·3	2·1	3·3
1:2·9	35	0·4	0·8	1·4	2·3	0·5	1·0	1·8	2·8	0·9	1·5	2·4	3·8
1:2·5	40	0·5	0·9	1·6	2·6	0·6	1·2	2·0	3·1	1·0	1·7	2·7	4·2
1:2·2	45	0·5	1·0	1·8	2·9	0·7	1·3	2·2	3·4	1·2	1·9	3·0	4·6
1:2	50	0·6	1·1	1·9	3·1	0·8	1·4	2·3	3·7	1·3	2·1	3·2	4·9
Conversion factor to obtain average value of I.R.C.		×1·9	×1·5	×1·3	×1·2	×1·8	×1·4	×1·3	×1·2	×1·6	×1·4	×1·2	×1·1

Table II-27 INTERNALLY REFLECTED COMPONENT OF DAYLIGHT FACTOR

(Average I.R.C.—percent)

Slope of glazing	*Ratio— Actual glass area to floor area*	*Actual glass area (% of floor area)*	*Floor reflectance (%)* 10			20			30		
			Wall reflectance (%) 20	40	60	20	40	60	20	40	60
0°	1:20	5	0·7	0·9	1·1	0·8	1·0	1·3	1·0	1·2	1·5
	1:14	7	1·0	1·2	1·6	1·1	1·4	1·8	1·3	1·6	2·0
	1:10	10	1·3	1·7	2·1	1·6	2·0	2·5	1·8	2·3	2·9
	1:6·7	15	1·9	2·5	3·2	2·2	2·9	3·7	2·6	3·4	4·6
	1:5	20	2·4	3·2	4·0	2·9	3·8	4·6	3·5	4·4	5·7
	1:4	25	3·0	3·9	4·9	3·6	4·6	5·6	4·2	5·1	7·0
	1:3·3	30	3·4	4·4	5·4	4·1	5·1	6·4	4·8	5·9	8·0
30°	1:20	5	0·6	0·8	1·0	0·7	0·9	1·1	0·8	1·0	1·3
	1:14	7	0·9	1·1	1·4	1·0	1·3	1·6	1·1	1·4	1·8
	1:10	10	1·2	1·5	2·0	1·4	1·8	2·2	1·6	2·0	2·5
	1:6·7	15	1·7	2·2	2·8	2·0	2·5	3·3	2·3	2·9	3·8
	1:5	20	2·2	2·9	3·8	2·6	3·4	4·2	3·0	3·8	4·8
	1:4	25	2·7	3·5	4·5	3·2	4·1	5·1	3·7	4·6	5·7
	1:3·3	30	3·2	4·1	5·1	3·7	4·6	5·8	4·2	5·3	6·7
60°	1:20	5	0·4	0·6	0·7	0·5	0·6	0·8	0·6	0·7	0·9
	1:14	7	0·6	0·8	1·0	0·7	0·9	1·1	0·8	1·0	1·2
	1:10	10	0·8	1·1	1·4	1·0	1·2	1·6	1·1	1·4	1·8
	1:6·7	15	1·2	1·6	2·0	1·4	1·8	2·3	1·6	2·0	2·6
	1:5	20	1·6	2·1	2·6	1·8	2·3	3·0	2·1	2·6	3·4
	1:4	25	1·9	2·5	3·3	2·2	2·8	3·7	2·5	3·3	4·1
	1:3·3	30	2·2	3·0	3·8	2·6	3·4	4·3	3·0	3·8	4·8
90°	1:20	5	0·2	0·3	0·4	0·3	0·4	0·5	0·3	0·4	0·5
	1:14	7	0·3	0·4	0·5	0·4	0·5	0·6	0·5	0·6	0·7
	1:10	10	0·5	0·6	0·7	0·5	0·7	0·8	0·6	0·8	1·0
	1:6·7	15	0·7	0·8	1·0	0·8	1·0	1·2	0·9	1·1	1·4
	1:5	20	0·9	1·1	1·4	1·0	1·3	1·6	1·2	1·4	1·8
	1:4	25	1·0	1·3	1·6	1·2	1·5	1·9	1·4	1·8	2·1
	1:3·3	30	1·2	1·6	1·9	1·4	1·8	2·2	1·6	2·0	2·5

The data of Table 9.9 are based upon the following assumptions:
Dimensions of space: 120 ft × 60 ft × 15 ft ceiling clear height.
Bay width: 30 ft, i.e. 4 bays.
Reflectance of ceiling: 60%.
Obstruction angle: 20°.
Glazed area in the table is the actual glass, not including glazing bars, etc.

C.2.3 The total daylight factor

C.2.3.1 Summation of direct and reflected light

The total daylight reaching a reference point in an interior is the sum of the direct skylight and the externally and internally reflected daylight. The sum of the three components is :

Daylight Factor = S.C. + E.R.C. + I.R.C.

C.2.3.2 Single-stage calculation of total daylight factor

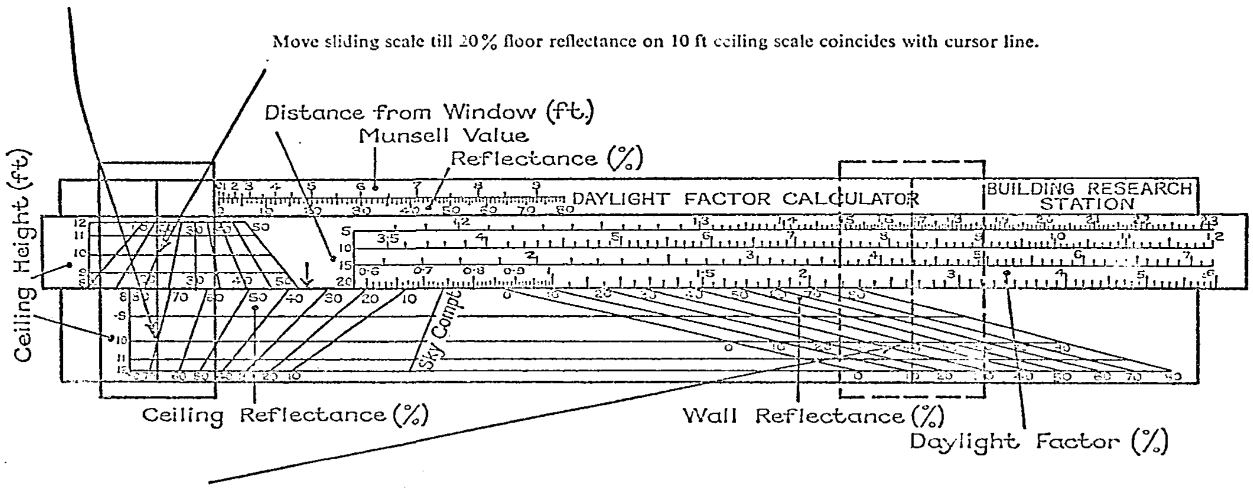
Under certain conditions, the total daylight factor at the reference point can be obtained in one step. The methods of single-stage calculation are based on either computations using a formula or the use of a calculator. The B.R.S. Daylight Factor Slide-Rule Calculator (shown as Fig. 2-18) is a single-stage calculator which allows one to determins total daylight, direct daylight together with reflected daylight, for points at different distances from the window, taking into account the reflectances of the principal room surfaces. The calculator can also be used in reverse to obtain a reflectance when the necessary daylight factor is specified. (C-15)

A one-stage formula method based on a flux-transfer calculation for the Daylight Factor was devised by Friihling. It is giving the average daylight factor on a horizontal reference plane as follows :

$$\text{Average Daylight Factor} = F \times U \times \frac{Ag}{Af} \times 100\%$$

Set cursor line against 70% ceiling reflectance on 10 ft ceiling scale.

Move sliding scale till 20% floor reflectance on 10 ft ceiling scale coincides with cursor line.



(i) Then set cursor line against 40% wall reflectance on 10 ft ceiling scale:
Read off, on daylight factor scale, values of daylight factor at distances of 5, 10, 15 and 20 ft from window, i.e. 16·8, 8·2, 4·3 and 2·6% respectively.

(ii) Alternatively, set second cursor line against 2% daylight factor at 20 ft from window:
Read off, on 10 ft ceiling scale, the required wall reflectance, i.e. 17%.

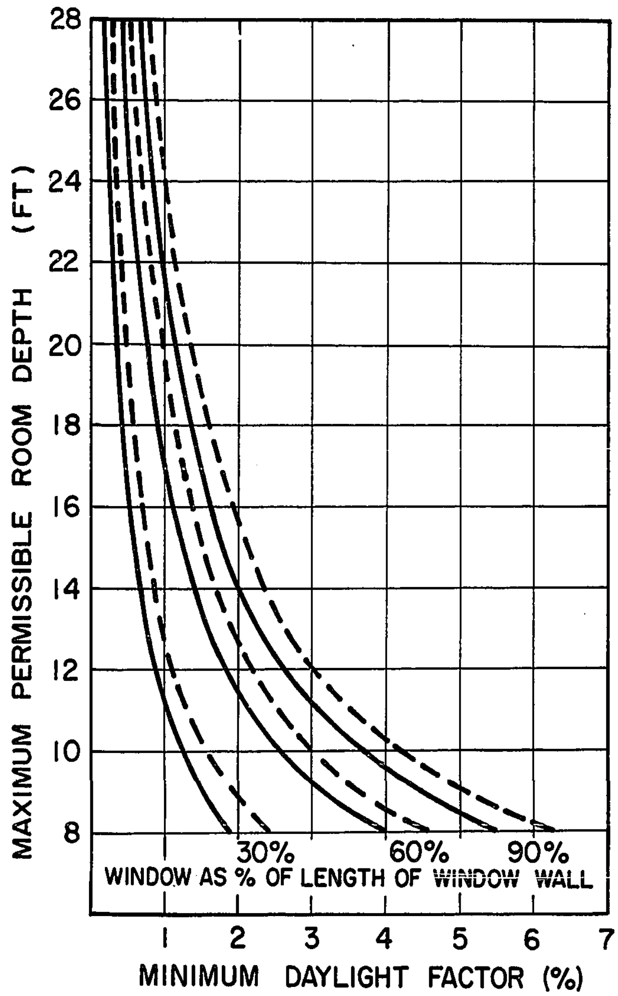
Fig. 2-18 Method of operation of the B.R.S. Daylight Factor Calculator.

where F = a window factor, the ratio of the average verti^al illumination on the window plane from the sky to the total outdoor illumination on a horizontal plane.

U = a coefficient of utilization, the ratio of the flux reaching the reference plane to the total flux entering the window.

$\frac{Ag}{Af}$ = the area of glazing ralative to the reference plane (or floor) area. (C-16)

The D.L.N.S. daylight design diagrams (Figs. 2-19, 2-20 & 2-21) that developed by Desler and published by the Australian Department of Labour and National Service (D.L.N.S.) was an approved simple guide to davlight calculation which promises to be widely used in the future. It consists of graphs relating daylight levels with the dimensions of the interior and of the windows. The purpose of the diagrams is to enable the architect to readily obtain the maximum permissible depth of room for a known fenestration, after he has assumed a certain limiting standard of Daylight Factor. (C-17)



Ceiling height 9'-0"
Ext. Obstruction 10"
Depth of Lintel 12"
Sill height 3'-0"

Reflectances :
Ceiling 70%
Walls 50%
Floor 15%

——— Room length ≤ 25'-0"
------ Room length > 25'-0"

Fig. 2-19 Australian D.L.N.S. Daylight Design Diagram for a room with vertical windows on one side and flat ceiling.

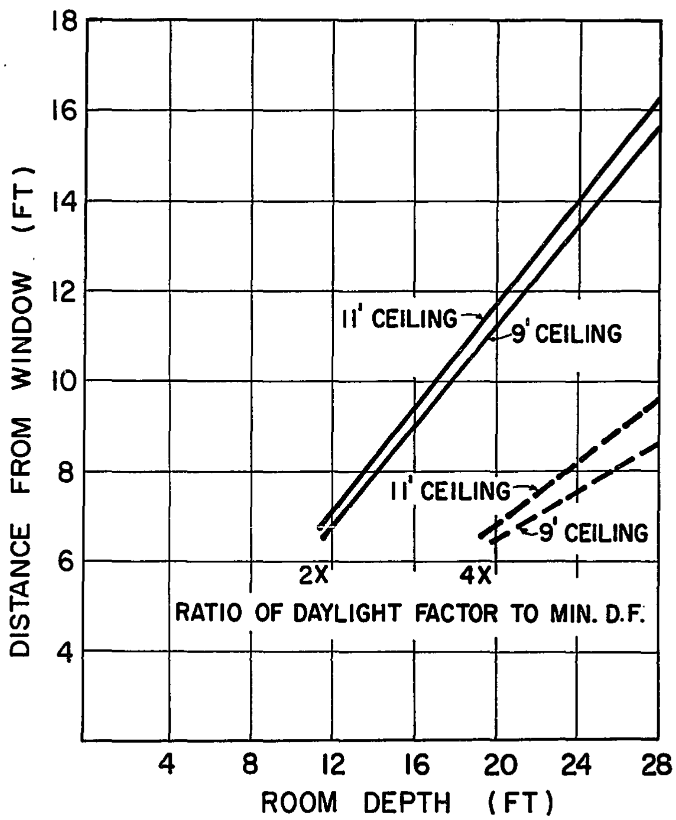


Fig. 2-20 Australian D.L.N.S. Daylight Design Diagram, vertical windows on one side, flat ceiling. Distance from window at which daylight factor 2 ft. from the rear wall. (conditions same as Fig. 2-19).

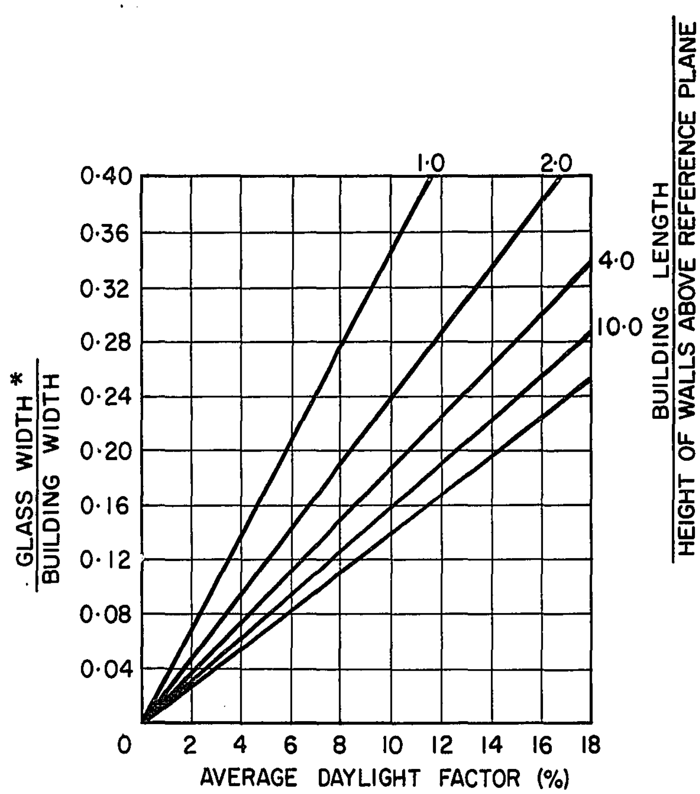


Fig. 2-21 Australian D.L.N.S. Rooflight Design Diagram.
Roof slope 20°, average reflectance of interior surfaces 20%.
(The distance between adjacent areas of glazing should not exceed twice the height of the roof-lights above the reference plane for optimum uniformity of illumination).

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PART III

DAYLIGHTING

IN

ARCHITECTURAL

DESIGN

Section A Daylight Control in the Room

Daylight is a universal, freely distributed element which is a constituent of most buildings. For all structures that have windows, daylight should be considered in relation to the function and planning of the building.

Each type of building has its own particular daylighting problem, and the intensity of daylight used should be adequate for functional needs.

The factors upon which good natural lighting depends are as follows :

1. The amount of daylight available at the site of a building,
2. The size and position of the openings which admit daylight into a building,
3. The use of appropriate transparent or translucent material for filling these openings to admit and distribute daylight and to satisfy such requirements as insulation from weather, heat, and sound. (A-1)

A.1 The necessary level of illumination

The most important task in lighting design is to achieve the necessary level of illumination to enable work to be done easily, without visual strain. (A-2)

Overhead, an overcast sky is three times as bright as at the horizon, therefore it is desirable to introduce light from above while avoiding glare. The following points should be considered :

a. As the height of the window head increases so does the light penetration.

b. For windows of equal area, a tall window gives a larger adequately lit space than a broad one, although it may be a greater source of glare.

c. With high broken skylines, broad windows give the best spread of light; with low, horizontal skylines, tall windows should be used.

d. Window should be evenly spaced to give a uniform penetration of light.

e. Although projecting balconies overhead curtail the light, small external soffits reduce sky glare.

f. Clerestory windows increase light penetration, but must be carefully designed to avoid glare.

g. Top lighting gives three or four times more light on the working plane than windows of the same area, but the size of top lights must be kept small, with adjustable screening provided, or there may be severe thermal problems. (A-3)

A.2 Daylight and visual comfort

Before the discussion of the visual comfort, we should understand certain basic laws of psychophysics which relate the "sensations" which human beings experience and the physical causes of these sensations —— the stimuli. For example, we can determine the relationship between the amount of light provided in a room and the sensation of brightness. Table III-1 shows the sensation of comfort associated with lamp bulbs of various sizes.

Table III-1 The Sensation of Comfort in a Living Room

Stimulus - Size of bulb	Sensation of light	Sensation of comfort
40 W	Very dim	Uncomfortable (too dim)
60 W	Dim	Uncomfortable (too dim)
100 W	Bright	Not uncomfortable
150 W	Bright	Not uncomfortable
200 W	Very bright	Uncomfortable (too bright)
300 W	Extremely bright	Uncomfortable (too bright)

Similarily, we must consider the " visual adaptation " —— a form of physiological adaptation, that can alter our sensitivity to amount of light, and also our sensitivity to change or contrast. If we are out of doors on a bright day, and look through an open door into a room, the interior of the room looks dark, and we cannot distinguish details of objects in the room. This effect arises, because we are adapted to the brighter conditions out of doors. If we come into the room and we have to give our eyes time to re-adapt to the darker room interior, then after a short time interval things will look quite bright and detail will be easily distinguished. Based on this effect, it can be suggested that the visual comfort in a room is related to the brightness of out doors and other connecting rooms.

We architects must learn about psychophysics to distinguish between the two situations known as the " linked situation ", where the primary and secondary sensations both vary directly with the stimulus, and the " unlinked situation ", where the secondary sensation does not vary as the primary sensation with the stimulus.

The glass-in-school-classrooms problem, is a typical unlinked situation. The more glass is provided, the better the natural lighting up to a point. Beyond that point the lighting gets worse, due to excessive glare, so that the addition of glass, only worsens the lighting. Failure on the part of architects to appreciate that this is an unliked situation has resulted is many complains of glare by school children and staff. (A-5)

Because our eyes have been developed for frequent changes in distance adaptation, for objects far away, it is little wonder that eyestrain is caused by continuous adaptation to the close tasks imposed by civilization. The strain is relieved by looking at distant objects from time to time, even if it be only for a few seconds. This relaxation is usually achieved by looking out of the window, shown as Fig. 3-1. (A-6)

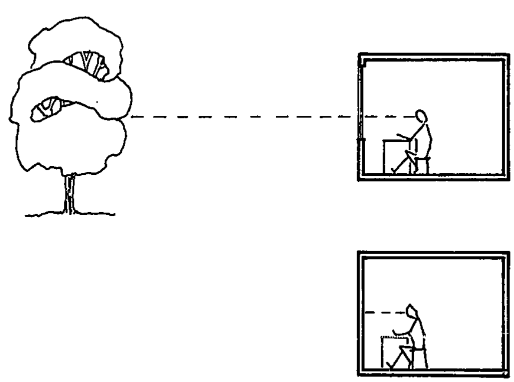


Fig. 3-1 The importance of a distant view.

There is often a need for some negative area on which the gaze can turn when in need of a visual or mental rest. A view through a window is such a " visual rest centre ". It permits the eyes, which have been concentrating on near work, to relax a little before starting up the task again. A good visual rest centre should in no circumstance be excessively bright in relation to the work. It is preferable that it should be of the same brightness or slightly lower. If the eye has to undergo significant changes in its adaptation when the gaze wanders away from the work, there will be temporary difficulty in seeing when the work is taken up again. (A-7)

Generally this physiological function of the distant view is overlooked and the desire to " look out " is attributed to a mental urge only. Hence ugly views are deemed worse than useless and are excluded. They do afford some relaxation, however, though this may sometimes be partically offset by their depressing effects on the mind.

Without a view through a window a degree of distance adaptation is possible in large rooms, provided that the view of the end of room is not obstructed by glare. Therefore equalization of surface brightness is far more important with artificial lighting than it is when daylight is received through windows. At a distance less than 20 ft. no satisfactory visual relaxation is possible. It is not an accident that rooms are generally considered small if their greatest dimension does not attain this minimum. (A-8)

A green court yard is often provided in the building in order to produce a good visual rest centre. Some architects even plan for green courts in office buildings.

A.3 Glare and visual comfort

It is important to introduce some form of glare in achieving the necessary level of illumination and controlling daylight from window.

Glare is defined as " a condition of vision in which there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of brightness or to either simutaneous or sucessive, extreme contrasts in the field of view". (A-9)

A.3.1 Disability glare

There are two types of glare : Disability glare and Discomfort glare.

Glare disability is due to excessive amounts of light reaching the eye and resulting in scattering of light inside the eye. A form of disability glare which is commonly found in buildings is due to the reflection of either artificial light or sky light, from the polished surfaces of furniture. Although the worker is often unconscious of this type of glare, the effect is detectable by errors or a slowing down of his performance.

A.3.2 Discomfort glare

This form of glare is more common in building interiors and causes direct discomfort. Discomfort glare is frequently present in bright surroundings. It can also result when the work is placed in a bad position relative to a window. In both case the glare results in discomfort but does not affect the ability of the worker to preform his duties. (A-10)

A.3.3 Control of glare

Equalizing the brightness on all surfaces of the visual perisphere is the best way to avoid glare. As light attracts the eye, the highest brightness should be in the focal point, and gradually fade outwards. Because the eye is more sensitive to light from below, brightness should decrease rapidly towards the bottom, and slowly towards the top and sides. In the ideal case the object itself is the source of light. (A-11) The following suggestions will assist in the control of glare :

a. Grade the contrast from the extreme brightness of the window to the much lower brightness of the room. Shadows and dark colours (Munsell values less than 7) should be avoided on the window wall; and where possible the wall should be lit from another source. The framing members of the windows themselves should be designed with particular emphasis on these points.

b. Build low sills to allow more light to fall on the floor and to subsequently be reflected, softening the shadows on the window wall and ceiling. They also allow more of the light reflected from the ground to strike the ceiling at the back of the room.

c. Position the windows so that they give views of buildings and trees outside, as well as the sky. (A-12)

If the walls are dark in colour the sky will appear to be very glaring. By reprinting the walls off-white or a light colour, the glare will be greatly reduced.

A.3.4 Control of daylight by glass type

Daylight control in a room can be improved by choosing the right type of glass. In certain situations it can reduce glare and re-direct the light from bright sky outside.

Some examples for achieving the results of glare reduction and re-direction by using different types of glass are as follows :

a. Single glass (Fig. 3-2)

1. Transmission
2. Diffusion
3. Obscuration
4. Re-direction

b. Double glazing (Fig. 3-3)

1. Glare reduction + Re-Direction
2. Glare reduction + Diffusion
3. Re-Direction + Diffusion
4. Increased Diffusion
5. Increased Re-Direction

6/6a Diffusion by Insertion of a Diffusion Screen (which needs protection.)

7. Movable Devices Protected Between Two Panes of glass, for Light Direction, Diffusion and Glare Reduction. (A-13)

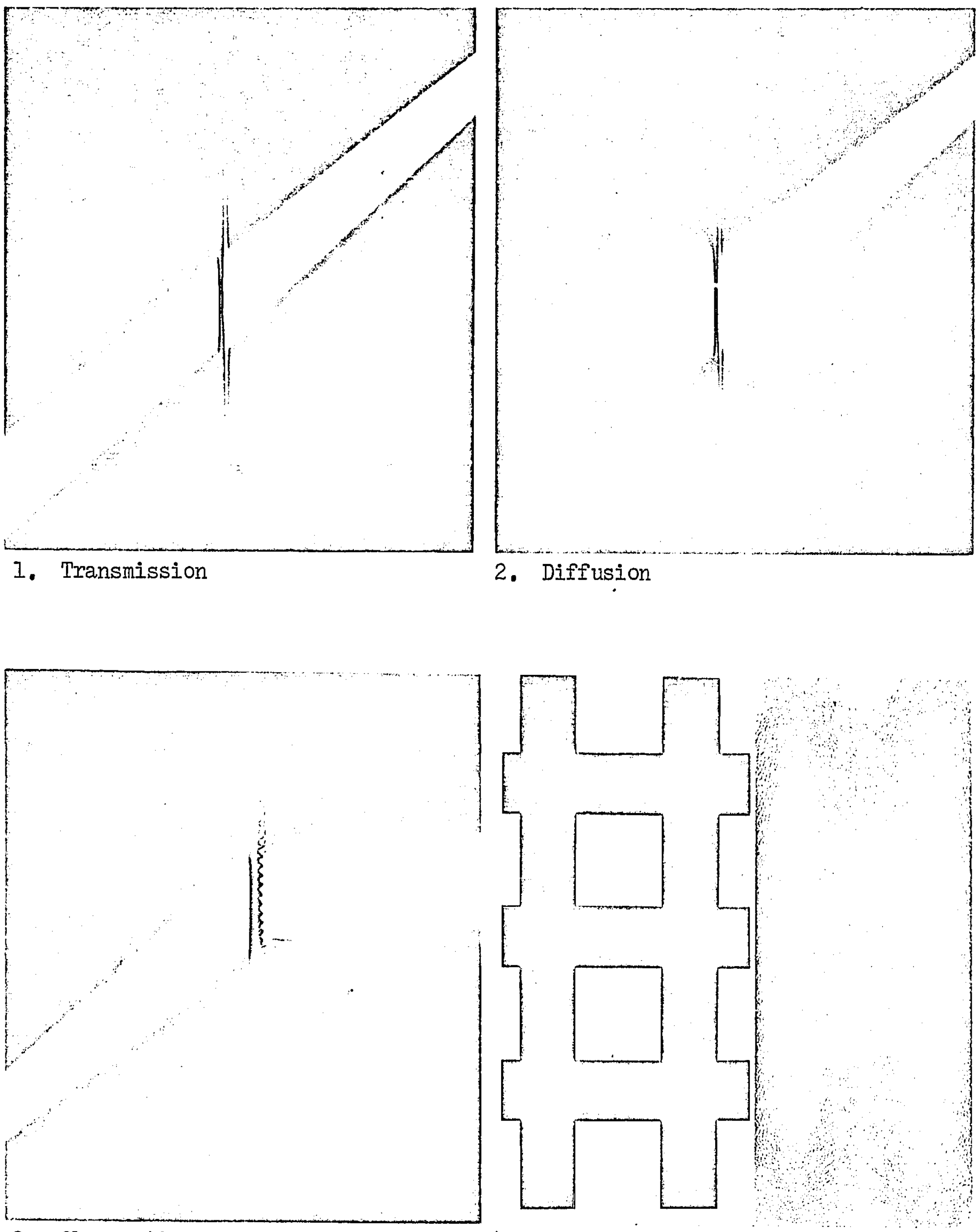
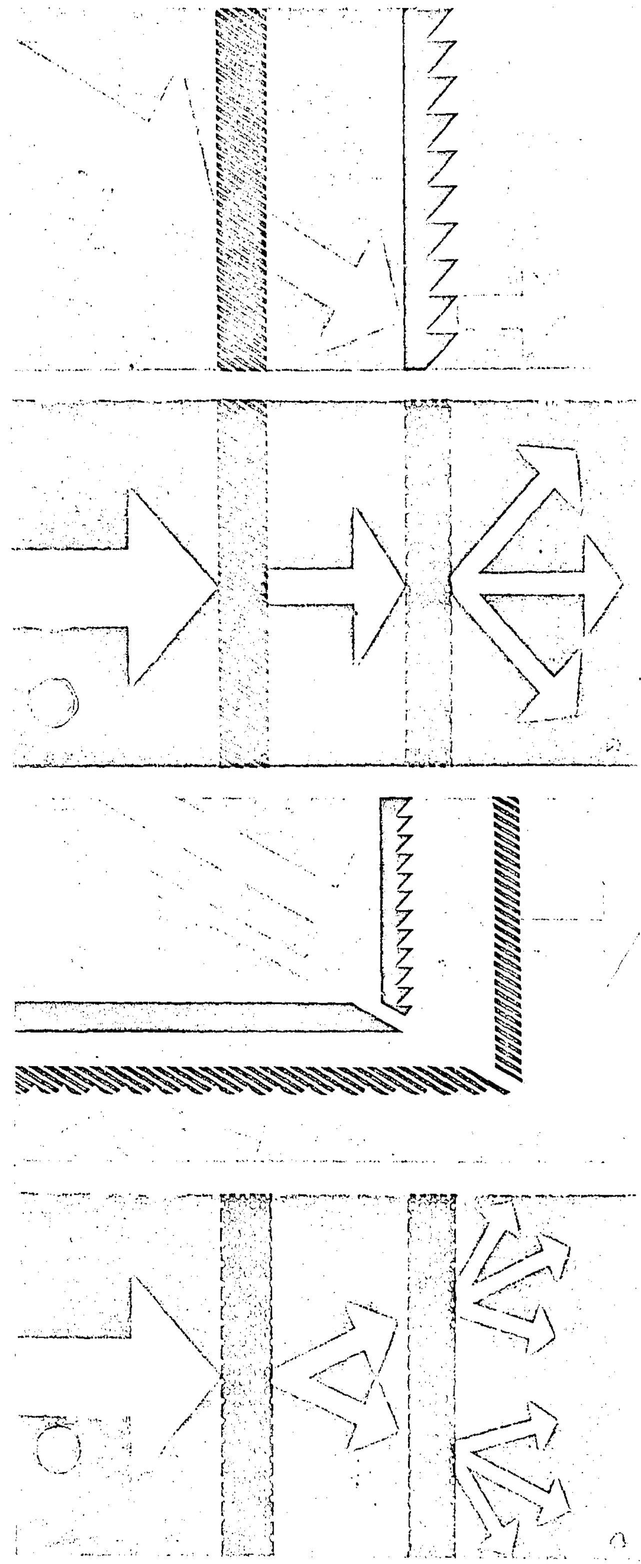

1. Transmission
2. Diffusion
3. Obscuration
4. Re-direction

Fig. 3-2 Single glass.



1. Glare reduction & Re-Direction

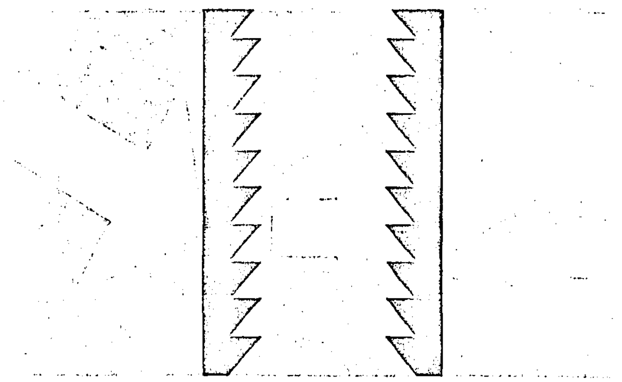
2. Glare reduction & Diffusion

3. Re-Direction & Diffusion

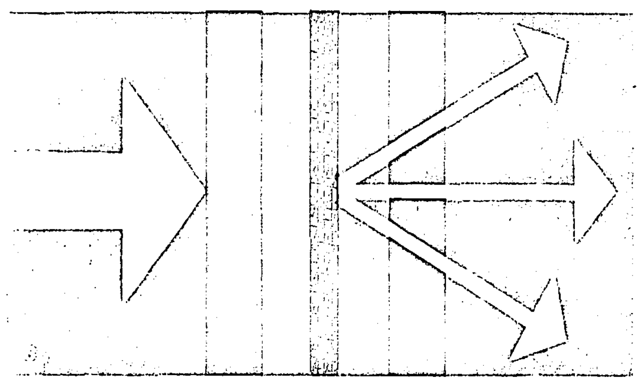
4. Increased Diffusion

Fig. 3-3 Double glazing.

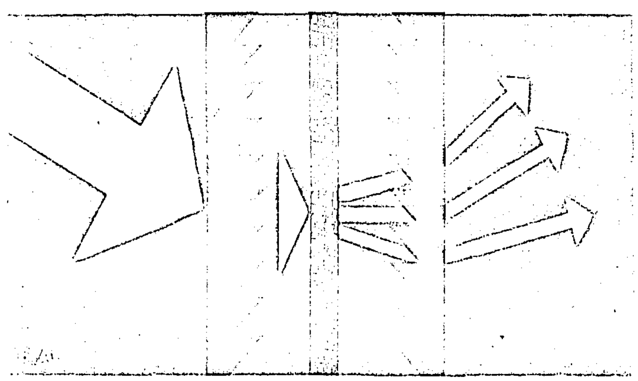
5. Increased Re-Direction



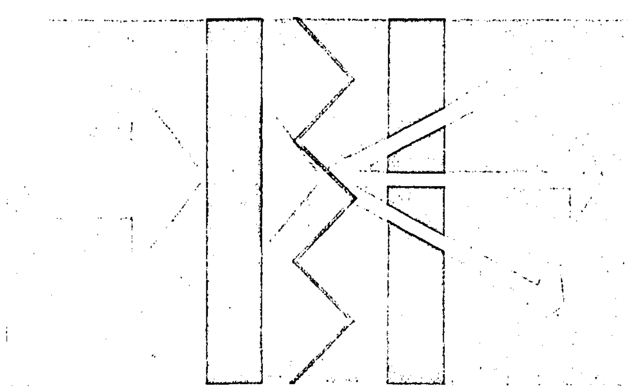
6. Diffusion by Insertion of a Diffusion Screen



6a. Diffusion by Insertion of a Diffusion Screen (Re-Direction)



7. Movable Devices Protected Between Two Panes of glass, for Light Direction Diffusion and Glare Reduction



A.4 Solar heat control

Most people like to be in sunlight during the day. They like its radiant warmth in winter but prefer to be shaded from that warmth in summer. In daylight design, both conditions should be satisfied with some forms of sun control. (A-14)

Orientation to the sun is very important for getting adequate sunlight (It will be discussed in A.6 of Part III). Some of the most important techniques for sun control are :

a. NATURAL DEVICES : building orientation, trees and other buildings and projecting wings, geographical elements such as hills.

b. AROUND WINDOWS, OUTSIDE : balconies, arcades, canopies and overhangs, arbors, eggcrate overhangs, solid horizontal and vertical fins, deep reveals, awnings of cloth or metal.

c. OVER WINDOW, OUTSIDE : shutters fixed or movable louvers, fixed exterior venetian blinds, heat-absorbent storm windows or glass jalousies in addition to the regular window, venetian screenings, paint or whitewash (used mainly in greenhouses and, rarely, in factories where glare has proved an annoying problem).

d. THE WINDOW ITSELF : heat-absorbing glass, double glazing, glass jalousies and awnings, glass block, frosted glasses, elimination of windows entirely.

e. OVER WINDOWS, INSIDE : single or double cloth roller shades, slatted bamboo shades, venetian blinds either horizontal or vertical, draperies, glass curtains, venetian screens inside casement windows.

f. INTERIORS : scientifically planned interior decoration and furnishing to reduce glare. (A-15)

A.5 Colour

Bright colours as well as bright lights attract attention. In modern architecture colour is quite important, and widely used in building design and interior decoration. Colour design is very complex, therefore we will only consider the colour relation with light and how it may affect the visual comfort, colour design of the interior, and the effects of light and colour interactions on the design.

Firstly, colour design affects the visual adaptation in a room. For example, the sky may be very glaring if the walls are dark in colour. By reprinting the walls off-white or some light colour, the glare will be greatly reduced.

In this Part III. A.2, a " visual rest centre." was mentioned. I think that a "visual rest centre" can be established by soft light and lovely colour if it cannot be obtained through a window. (A-16)

Secondly, the light can affect the colour design in the interior. Usually, you add as much colour as you wish in the rooms facing the north, while the walls of a room that looks to the south may be almost colourless. A dark ceiling is restful, unless the room is a low one. The ceiling should not be the blank white as is so generally and complaisantly accepted. Even where the walls are white, a tinted ceiling, unless the room is a low one, tempers any tendency to glare and distributes an opalescent bloom on the walls themselves. (A-17)

A.6 Orientation of buildings and daylight

Building orientation is an ancient problem. In the last hundred years many new developments have occurred as the direct result of specific scientific investigations. Many years ago, people knew enough to design their houses facing towards the south or south-east and west, or to use the skylight in order to get more sunlight. But nowadays, with the aid of science, we can use different observations and the result of experiments or calculations to find out the most suitable orientation for different kinds of buildings.

The principles of orientation are different for different climates. In the tropics where the sun is generally very bright and hot, the preferable orientation is away from the sun and in the direction of prevailing breezes.

In temperate zones buildings should be designed for two distinct climates: tropic in summer and sub-arctic in winter. To meet both conditions is a problem of northern architecture. (A-18)

The developments in studies of building orientation of the past forty years have shown the topic to be so important that it is now considered in computing heat loading factors for air-conditioning, since the amount of solar radiation entering a building through its walls and windows is so difficult to exclude from the building and varies so greatly, depending on the direction the wall or window faces. (A-19)

Observations in New York City have shown that the amount of solar heat on vertical walls in different directions can be easily obtained by Fig. 3-4. (A-20)

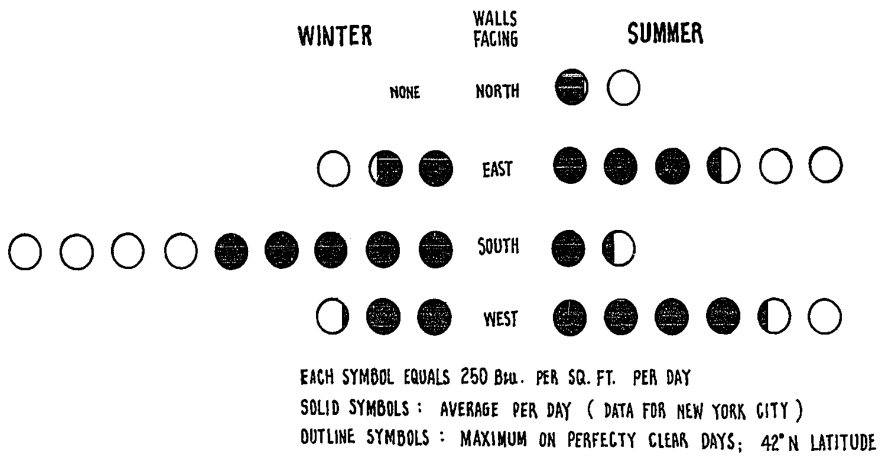
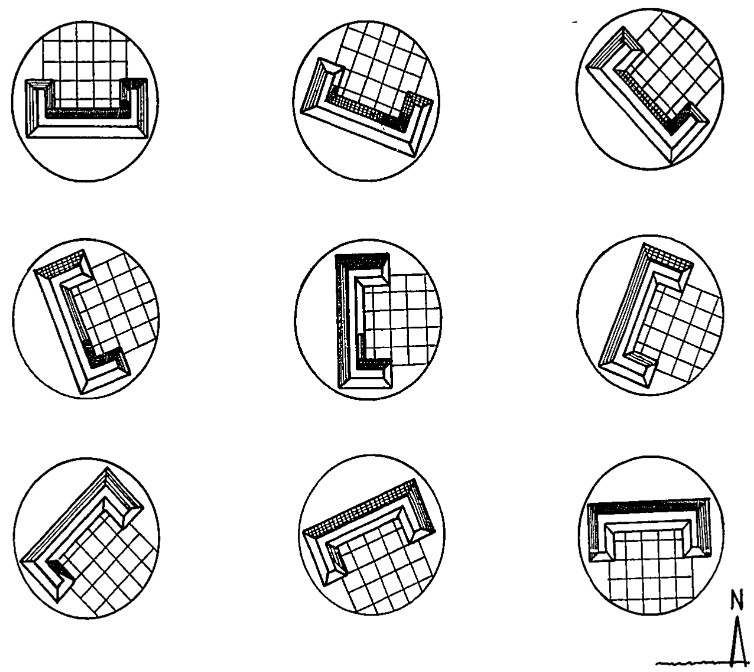


Fig. 3-4 Sun-heat on vertical walls

From thousands of examples, it can be demonstrated beyond doubt that the rooms which face the south have plenty of daylight and sunshine, and by the methods which will be illustrated in section B and C of this Part it can be shown, that adequate daylight is provided in the working rooms facing different directions. Fig. 3-5 shows the conditions of sunshine of a U shape building which faces to the various directions. (A-21)

The amount of sunlight received by a building depends on both the building's shape and orientation. The several simple diagrams of building shapes shown in Fig. 3-6 will exploit sunlight to the maximum when they are properly oriented. (A-22)



the most adequate sunlight and daylight
good sunshine orientation
poor sunshine orientation
no sunshine in whole year

Fig. 3-5 The conditions of sunshine of a U-shape building which faces to the various directions.

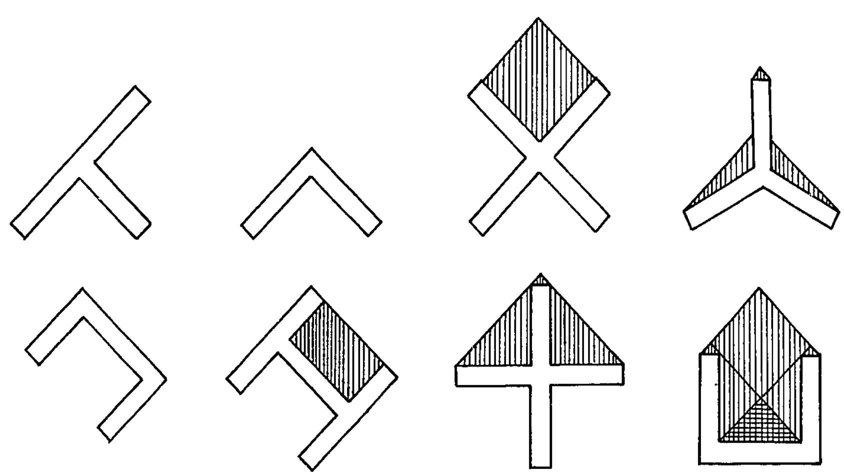


Fig.3-6 Sunlighting and shadowing of various plan types:north is at top.

In order to provide ample sunlight and increase the psychological effect on well-being, all living quaters should be faced towards south direction as much as possible. In Fig. 3-7 the four simplified sketches are the fundamentals of orientating or planning living areas to face the sun. Although such orientation may be not accomplished in every instance for many different conditions of the site, it is important to design the main rooms - even only the living room - facing south regardless of which direction the lot faces. (A-23)

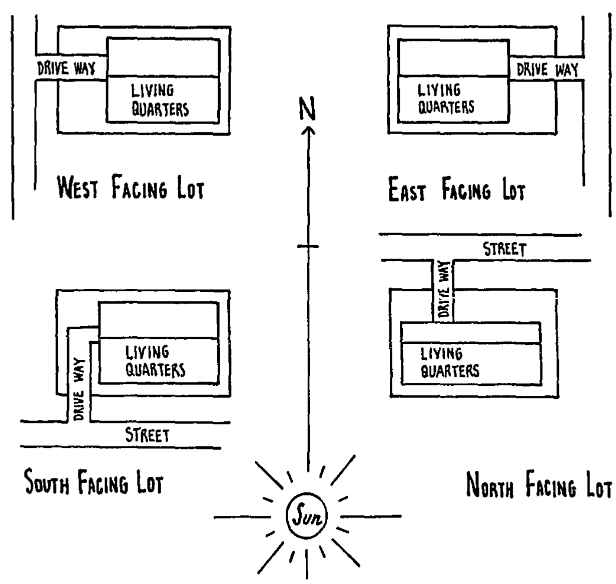


Fig. 3-7 The orientation of living area

The most sucessful residence designs, from the point of view of building orientation, make sunlight available in a kitchen in the morning, especially in winter, and provide sunlight in the living room in the afternoon. (A-24, A-25)

Owing to the different climates and various sites, and variations of individual tastes or requirements, it is difficult to present a standard of orientation for natural lighting. But diagrams of appropriate orientations for various rooms in different building types are proposed in the following figures. (A-26)

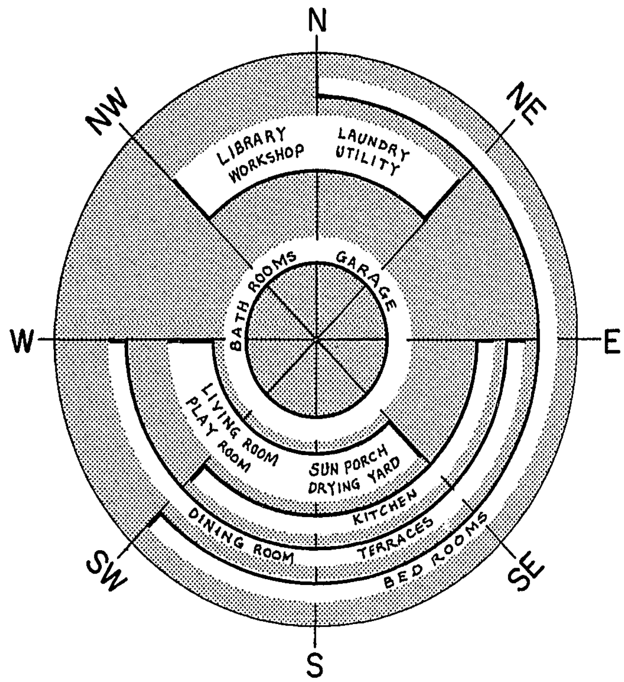


Fig. 3-8 Orientations for the rooms of residences.

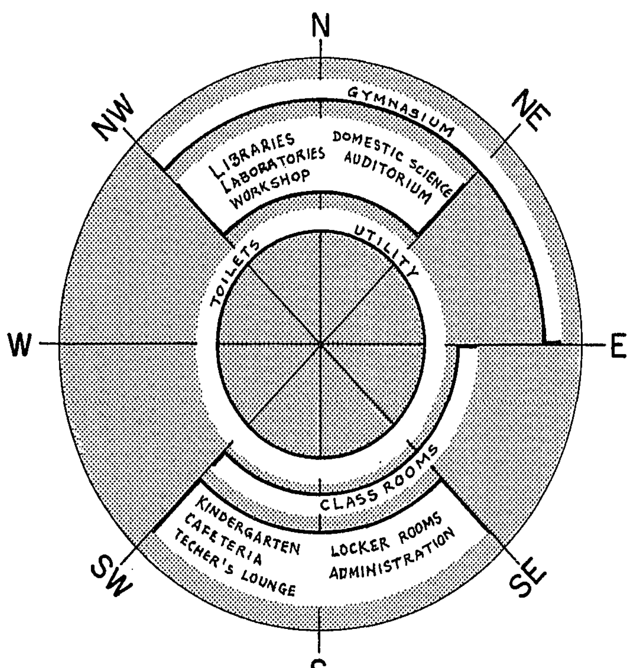


Fig. 3-9 Orientations for the rooms of schools.
(Some architects prefer the classrooms facing to the North in order to obtain 'north' light.)

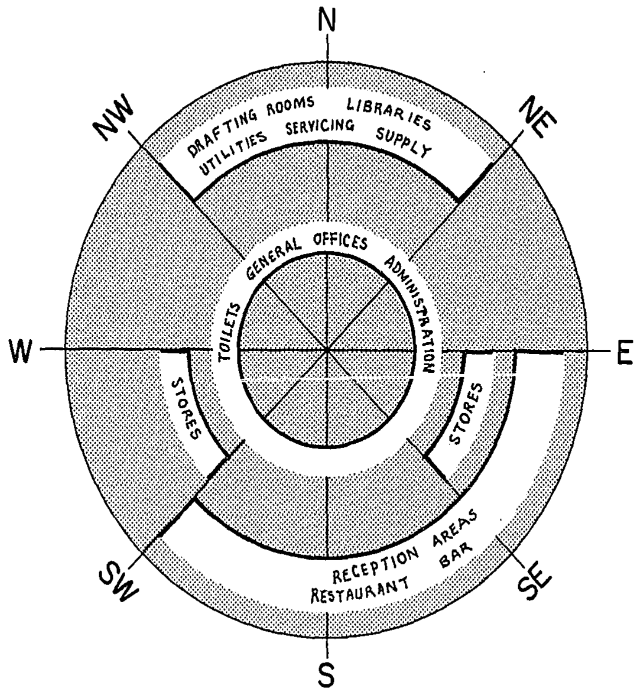


Fig. 3-10 Orientations for the rooms of offices and stores.

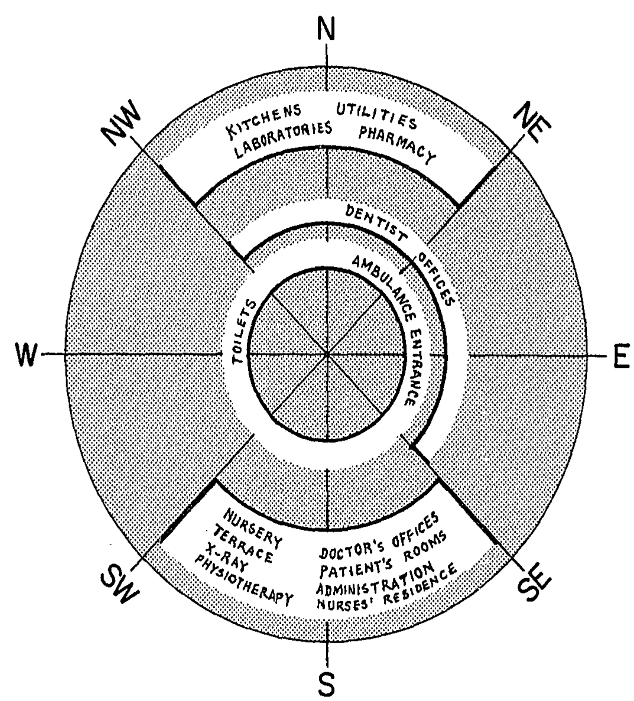


Fig. 3-11 Orientations for the rooms of Hospitals.

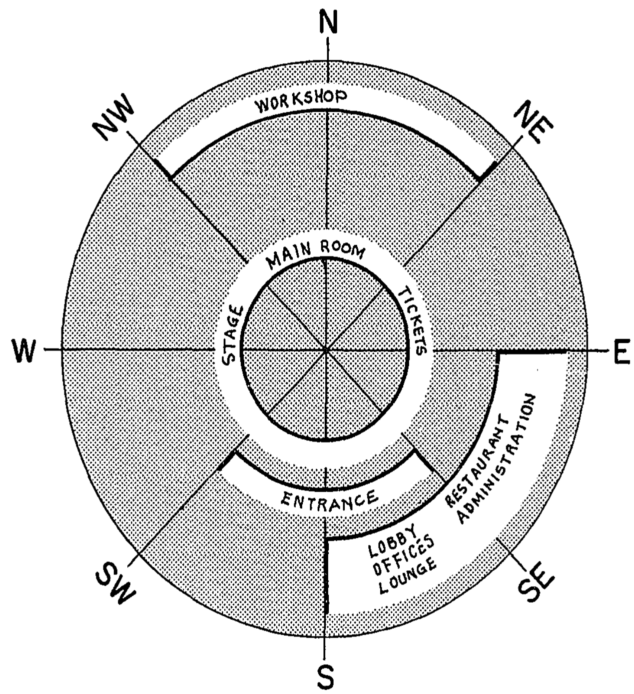


Fig. 3-12 Orientations for the rooms of Churches and Auditoriums.

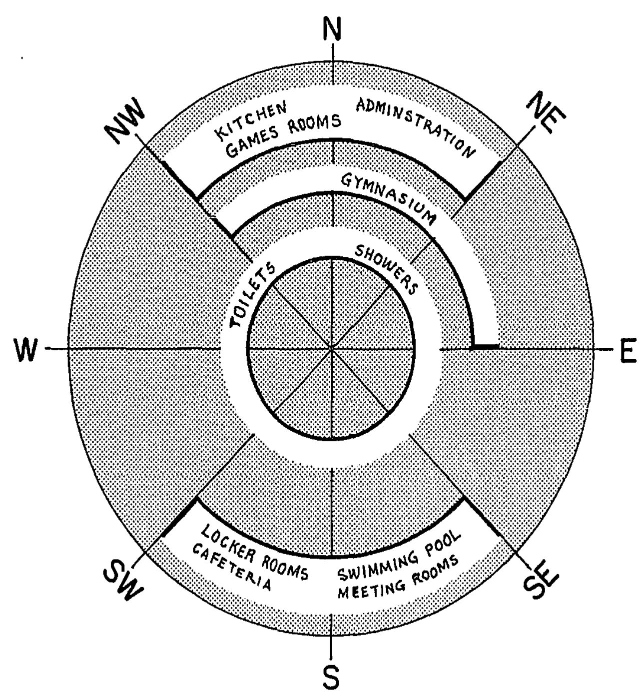


Fig. 3-13 Orientations for the rooms of Athletic buildings and Community centers.

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Section B Daylight Design and Town Planning

B.1 Town planning and daylight

The famous architect, Le Corbusier confided that sun, space and verdure are the " Essential Joys " of modern dwellings. These ancient influences have fashioned our body and our spirit. There is a very visible comparison in Fig. 3-14. The upper diagram A, presents the plan and section of a town, poorly-planned by modern standards. In the lower diagram B, a building with an equal volume to those shown in diag. (A) demonstrates the space-saving capabilities of modern housing techniques. It permits a new plan of habitable quarters that integrates within itself the " essential joys ". (B-1)

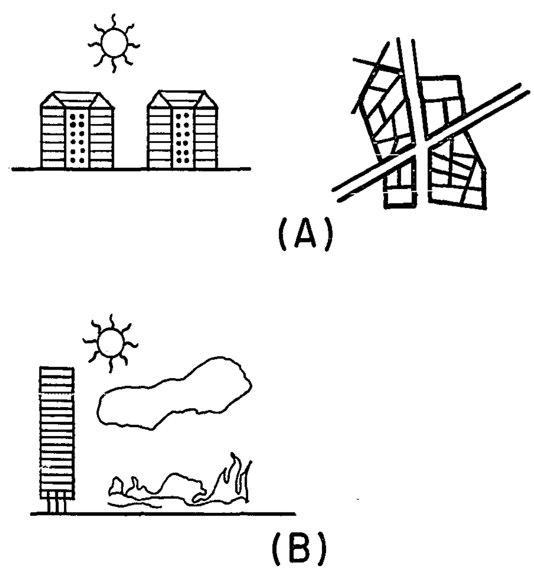


Fig. 3-14 The comparison of old and modern town planning.

Enthusiasm for " light, space and air " was an impulse shared by almost all the pioneers of the modern movement in architecture and town planning. They condemned the traditional corridors street, —— the Georgian and Victorian conception, lined with buildings around internal light wells, in favour of a more open layout of tall slabs or towers, which, as Fig. 3-15 and Fig. 3-16 suggest, should lead to better natural light. Other benifits were also expected from open planning. The space between buildings would be freed for gardens, landscaping or parking. The spread of fire would be hindered. Upper storeys would be more remote from the noise of traffic. Building tall blocks also ensures better penetration of daylight. (B-2)

B.2 The influence of daylight on civic planning

Planning for daylight demands that the effects of neighbouring obstructions be considered. In the large cities, such as New York, where the erection of lofty, tower-like structures is contemplated for economic and administrative reasons and considerations of amenity, it is desirable to explain that buildings of this kind need not necessarily entail loss of daylight to the extent that has caused such deep concern in the cities.

But, in point of fact, there are many cases where high buildings have destroyed the rental values of neighbouring buildings, only to have had in some cases their own rental values destroyed by other buildings. There are limited areas that seem in the process of being smothered by their own growth; light and air are being shut off and the streets are becoming entirely inadequate. (B-3)

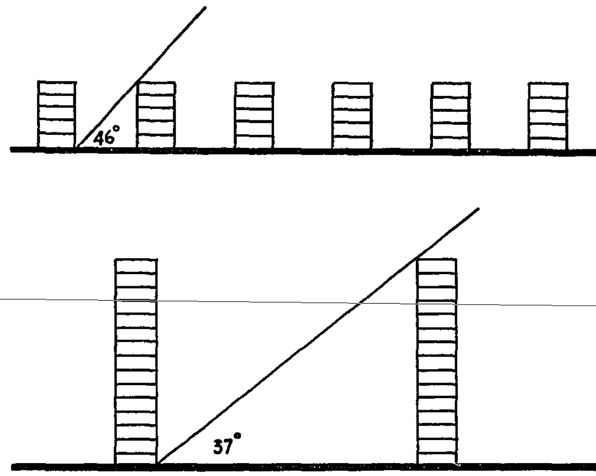


Fig. 3-15 Mutual shading by parallel buildings.
Tall blocks ensure better penetration of daylight.

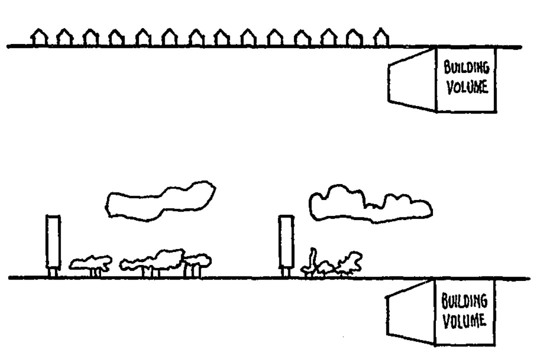


Fig. 3-16 With equivalent built volumes, one can be.
live in a "garden" city, or in a town of
type "radiant" city.

At the present time, the standard of daylighting found on the lower floors of buildings in urban districts is governed largely by building codes and bye-laws which limit the heights of buildings, angles of setback, and so forth.

By limiting the extent of the loss of frontal light caused by a high building or skyscraper, on the opposite side of the street, and by making it possible for compensating lateral rays from a low altitude to have free access to the interiors of the opposite buildings, the quantity of illumination received would be very much higher than that obtainable without low lateral light. Everything depends upon the width of the frontage of the high building and the extent to which lateral light can be made available. Fig. 3-17 gives an example of the method suggested. It has been hypothetically assumed that the low lateral buildings might be erected within an angle of 45 degrees above the ground, at the opposite side of the street. The extent to which the light available would penetrate the interiors would, in fact, depend to some extent upon the height and width of the window openings and the widths of the intervening piers. For buildings rising to an altitude of 20 storeys above the street, scientific investigation by means of daylight plans would prove that desirable standards of illumination cannot be received without lateral light, in the case of 100 feet and 60 feet streets. All that this diagram suggests is a method of approaching the problem of scientific daylight investigation. As in all town planning schemes, some land would have to be depreciated, in order to produce conditions that would permit selected sites to be fully developed, with some degree of amenity. When we rebuild our town and

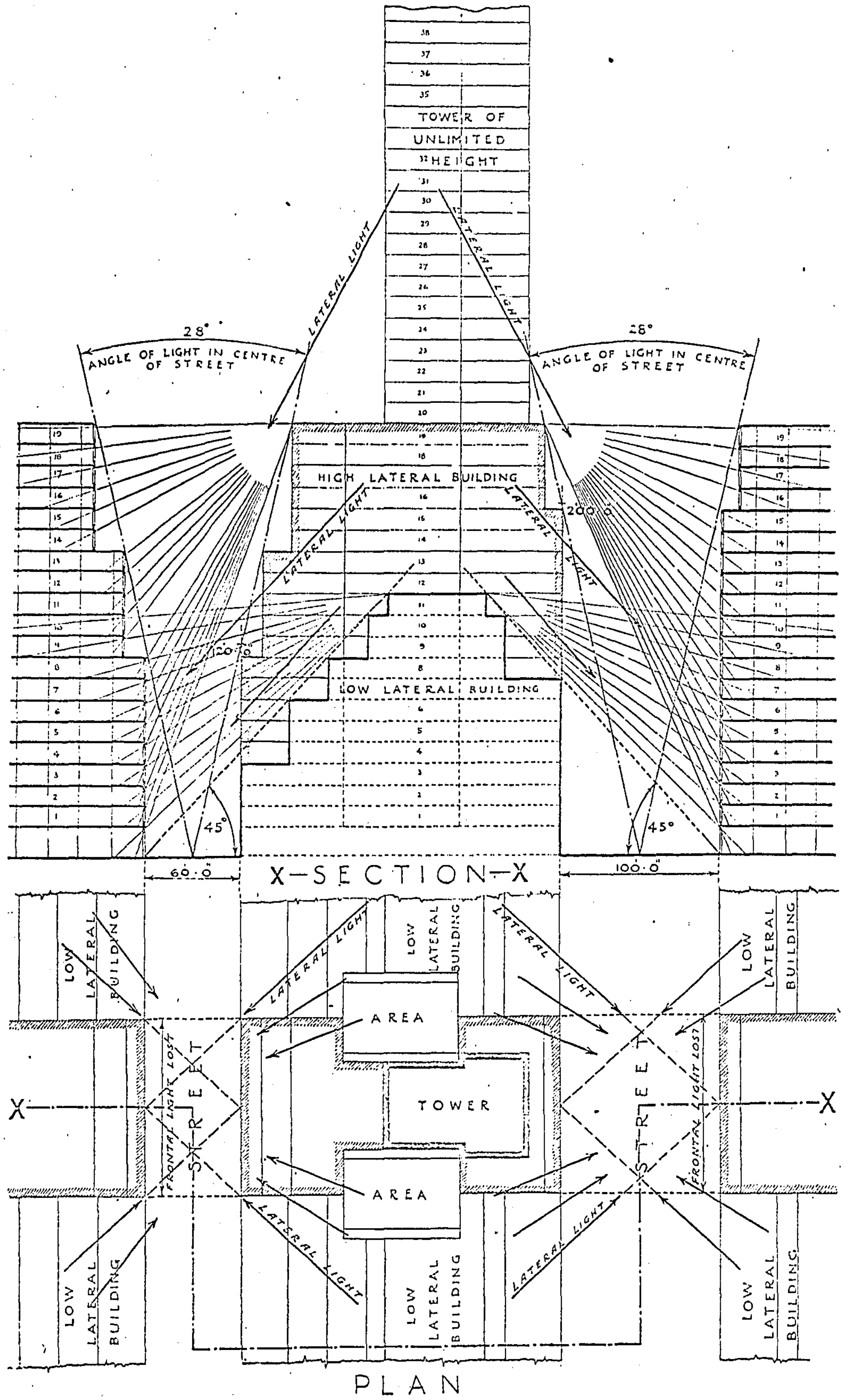


Fig. 3-17 A diagrammatic method for obtaining available lateral light.

introduce the contemplated high buildings, as presumably we must, we shall have to remember the importance of lateral light and insist upon its reservation to the greatest practical extent and, wherever possible, arrange for low lateral buildings to subtend an even smaller angle than 45 degrees. We must also contract the width of the high buildings as far as practicable and recess the external angles, when this would not detrimentally affect the plan and aesthetic design. (B-4)

B.3 Daylighting of buildings in Urban Districts

More than twenty years ago, using parallel buildings, W.Gropius observed, by a graphical method, that for a given total floor space on a site, it was better to build higher buildings farther apart. In this way the angle subtended from the top of one building to the ground floor of the next was reduced, making it possible to see sky farther into the lower rooms, as shown in Fig. 3-18. For the same reason, we may find that a gap will occur between the ends of the buildings, and through it a view could be obtained of at least part of the sky at a sufficiently low angles

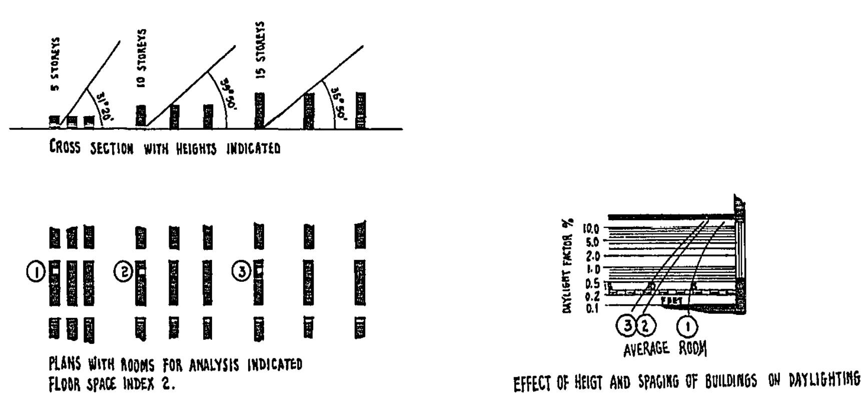
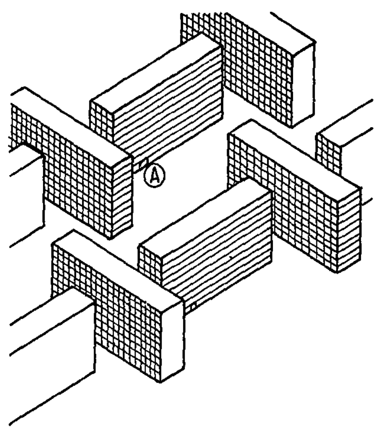
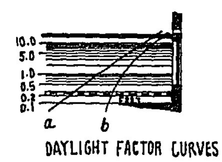


Fig. 3-18 Effect of height and spacing of buildings on daylight.

for the light to penetrate better into the room. Fig. 3-19 shows a alternative arrangement by turning every second building through 90° on plan. The result so far as daylight is concerned was almost startling; inpenetration is increased by 70 per cent, or more as shown in Fig. 3-19. The curves for the two arrangements are illustrated together for purposes of comparison. (B-5, B-6)





a - daylight curve for buildings as shown (for window A)

b - daylight curve for parallel building.

Fig. 3-19 Comparative daylight curves for buildings parallel and at right angle to each other.

Keeping the spacing of each type centre to centre, the same, and also the total floor space, or floor space index, $(= \frac{\text{total floor space}}{\text{total site area}})$ we may propose four major plan types other than the type of the simple rectangle. They are the hollow square, the cruciform, including the "L" and "T" which are simple variations, the "Y", and the rectangle, as shown in Fig. 3-20. The height of each plan was changed because they had different areas on a single floor. Each type was assumed to be on a site of equal area, 200 ft. square, and built up to the street line. The constant, known as the density of the development and represents the ratio of the floor space to the site area, has been set equal to three. Thus the hollow square was the lowest, the cruciform next and so on. The resulting daylight curves are shown in Fig. 3-20, for the comparison of average penetration for ground floor rooms. Evidently, the average penetration of the hollow square was very unfavourable compared to the penetration for the cruciform building, but beyond this no significant improvement is obtained even with buildings at right angles to each other. We may observe the variation of daylighting with different

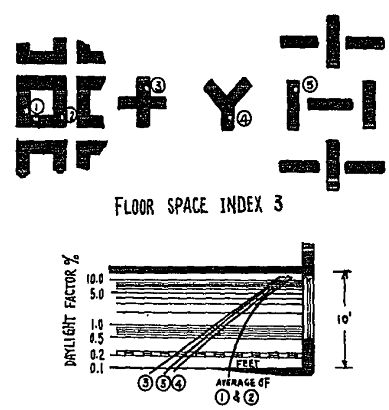


Fig. 3-20 Daylight curves for alternative arrangements of building.

heights in Fig. 3-21. This is a family of curves for floor space indices from 1 to 3. It is clear from curves of this type that the improvement in daylighting is rapid up to a point, but beyond this there is little to gain by additional height. The effects of the spacing of buildings on daylighting is shown in Fig. 3-22. By increasing the space between buildings and also increasing the height to keep the floor space index constant, the initial effect is to increase the penetration, however these increases are limited. Increasing street widths will improve some present conditions because the floor space index has been based on site areas which include streets and open spaces. (B-5, B-6)

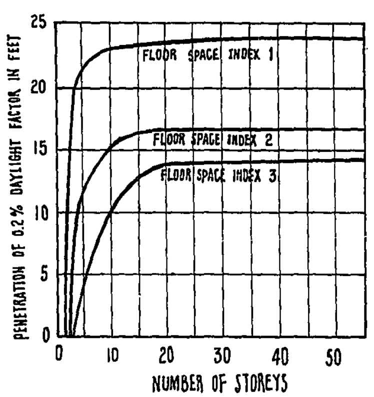


Fig. 3-21 Variation of daylighting with number of storeys.

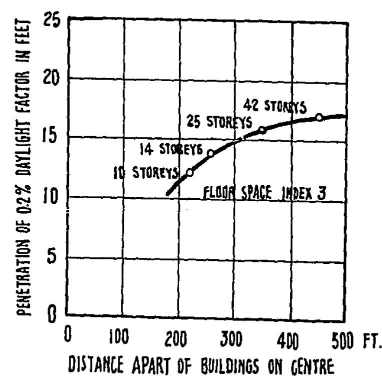


Fig. 3-22 General variation of daylighting with spacing of building.

B.4 External obstructions

External obstructions always limit the areas in a room which have direct access to skylight. These areas will not be deprived of light entirely, since there will be a greater or lesser amount of reflected light depending upon the reflectance of the external and internal surfaces and, of course, there will be a certain amount of light reaching these areas after reflection from the external obstruction itself. Adequate lighting in these areas without direct skylight will then depend entirely upon the success with which the original decoration scheme with light reflecting surfaces is maintained. (B-7)

The line of demarcation between the areas of the room which receive direct skylight and those which do not is called the no-sky line. The no-sky line in a room is obtained by projecting the edge of an external obstruction through the head, as shown in Fig. 3-23, or sides as shown in Fig.3-24, of the window to the reference plane in the interior. The Fig.3-23 shows that the no-sky line in a room facing a parallel building across the street will be a straight line parallel to the window and to the building opposite the window. The higher the opposing building, the nearer will be the distance d, from this line to the window, where $d = \frac{Dh}{H-h}$, and D is the horizontal distance of the opposing building from the window, h and H are respectively the heights above the reference plane of the window head and the parapet of the obstructing building.

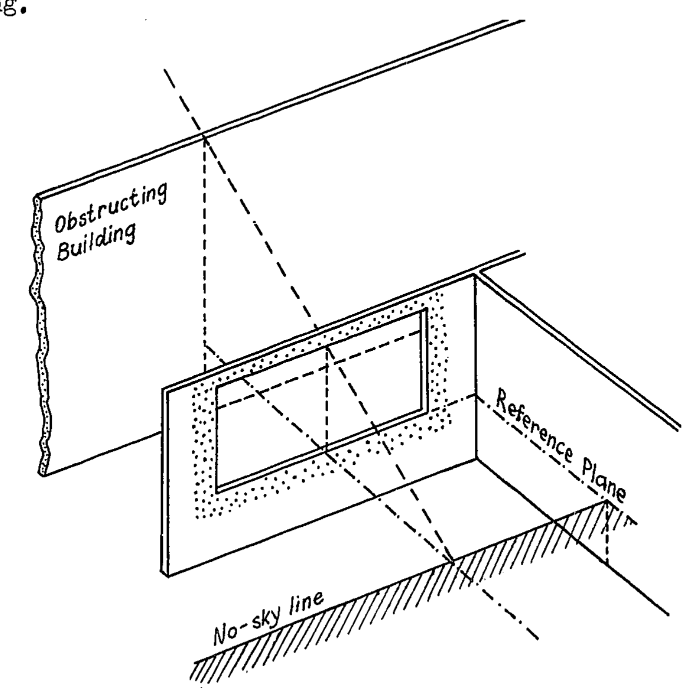


Fig.3-23 No-sky line for obstructing building parallel to window.

Fig.3-24 shows the no-sky line which is drawn from the vertical edge of the obstruction to the far vertical edge of the window. The effect of a building at right-angles is therefore to limit skylight to only one side of the building. The penetration of direct skylight to the back of a room is generally not seriously affected. If a large site is available for development, town planning should control the spacing of the buildings, ensuring that the long sides are at right-angle to each other rather than parallel in order to maximize the amount of sky line available to the streets.

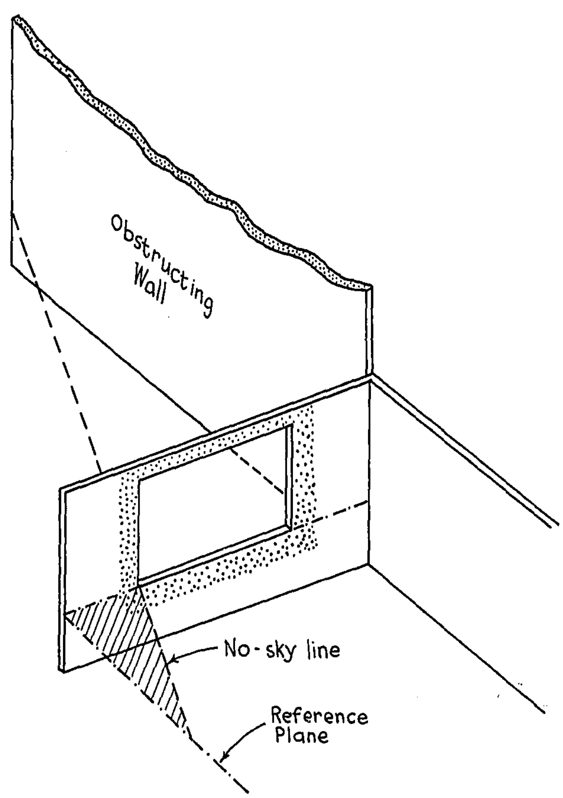


Fig.3-24 No-sky line for an obstructing wall perpendicular to the window wall.

In the examples given above, it is apparent that skylight can penetrate deeply into a building if the width rather than the height of an opposing building is limited. (B-7)

B.5 Town planning control for daylight

In Great Britain, the method of town planning for daylight at present in use, frequently referred to as the " Daylight Code ", was developed by the Ministry of Housing and Local Government (formerly the Ministry of Town and Country Planning) with advice from the Building Research Station, London. Its control could be effected by using the Waldram Diagram in the way illustrated in Fig.3-25. It is possible to establish by trial and error a building layout which would permit the necessary level of sky factor to be achieved for any building on the site, although this is a tedious process. (B-8)

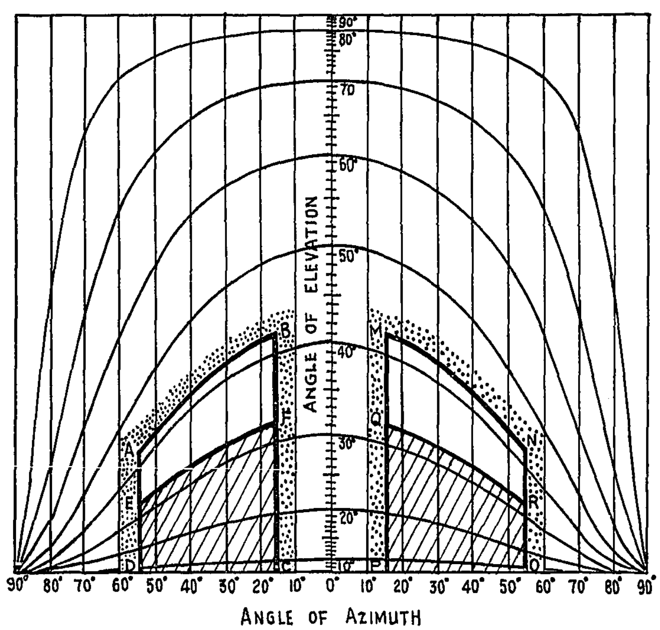


Fig. 3-25 Waldram Diagram used to determine sky factor for partially obstructed windows.

Another method, using the Permissible Height Indicators shown in Fig.3-26, is simpler and more economical. The Permissible Height Indicators which were devised to allow us to compute the limitations on angular width and angular height of obstructing buildings, are described in detail in a publication by the Ministry of Housing and local Government in England. They consist of four sets, two for non-residential buildings (the A and C series) and two for residential buildings which demand higher standards of daylight, see Table III-2, (the B and D series). The series A and B are used respectively at the plot boundary, and the series C and D at the building facade. In order to accommodate the different combinations of angular width and angular height of obstructing buildings, each series comprises four indicators (e.g. A1, A2. A3 & A4.) corresponding to four distinct combinations of angular width and height. (B-9) Table III-2 gives the angular dimensions from which all the indicators shown in Figs. 3-27 and 3-28 can be constructed.

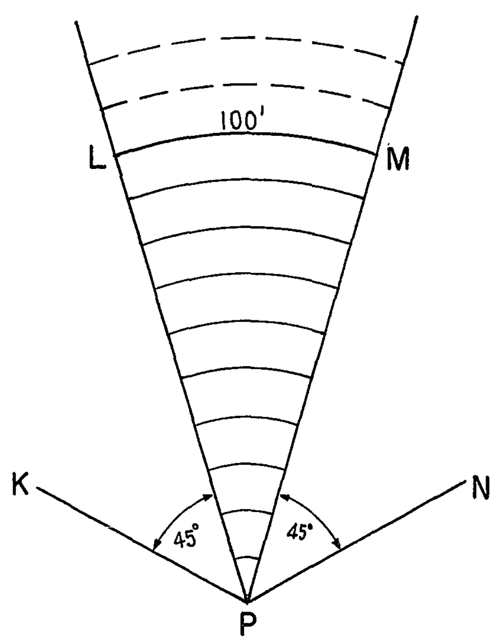


Fig. 3-26 Permissible Height Indicator.

Table III-2 PERMISSIBLE HEIGHT INDICATORS

Vertical angles of permitted obstruction and horizontal and vertical angular view of sky from the reference point

(*a*) Indicator		(*b*) *Distance to permitted obstruction 100 ft high*	(*c*) *Vertical angle of obstruction*	(*d*) *Horizontal angle of sky visible*	(*e*) *Vertical angle of sky visible above obstruction*
Residential	D1	214	25°	45°	5°
(Facade)	D2	274	20°	35°	10°
	D3	374	15°	25°	15°
	D4	568	10°	20°	20°
Residential	B1	107	43°	65°	6°
(Street centre line or plot	B2	137	36°	45°	13°
boundary)	B3	187	28°	30°	21°
	B4	284	19°	20°	30°
Non-residential	C1	120	40°	45°	5°
(Facade)	C2	142	35°	30°	10°
	C3	174	30°	20°	15°
	C4	214	25°	15°	20°
Non-residential	A1	60	59°	65°	4°
(Street centre line or plot	A2	71	55°	35°	8°
boundary)	A3	87	49°	20°	14°
	A4	107	43°	15°	20°

Note: Columns (*c*) and (*d*) give the angular limits determined by the Indicators. Columns (*d*) and (*e*) give the angular limits of the view of sky from the indoor reference point. Adjustments to the above values for special uses of the Permissible Height Indicators are discussed in the publication of the Ministry of Housing and Local Government.[16]

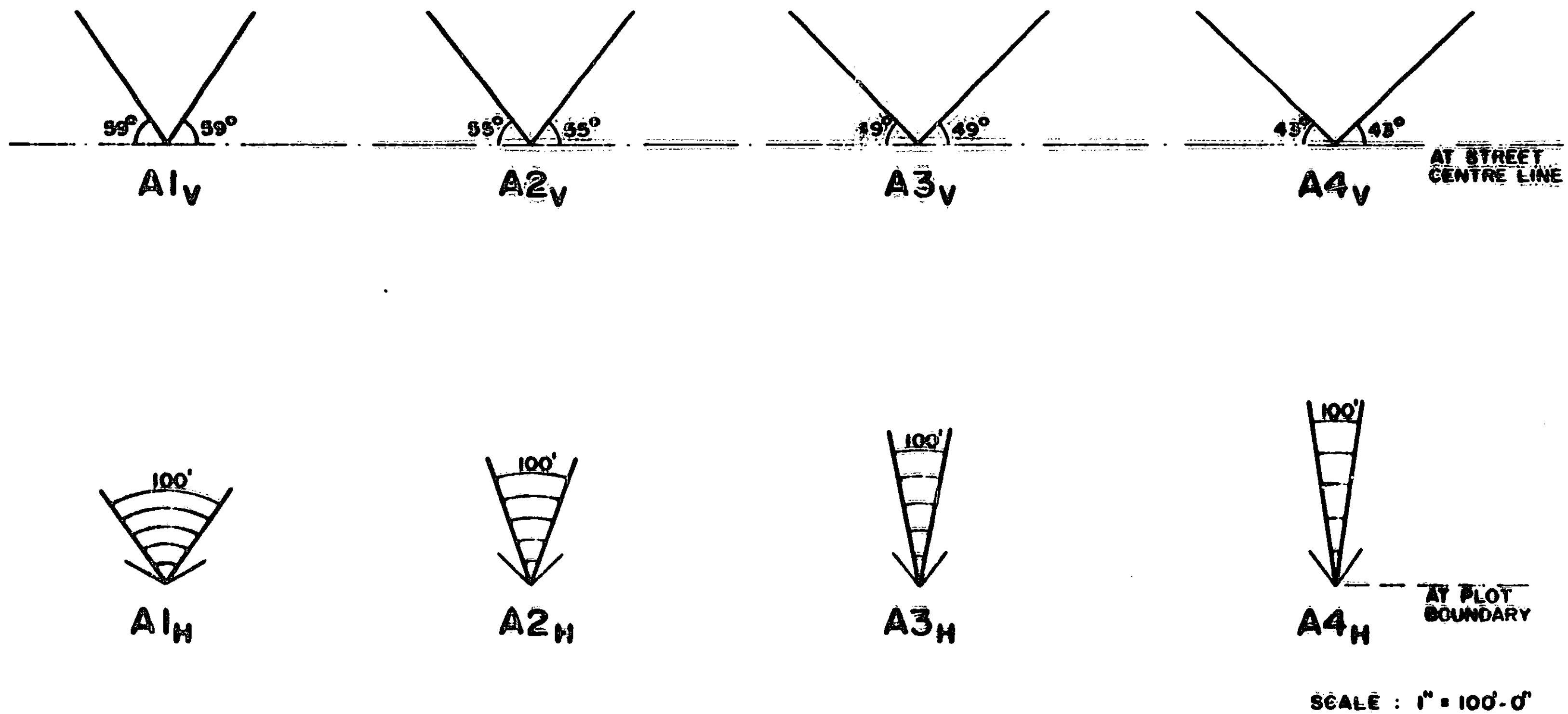


Fig. 3-27(a) Permissible Height Indicators for non-residential buildings.
(at street centre line or plot boundary)

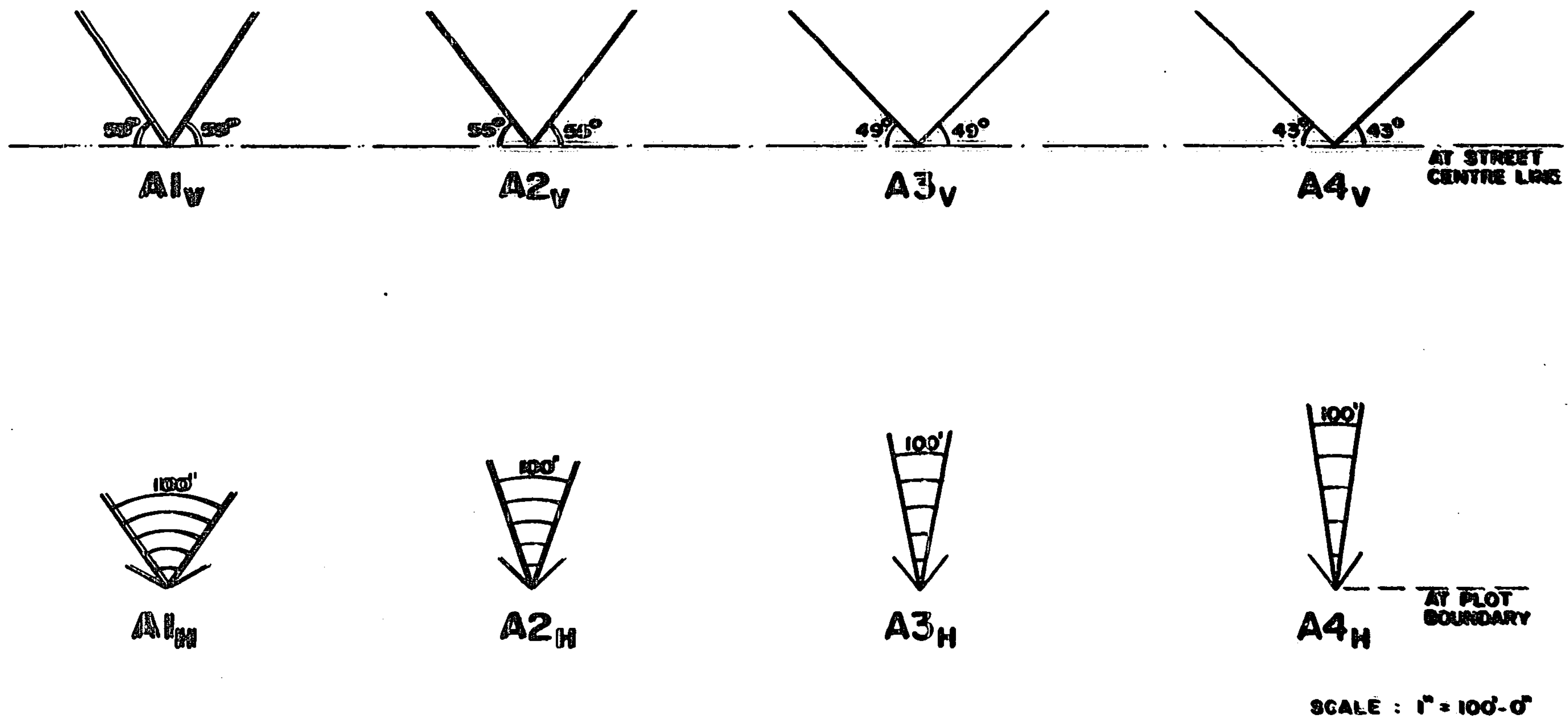
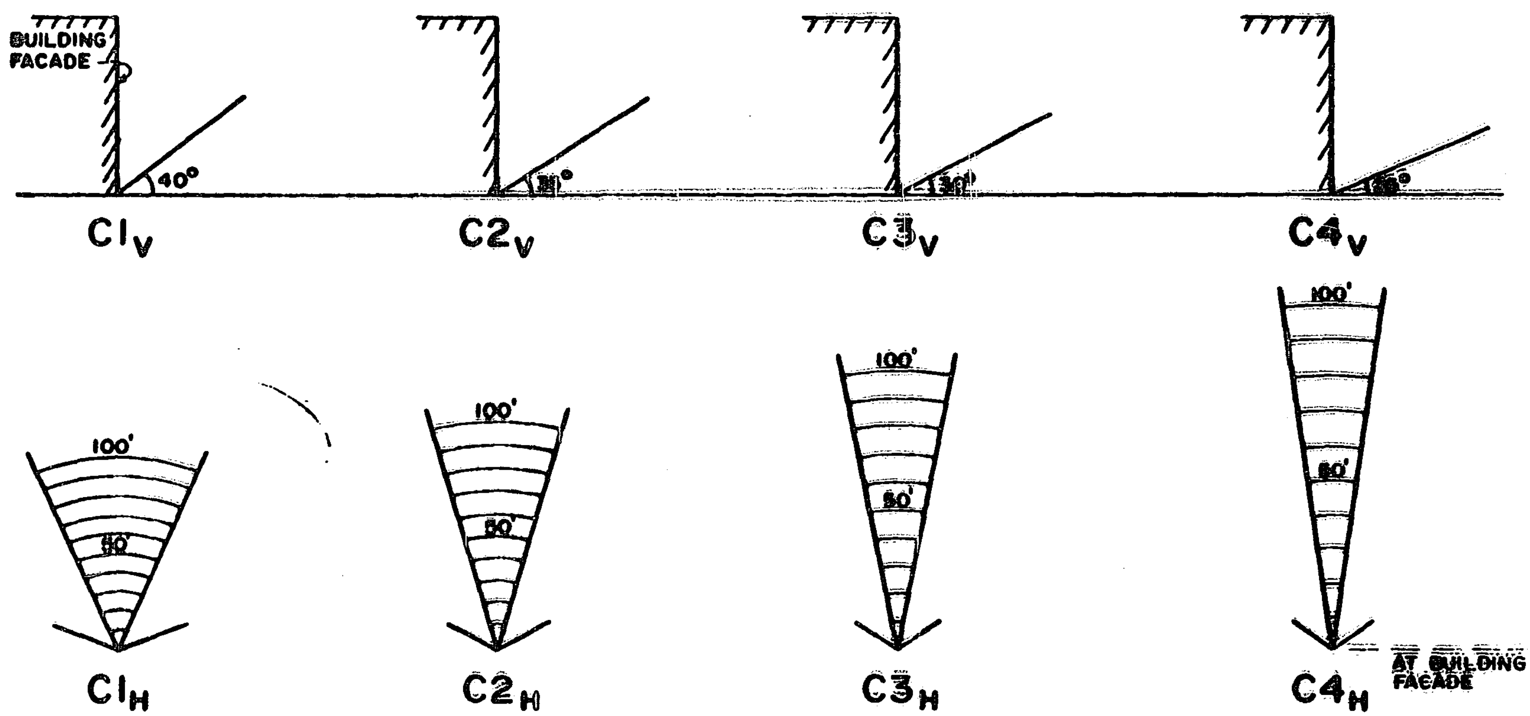


Fig. 3-27(a) Permissible Height Indicators for non-residential buildings.
(at street centre line or plot boundary)



SCALE : 1" = 100'-0"

Fig. 3-27(b) Permissible Height Indicators for Non-residential buildings.
(at building facade)

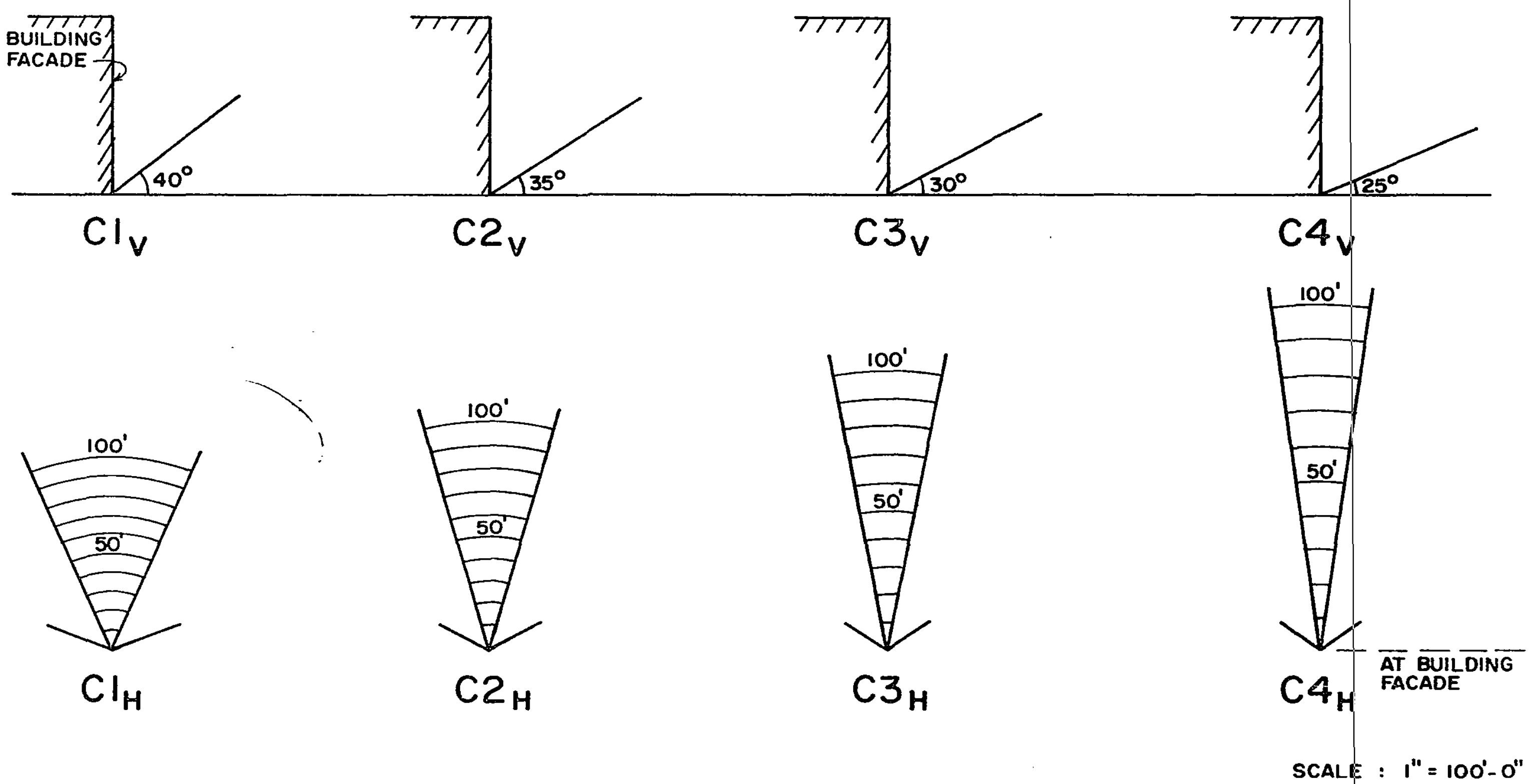
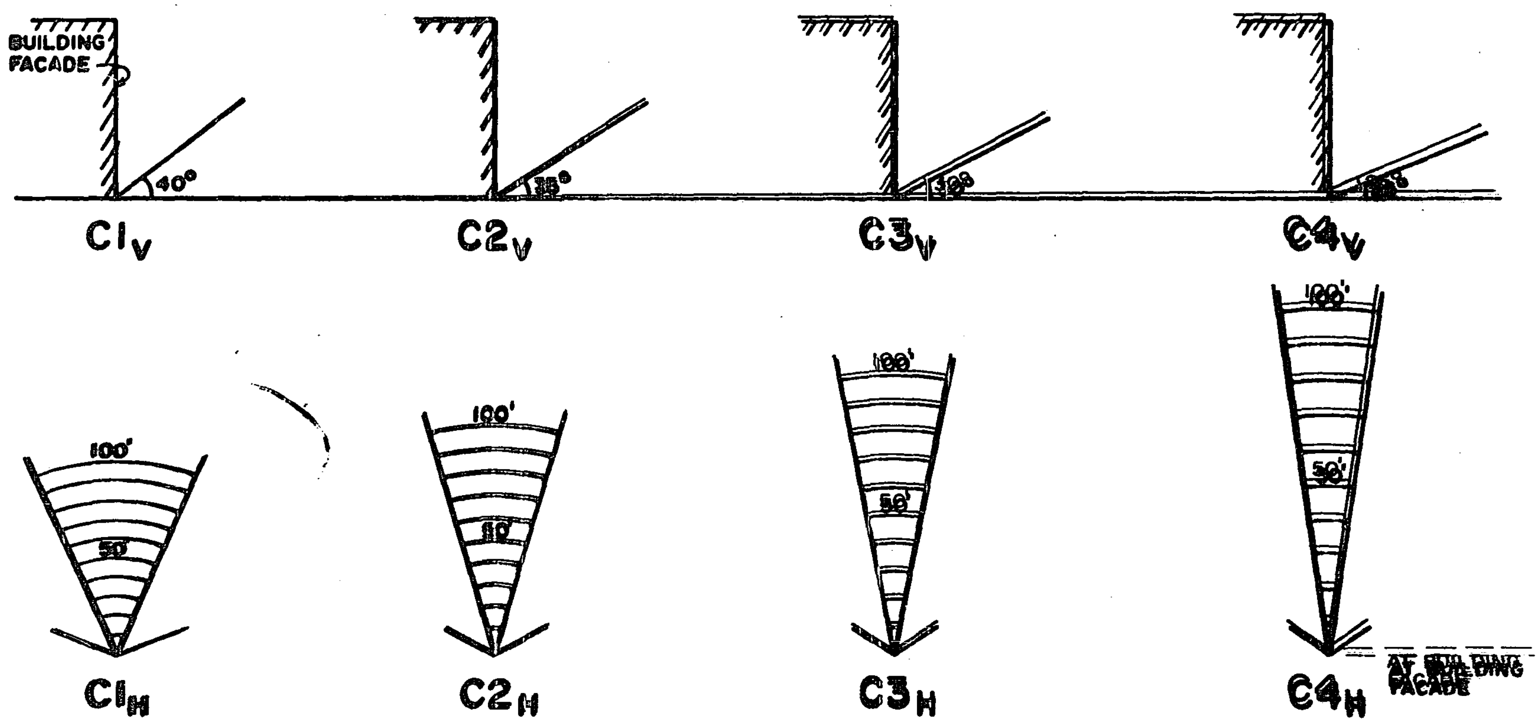


Fig. 3-27(b) Permissible Height Indicators for Non-residential buildings.
(at building facade)



SCALE : 1" = 100'-0"

Fig. 3-27(b) Permissible Height Indicators for Non-residential buildings.
(at building facade)

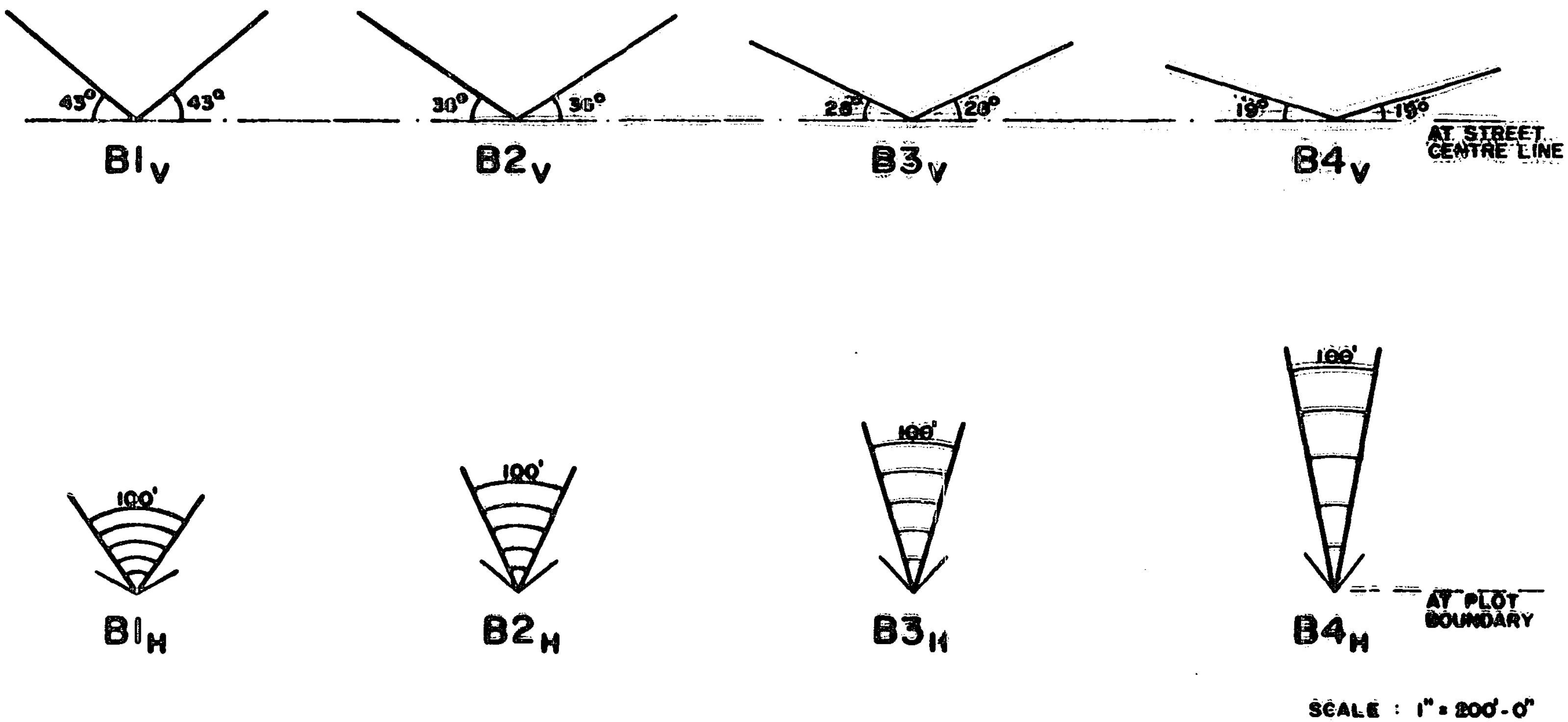


Fig. 3-28(a) Permissible Height Indicators for residential buildings.
(at street centre line or plot boundary)

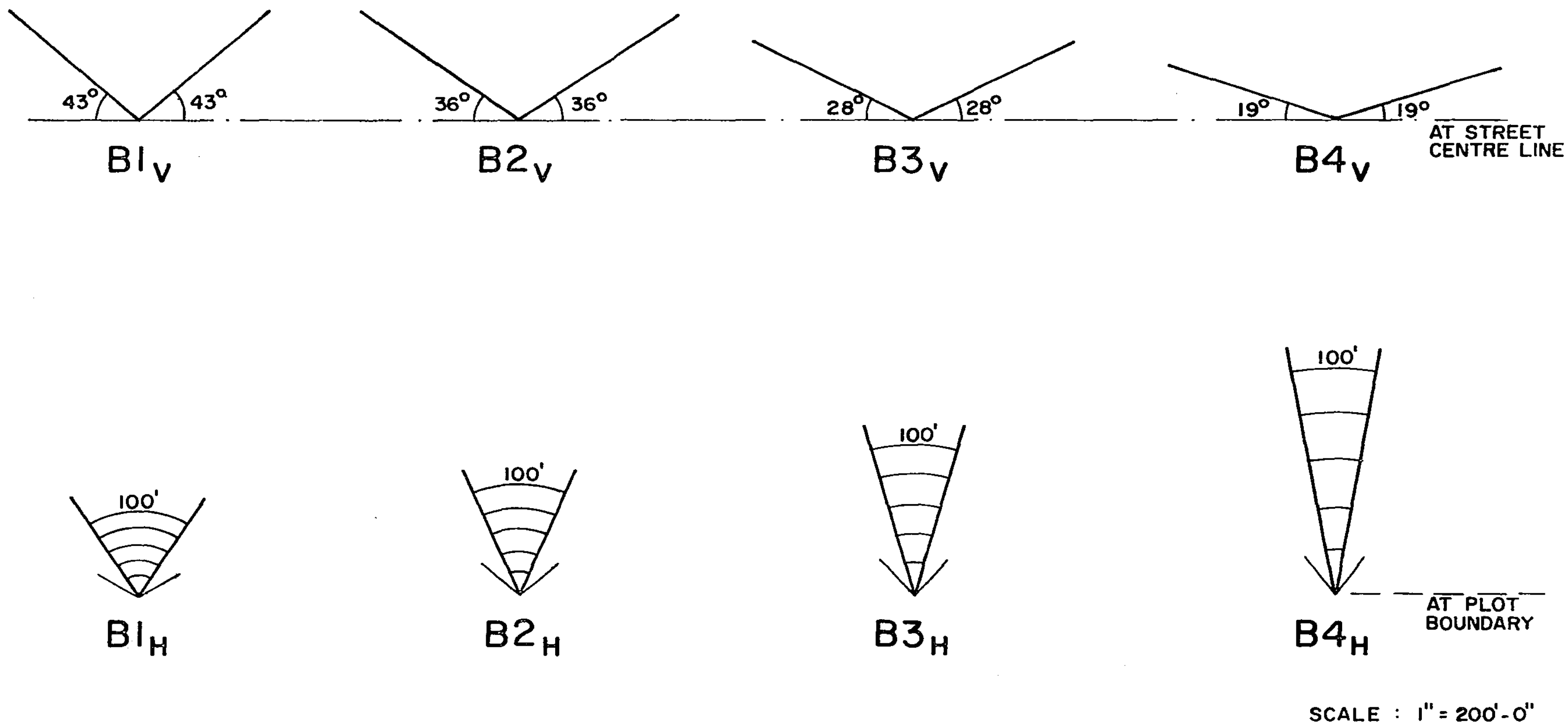


Fig. 3-28(a) Permissible Height Indicators for residential buildings.
(at street centre line or plot boundary)

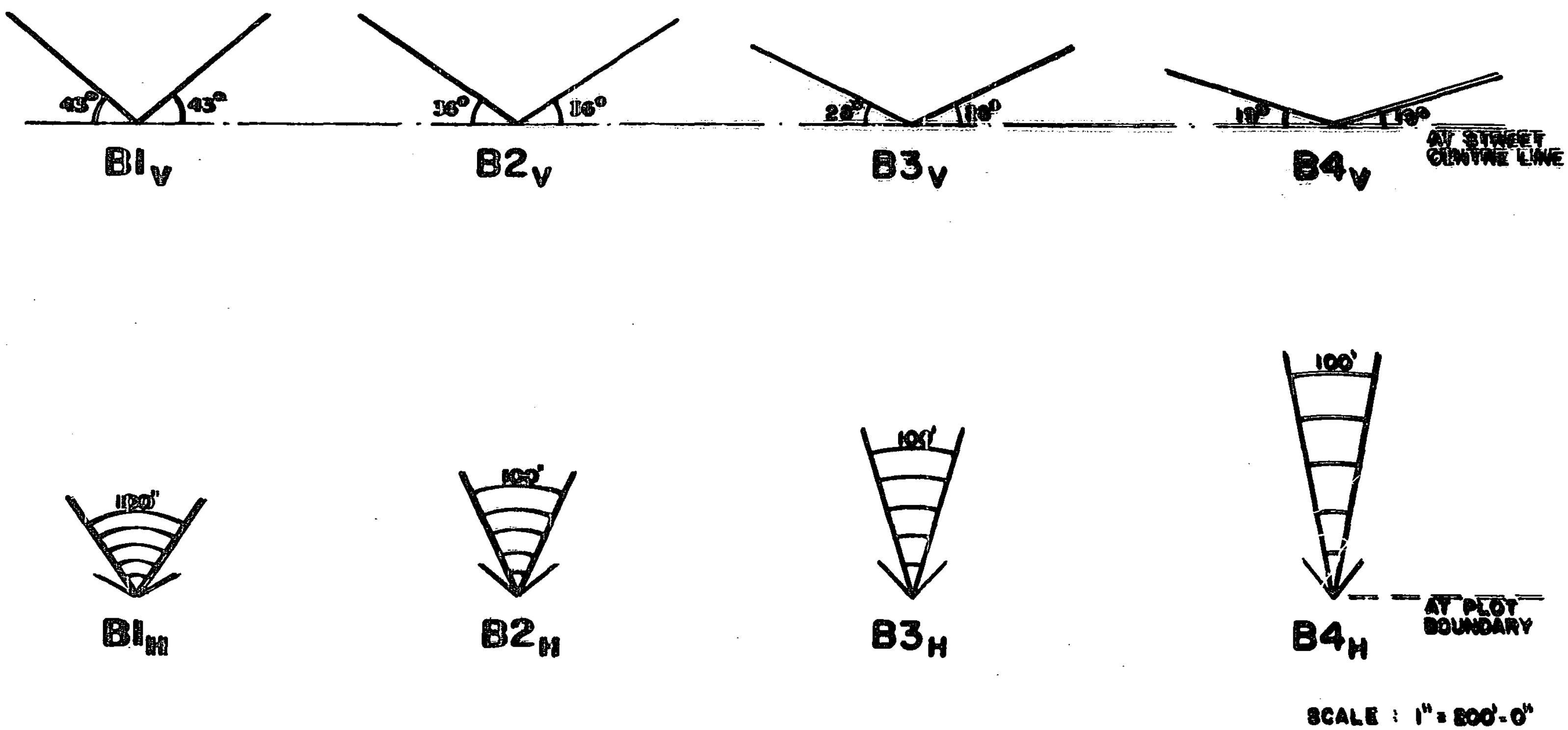


Fig. 3-28(a) Permissible Height Indicators for residential buildings.
(at street centre line or plot boundary)

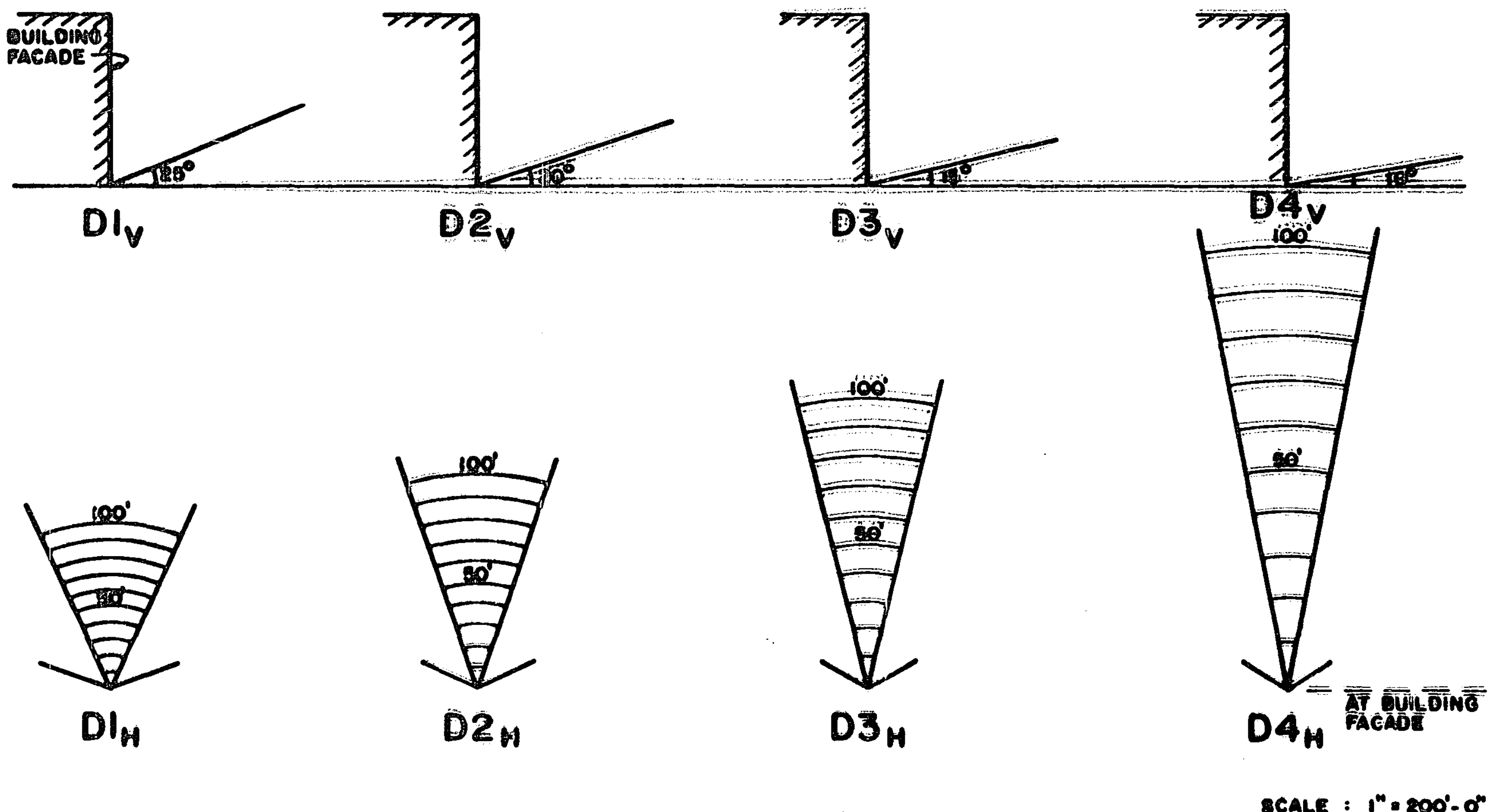


Fig. 3-28(b) Permissible Height Indicators for residential buildings.
(at building facade)

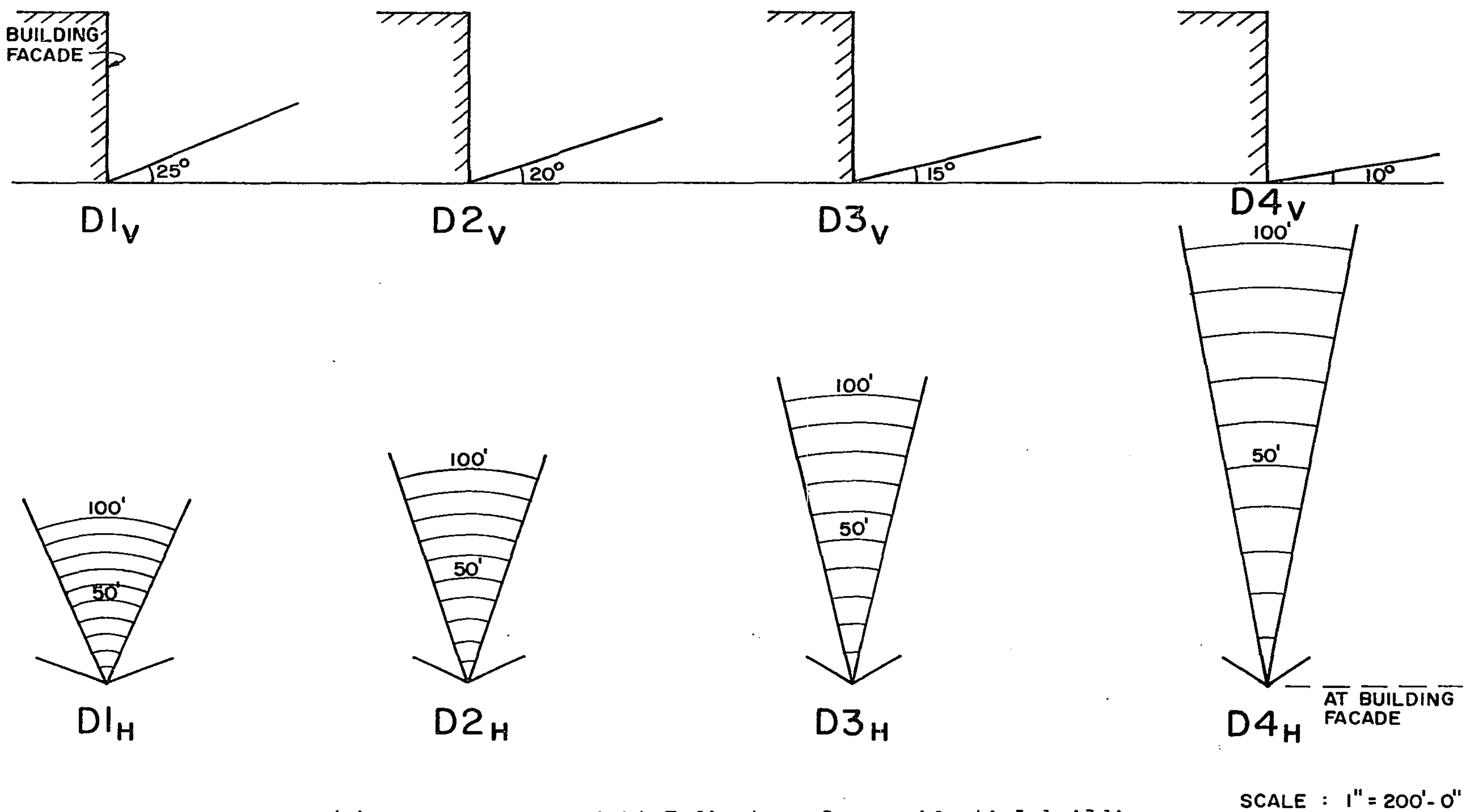
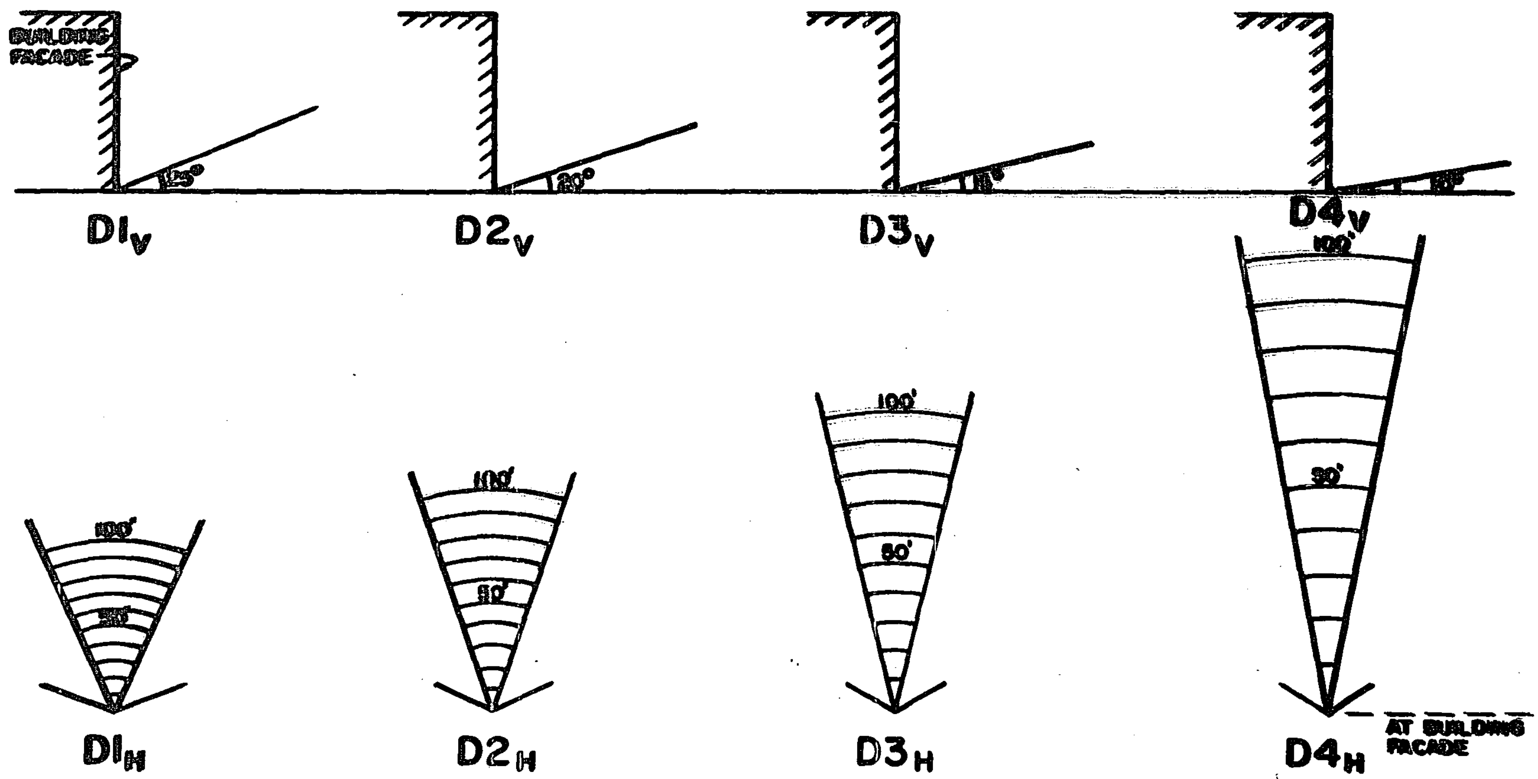


Fig. 3-28(b) Permissible Height Indicators for residential buildings.
(at building facade)



SCALE : 1" = 200'-0"

Fig. 3-28(b) Permissible Height Indicators for residential buildings.
(at building facade)

The indicators enable town planners and site developers (a) to ensure that the arrangement of building blocks on a site will allow sufficient daylight will reach the facade of any building and thereby quarantee the designer enough daylight at his command for interior design, and (b) to ensure that a proposed building will not unduly obstruct the skylight enjoyed by its neighbours., The application of these indicators in densely populated urban areas where it is desireable to obtain the maximum available floor space area in the buildings, in the minimum site area demonstrates the efficiency of the 'slab and podium' type of development. (B-10, B-11)

Figures 3-29, 3-30 and 3-31 are examples of operation of the indicators. Fig. 3-29(a) shows a plan of a proposed building layout. It is necessary to examine the adequacy of the plan in allowing a sufficient quantity of daylight to reach the reference point P. A series C indicator (C_2) is laid with its apex at P on the facade of building K, and moved along the facade to check that at no point does the 100 ft. high blocks L and M infringe the 100 ft. area marker on the indicator. This check shows that blocks L and M would cause on obstruction at this angular width.

On the other hand, there is a gap between blocks L and M which is filled by another 100 ft. block N, and it may be that this gap can provide the necessary skylight to block K, since block N is some considerable distance from P. The skylight would be received at P above the top of block N, giving a deep narrow patch of sky.

Another indicator for narrower angles is therefore tried. An indicator with its radial arms seperated by 15° (C_4) is laid at

P on Fig.3-29(b), whence it is seen that the 100 ft. marker lies nearer to P than the obstruction caused by block N. The necessary quantity of daylight will be received at P over the top of block N, through the gap left between L and M.

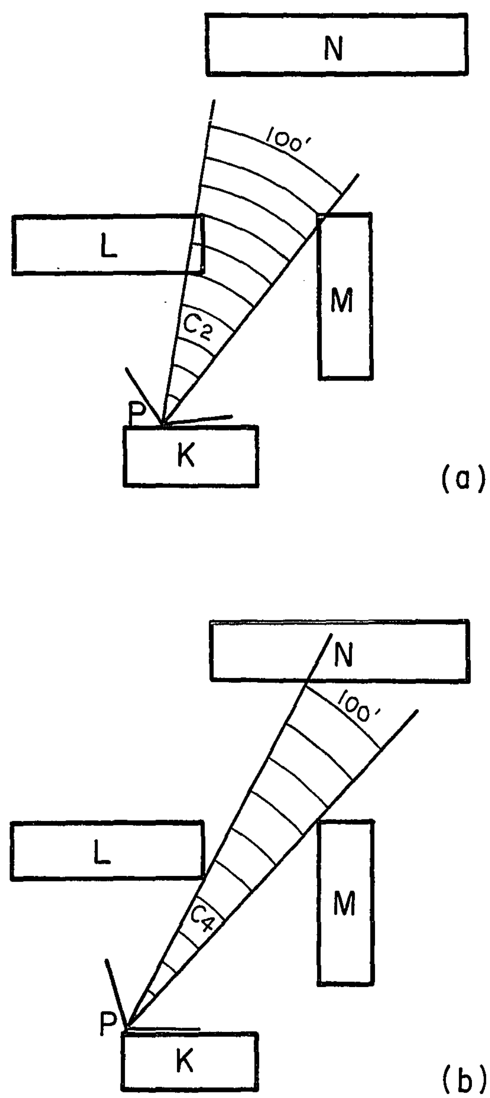


Fig. 3-29 The series C Daylight Indicators used to test adjacent buildings for daylight obstruction.

Fig. 3-30 is an example to show the operation of a facade indicator (series C) and a boundary indicator (series A). Identical results are given by the two indicators if the obstructing building facade is at the same distance from the street centre line as the building being tested. If, on the other hand, the obstructing building is twice as far away, the height of the building given by the boundary (series A) indicator is greater than that given by the facade (series C) indicator. The owner of an opposite site would therefore receive less skylight than he deserves. Experience in the use of the indicators permits variations in their use allowing greater freedom in the development of a site. In order to obtain the best building sitings possible these indicators must be operated by persons who have both experience with the many combinations of the individual scales and a complete knowledge of the principles upon which the scales are based. Frequently the building Daylight Codes of

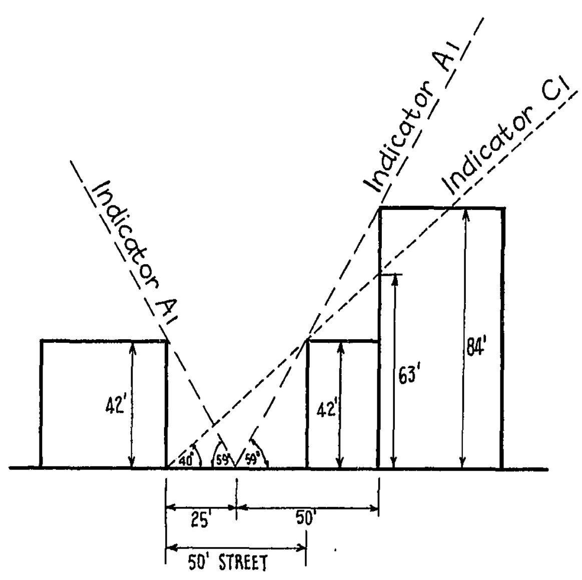


Fig.3-30 Comparison of use of Facade Indicator and Boundary Indicator.

Local Government apply these indicators in judging boundary or facade conditions to determine if permission should be granted to build. Methods of handling such decisions are dealt with in detail in the Bulletin issed by the British Ministry of Housing and Local Government. (B-12, B-13)

The setback of buildings can be handled with the indicators. They would be laid on the plan, and tests made for permissible height at both the front parapet and also at the higher parapet of the setback behind. The Fig.3-31 is an example showing the indicators being used to assess possible obstruction caused by future development of an adjoining site.

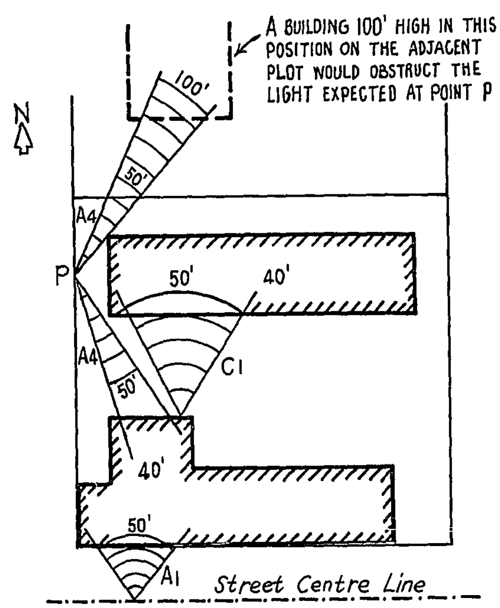


Fig. 3-31 Use of the Permissible Height Indicators to assess possible obstruction caused by future development of an adjoining site.

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P. 427

B-13 " Planning for Daylight and Sunlight," Ministry of Housing and Local Government Planning Bulletin No.5, H.M.S.O., London, 1964

Fig. 3-32 pictures typical post-war city development in England. It also illustrates a group of high and low buildings planned to satisfy the permissible height standards. (B-14)

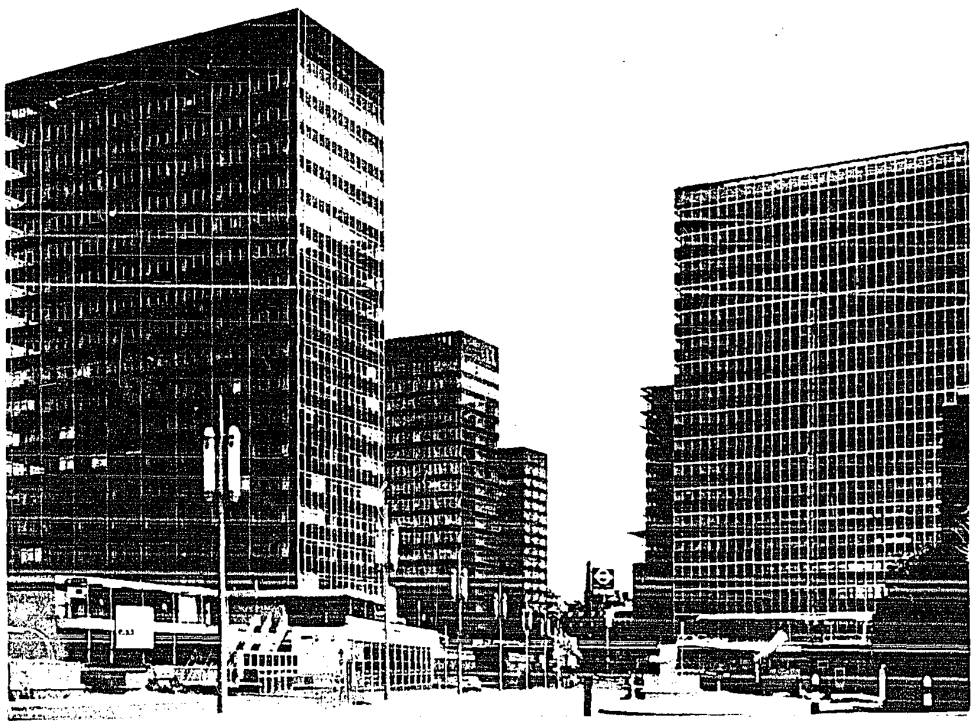


Fig. 3-32 Typical post-war city development in which a group of buildings has been planned to satisfy the permissible height standards.

B-14 Daylighting by R. G. Hopkinson, P. Petherbridge and J. Longmore, William Heinemann Ltd., London, 1966 P. 428

Section C   Daylight in Building Design

C.1   Schools

School building planning involves the development of environment, as well as spaces and facilities. One of the constituents of the environment is light, and therefore light has become an essential consideration in school design. A pleasant environment, designed to create interest and enthusiasm, and to stimulate learning, is the principal aim of school planners. Suitable lighting, both natural and artificial, may contribute significantly to these goals, by evaluating the educational and physiological needs of the children and teachers. (C-1)

Proper conditions for seeing are axiomatic. A high efficiency of lighting and suitable sunshine in the classroom of a modern school are highly recommened because lighting affects not only the eyesight but also the health and growth of school children. It may be an important force in the environment that can shape or distort the total child, his eyes, his muscles, his well-being, temporarily or permanently. One child, faced with bad lighting conditions will manage as time passes to conserve both his sight and his energy by devices of evasion. Another child, striving to do what is asked of him, may eventually develop a clinical eye defect and other serious evidences of bodily strain. (C-2)

Dr. Darell B. Harmon, the director of Division of Educational services, Texas State Department of Health, reports that 160,000 Texas school children were scientifically tested by doctors. Six months after architectural improvements including redecoration of the classrooms installation of daylight controls, and rearrangement of the seats, the occurrence of eye troubles in certain schools was reduced nearly 2/3, nutrition difficulties dropped by 44.5 per cent, and infection decreased by 30.9 per cent. (C-3)

These results demonstrate, that lighting in school architecture has a very important part to play in promoting efficiency, productivity, and the well-being of Tomorrow's People (school children).

In order to create an environment which will satisfy stringent requirements for good visual conditions, adequate brightness at the working surfaces and a good physiological and psychological environment for child growth, the importance of architectural lighting in schools should be acknowledged by the consideration of the following factors :

a. provision of adequate illumination at the working surface (quality and quantity)

b. elimination of the glare. (seating arrangement, proper direct of light source, using direct glass, glass block)

c. the reflectance of ceiling,walls, floor, blackboard, desks, ----- colour uses.

d. orientation of and the resultant sunshine in the classroom.

CONSIDERATION OF ADEQUITE ILLUMINATION

Practical experience and laboratory studies have been combined to demonstrate that the quantity and the quality of lighting are of equal importance. Quality refers to the effect of lighting on the eyes. Good quality lighting makes one feel comfortable and his work seem easy. When extremes brightness differences between various parts of the field of view are eliminated, a comfortable and efficient visual environment results. Table III-3 shows the recommended brightness ratios for school in American pratical standard. (C-4)

Table III-3 Recommendations for Limits of Brightness Ratios

		Ratio
a.	Between the seeing task and immediately adjacent surfaces, such as between task and desk top, with the task the brighter surface.	1 - 1/3
b.	Between the task and the more remote darker surfaces in the surrounding visual field, such as between task and floor.	1 - 1/10
c.	Between the task and the more remote brighter surfaces in the surrounding visual field, such as between task and ceiling.	1 - 10
d.	Between luminaires or windows and surfaces adjacent to them in the visual fields.	20 - 1

Because the high values of illumination intensity obtainable by daylight are best achieved with large window openings, window size constitutes another important problem of daylight design in schools. The esential systems of classroom daylighting are UNILATERAL LIGHTING AND BILATERAL LIGHTING.

1. UNILATERAL LIGHTING —— The only source of daylight is a large window in one outside wall as shown in Fig. 3-33. The chief disadvantage of this system is the rapid decrease of illumination intensity as one moves away from the window. The ratio of illumination on the outside row of desks to that on the inside row is usually about 10 : 1 (C-5). Such a system produces poor visual conditions for students seated in the inside row, due to low illumination and high brightness contrasts.Artificial lighting is usually

necessary over the inside row of desks at all times.

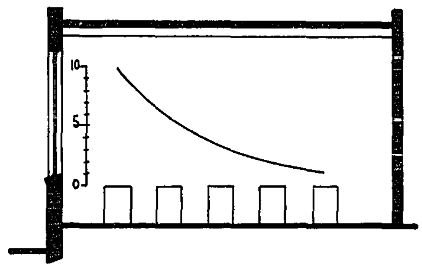


Fig. 3-33 Unilateral lighting

An improvement on this system is provided by installation of certain types of glass blocks in place of the upper part of the window, which reflect and refract skylight upward to the ceiling, thus diffusing it more uniformly over the room. The advantage of this improved system is automatic control of direct sunlight by reflection to the ceiling, but its effects are small unless the ceiling of the room is high and the area of glass blocks large. Wherever the unilateral system of daylight is used, the window must be to the left of the students. (C-6)

2. BILATERAL LIGHTING —— This system is provided an additional opening by using vertical or sloped clerestory window over the corridor roof as shown in Fig.3-34. This construction is usually possible in only one storey schools, or on the second storey of a two storey school. Its ratio of illumination on the outer row of desks to that on the inner

row is approximately 2 : 1 (C-7). This system of daylighting is highly recommended, especially where electricity is not available at reasonable cost.

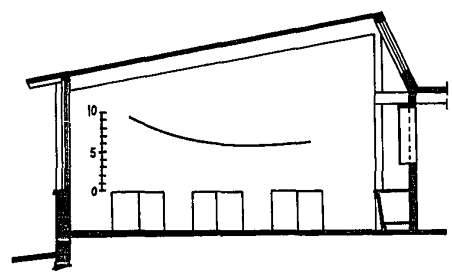


Fig. 3-34 Bilateral lighting

Where the bilateral lighting system is used, precautions must be taken to prevent direct sunlight from entering the room at undesirable angles through the clerestory windows. The preferred axis of such a room is north-south, allowing it to receive east and west light. (C-8)

In all of the allowable systems, the prime source of light is the large window in the outside wall of the rooms. This window should extend from a height less than three feet above the floor to a height as close to the ceiling as is required to admit skylight directly to the working plane at the opposite side of the room. The various types of windows, the different openings, the height of the ceiling, the depth of room and the overhangs also affect the interior lighting.

Fig.3-35 shows the punched-hole arrangement produced only 46 per cent of the light fond in the same relative position in the continuous strip window arrangement. (C-9)

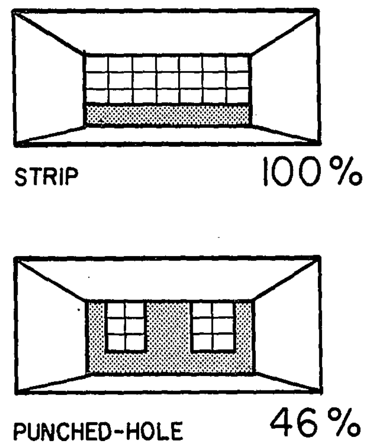


Fig.3-35 Punched-hole windows vs. strip windows.

When a supplementary source (opening) is provided and increased, the intensity and distribution through the classroom can be improved. The comparison of increasing the size of the supplementary opening is shown in Fig.3-36. In this case the distribution is 1.3 : 1 with an intensity

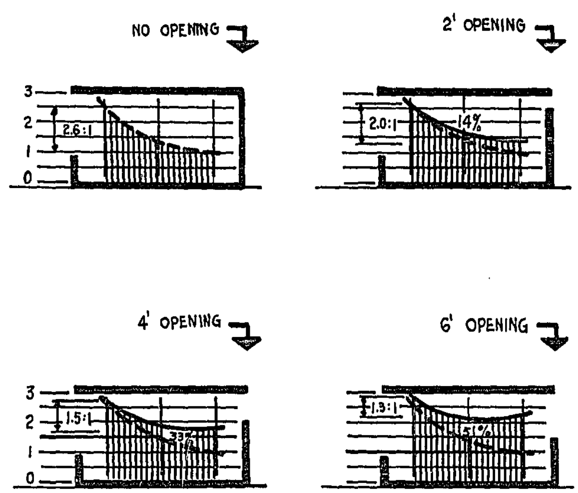


Fig. 3-36 How openings affect light.

increase at the center of the room of 51 per cent when the supplementary opening increases to 6 feet. (C-10)

The ceiling height always affects the lighting of a classroom. It is obvious that the higher the ceiling the higher the resulting intensity of illumination. Usually for unilaterally by lighted rooms, the ceiling heights should be greater than one-half the depth of the classroom to assure lighting near the back wall, but one must be careful to follow the law regulating ceiling heights. For example, a ceiling may work fairly satisfactorily in a unilaterally lighted classroom only 18 ft. deep, but the lighting might be very poor in a unilaterally lighted classroom 30 ft. deep. In bilaterally lighted classrooms, the diversity of illumination across the classroom is much less although the lower ceiling also decreases the illumination. Fig.3-37, which gives a comparative analysis of unilateral

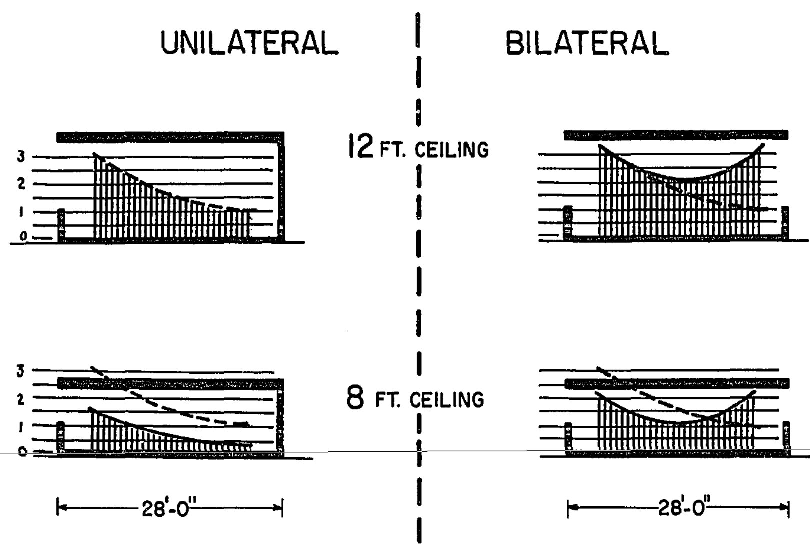


Fig.3-37 The Height of ceiling affects light.

and bilateral classrooms shows that the 8 ft. ceiling bilateral classroom has a higher minimum illumination and better distribution than does the 12 ft. ceiling in a unilaterally lighted room. (C-9)

The depth of classroom also affects the quantity of received light and it cannot be considered independently of the ceiling height. Evidently the unilaterally lighted classrooms simply cannot be very deep and have excessively high ceilings. The cross-sectional graphs of Fig.3-38, prove that if the ceiling height remains constant as the depth is increased

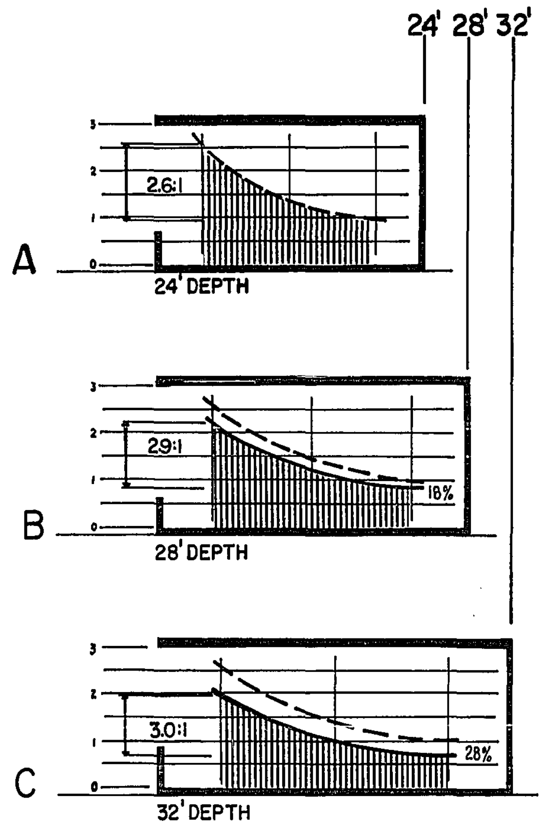


Fig.3-38 The effects of the depths of classrooms on natural lighting.

in unilaterally lighted classrooms, both the illumination intensity and the rate at which it decreases (diversity) across the classroom increase. (C-11)

In the classrooms the sun rays should not be allowed to fall on the work area. Overhangs are a good control device to exclude the sun rays from the classrooms. A study of the results of the testing, illustrated in Fig.3-39, shows that overhangs cut down the intensities but improve the distributions of illumination in the classroom. In unilaterally lighted classrooms, as the overhang is increased, the lighting near the window decreases at a much greater rate than the lighting near the windowless wall, therefore the distribution is generally improved. For example, the 4 ft. overhang causes a 24 per cent drop near the windows and a 15 per cent from near the opposite wall, thus improving the distribution to 2.3 : 1. In bilaterally lighted classrooms the overhang is an excellent lighting control device as well as a control for the sun. For example, it was found that the bilaterally lighted classroom with 6 ft. overhangs had more than twice as much light at the lowest point (center of the room) than the unilateral classroom with 6 ft. overhang had at its lowest point (near the wall). Therefore overhangs in bilaterally lighted classrooms can actually improve the general lighting patterns. (C-12)

CONTROL OF GLARE

Adequate control of sky glare and direct Sunlight is another important part of school lighting design. The unsuitable control of glare may affect the growth and health of school children. Fig.3-40 shows the

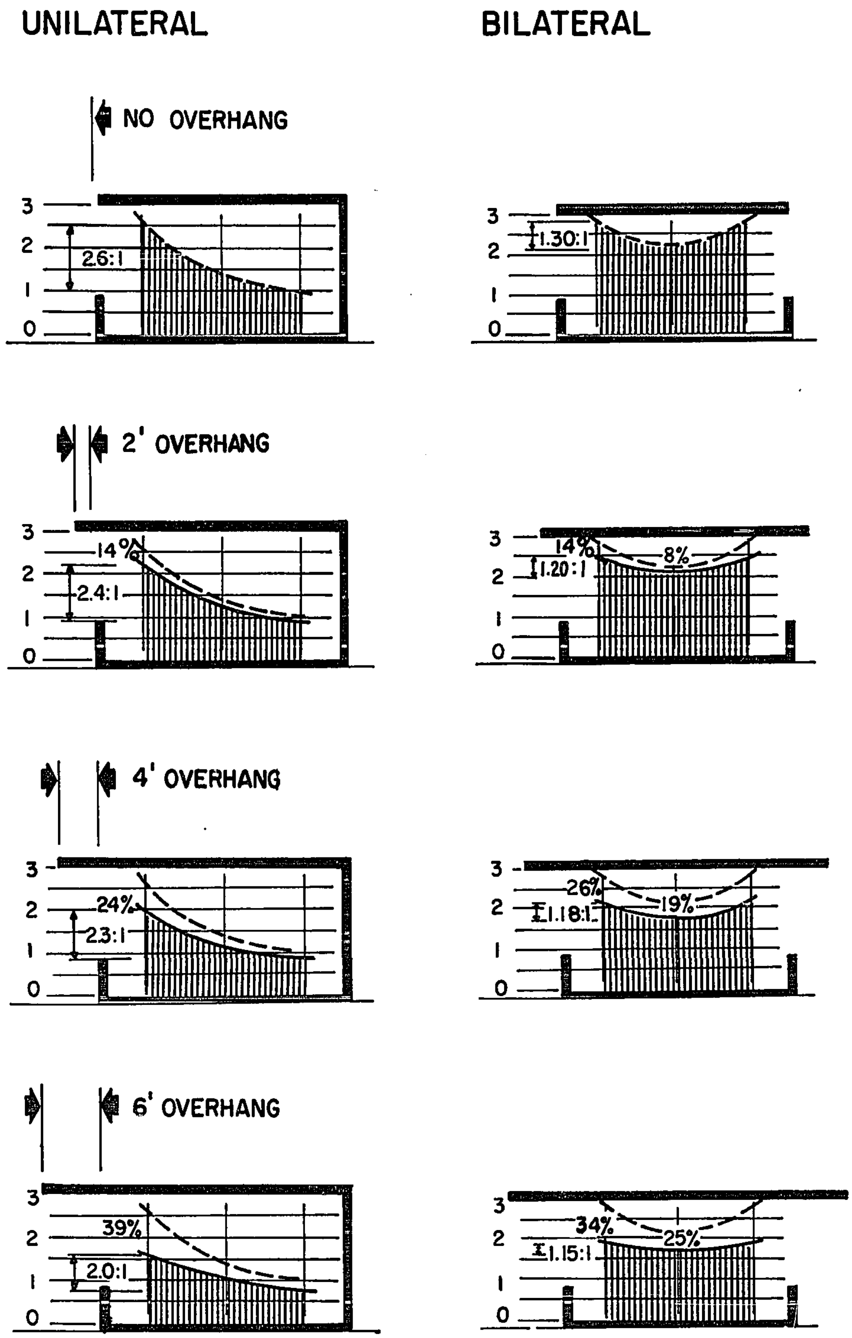


Fig. 3-39 Overhangs affect lighting.

differences in posture that are entirely conditioned by the effect of glare. At the left, the boy is seated comfortably at a working surface in a suitable lighting. At the right, he has shifted his head, by bodily

Fig.3-40 The difference in posture are conditioned by changing lighting.

reflexes, to shade his eyes from the glare of strong light source to his left. This action may lead to a distortion of a child's back. (C-13)

The scientific tests of Texas State Department of Health evidently show that the child with the bent back was working not under especially bad circumstances but rather under circumstances commonly accepted as good standard practice. The poor illumination resulted from the bad orientation of his desk. It is generally assumed that if light shines on a desk top from the student's left with the desk oriented perpendicular to the window, then the student is working in the best possible lighting conditions. Often this desk orientation will lead to a distortion of the student's back. From the experiments in improving classroom lighting, the ideal position of school seating was shown to be one in which a line projected from the mid-point of the child's eyes to the front limit of windows will form a 50° angle with his line of sight while he is working, as shown in Fig.3-41. This seating arrangement

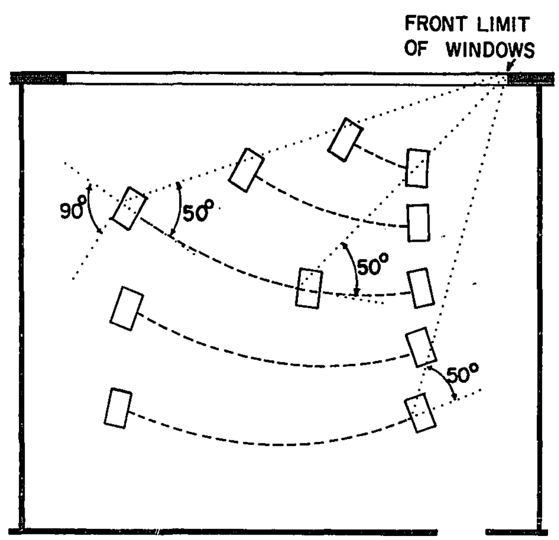


Fig.3-41 The ideal orientation of school desks to the windows.

allows daylight to be used as the main source of lighting in a classroom, while providing adequate protection from the sky's glare. (C-14)

The glare may also be kept out by conventional shades, venetian blinds, louvers, glass blocks, coloured glass or overhangs. These controls should be preferentially fixed if possible. Shades should be of a highly diffusing, light coloured material.

REFLECTIVITY OF SURFACES

Reflectivities of surfaces in a classroom have a very definite effect both on the level of illumination and on brightness contrast. Recommended reflectivities of ceilings, floors. walls and desk tops have been set forth in the "American Standard Practice for School Lighting" as shown as Table III-4. (C-15) These experimentally determined recommendations are based on studies of standard unilaterally lighted classroom. The multilaterally lighted classrooms, such as bilaterally, trilaterally or quadrilaterally lighted classrooms, have much more light

Table III-4 Reflectivities of American Standard Practice Recommentation

Elements of classroom	Reflectivities per cent
Ceiling	80 - 85
Floor	15 - 30
Wall	50 - 60
Desk tops	35 - 50

than unilaterally lighted ones, hence the recommentations for reflectivity in unilaterally lighted classroom should not be applied to multilateral situations, particularly since mutilateral lighting permits wide use of colour. Determining the degree of colour on the illuminated walls, ceilings and floors allows us to specify their effects on the overall classroom. The balance between illumination engineering and colour psychology should be also considered. (C-16)

Fig. 3-42 summarizes the effects of the reflectivity of surfaces tested in both unilaterally lighted and bilaterally lighted situations. Tests were made to try to isolate the effects of ceilings, walls and floors on the level of illumination by varying the reflectivity of each surface independently of all other surfaces. Pure white with reflectivity of 85 per cent was assumed the maximum reflectivity for walls and ceilings, and 60 per cent gray for the floor. The floor plan was 24 ft. deep and 12 ft. high and sign " + " is used position of the lowest intensity for each case. It was found the greatest decreases in illumination occurred when the ceiling was painted black while all other conditions remained the same. There was a loss of 61 per cent light at a point near the far wall in the unilateral situation, and a 51 per cent drop at the same point in the bilateral situation. This emphasizes the great importance that ceilings have in unilateral classrooms as far as reflectivities are concerned. Darkening the ceiling decreased the intensity of the illumination about twice as much as the average decrease which resulted from darkening all the other surfaces. The reflectivity of the back wall is also important. In bilaterally lighted classrooms the very high reflective surfaces are as important as in unilaterally lighted classrooms because bilaterally lighted rooms admit much more light than unilaterally lighted rooms. (C-17)

Table III-5 shows a suggested orientation for the various rooms in school buildings. Finally, some examples of designs used in daylighting classrooms are shown as Fig.3-43, 3-44 and 3-45. (C-18, C-19)

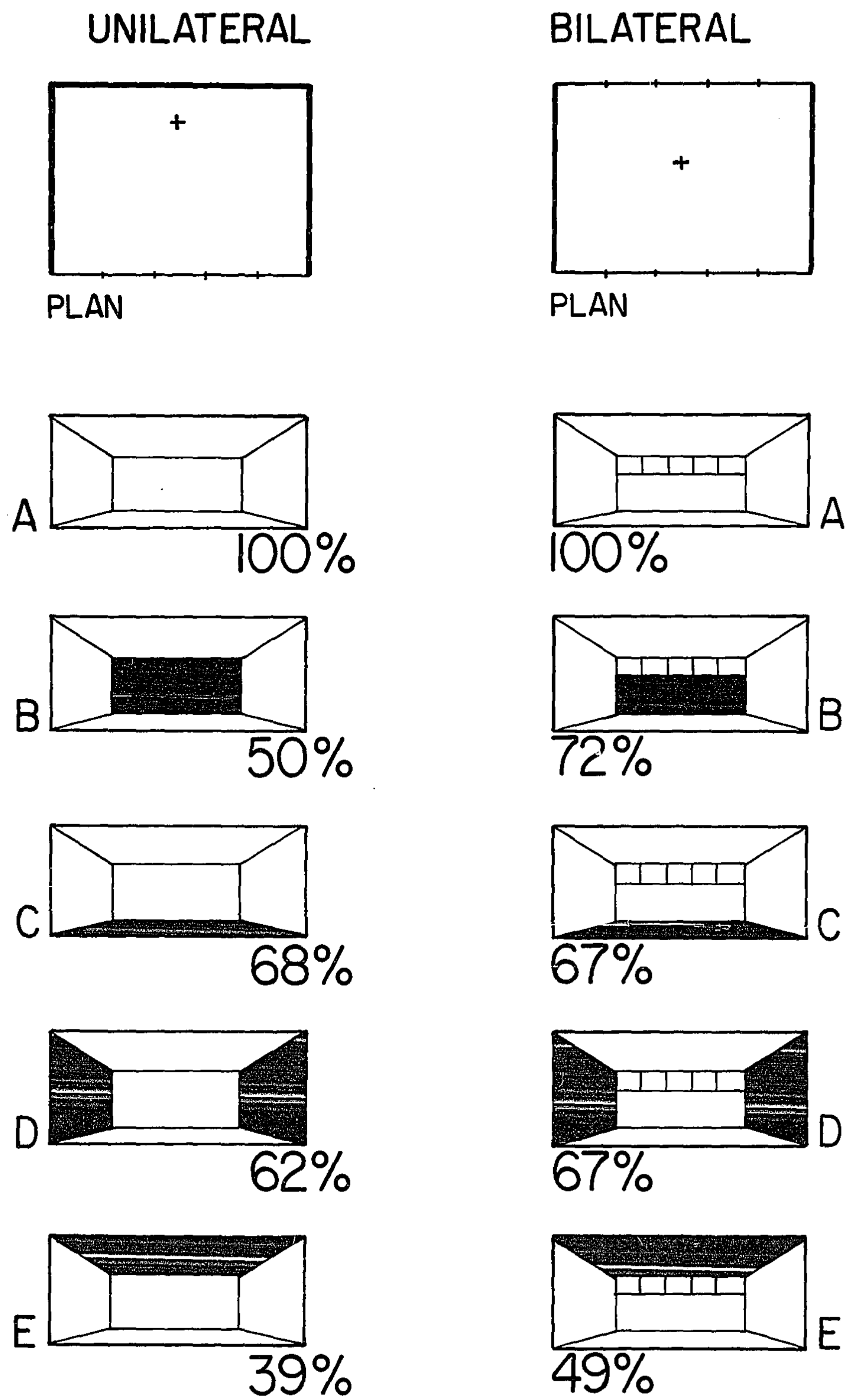
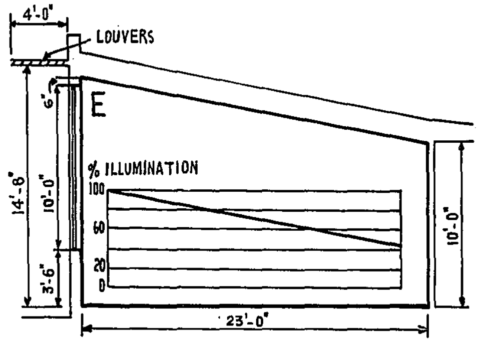


Fig. 3-42 Comparison of light reflectivities between the unilateral clas-room and bilateral classroom.

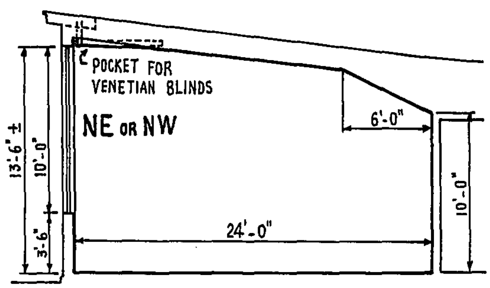
Table III-5 Orientation for the various rooms in school building

	N	NE	E	SE	S	SW	W	NW
classrooms+			*	*	*	*		
kindergarten				*	*	*		
workshops	*	*						*
domestic science	*	*						*
libraries	*	*						*
locker rooms				*	*	*		
toilets	*	*	*	*	*	*	*	*
cafeteria				*	*	*		
administration				*	*	*		
teachers' lounge				*	*	*		
labs	*	*						*
auditorium	*	*						*
gym	*	*	*					*
utility	*	*	*	*	*	*	*	*

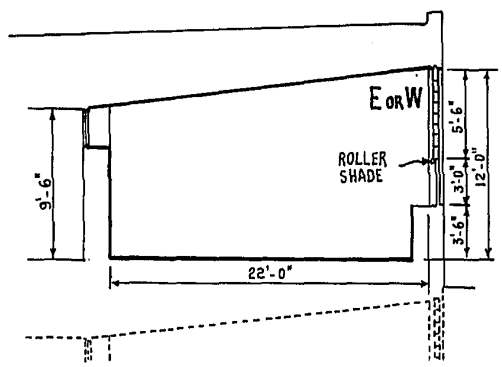
+ Some architects prefer the classrooms facing to the north to get north light in their sucessful design.



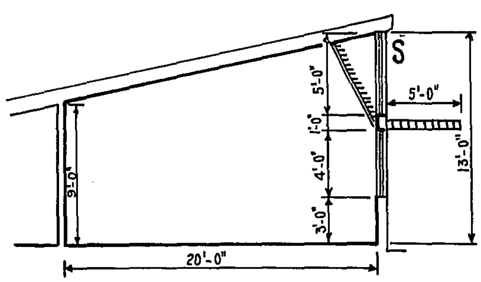
a. Sloped ceiling, louvered awning



b. Double ceiling slope (the second ceiling slope is not essential)

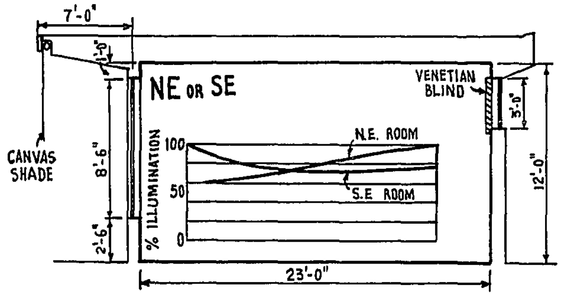


c. Directional glass block

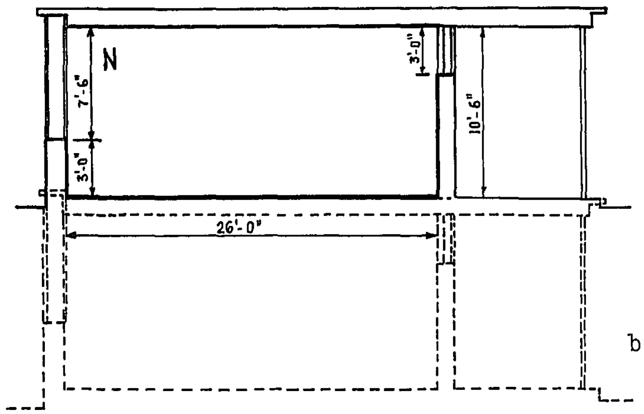


d. Reversed for solar heating

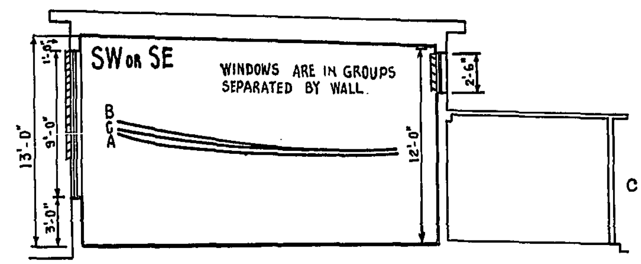
Fig. 3-43 Unilateral Lighting Classrooms.



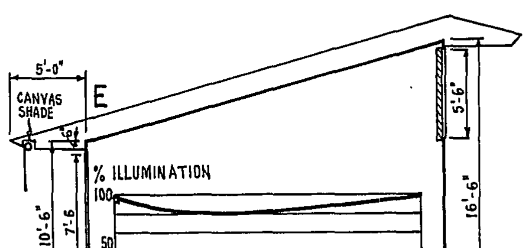
a. Level ceiling; solid roof projection shading the larger windows



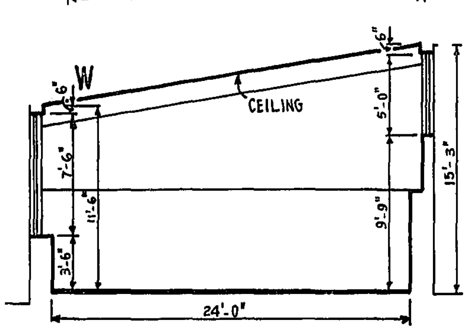
b. Level ceiling; solid roof projection beyond transom windows



c. Maximum Auxiliary shading devices

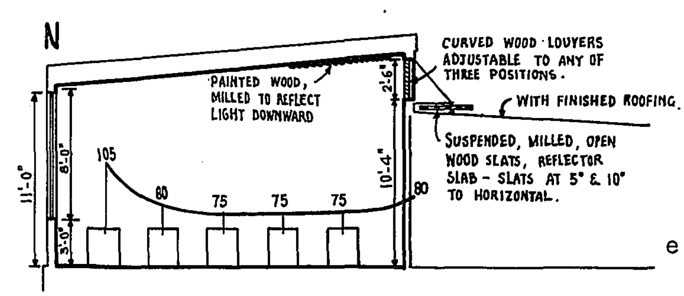


d_1. Slope upward downward transom windows instead of main windows. (window facing east)

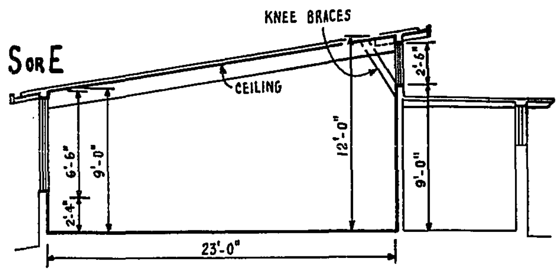


d_2. Slope upward downward transom windows instead of main windows. (window facing west)

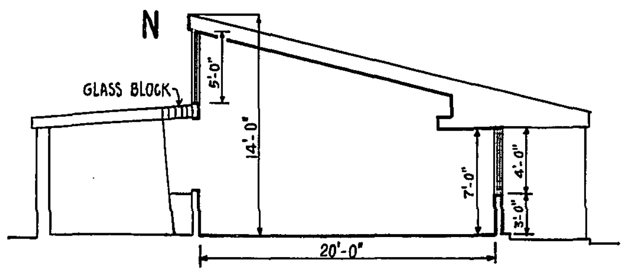
Fig. 3-44 Bilateral Lighting Classrooms.



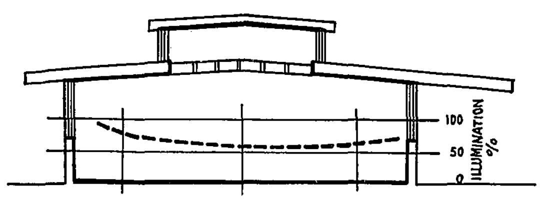
e. Low horizontal reflector outside



f. Clerestory north or west

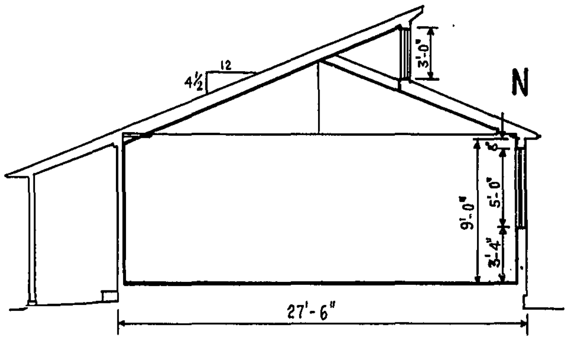


g. Clerestory north instead of south

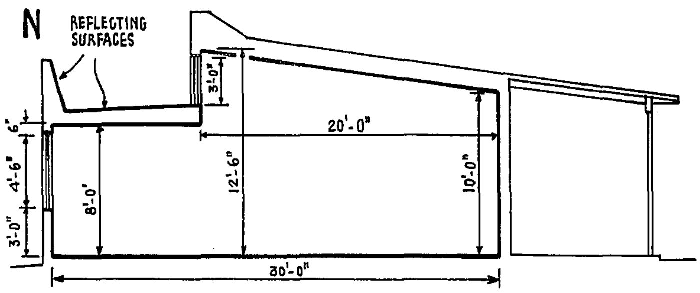


h. Double slope ceiling with monitor at middle

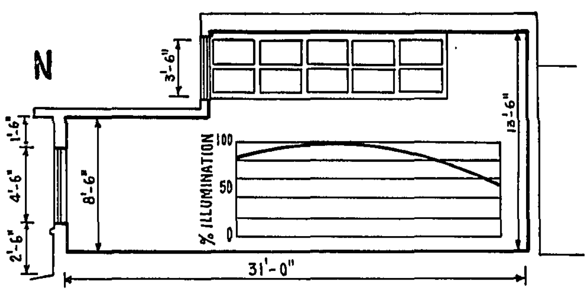
Fig. 3-44 Bilateral Lighting Classrooms.



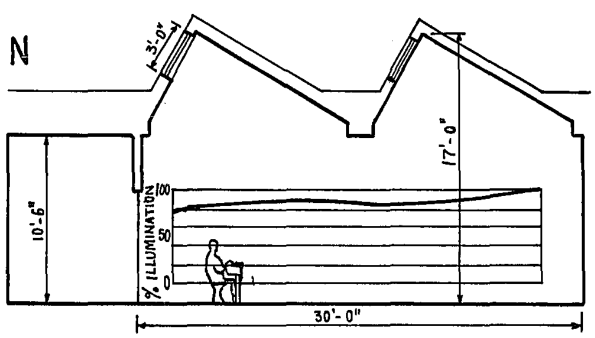
a. Unilateral clere-
story



b. With parapet
reflector



c. A "monitored"
effect



d. Transverse sawtooth
skylight

Fig. 3-45 Square Floor Plans of Classrooms.

C.2 Hospitals and Clinics

No one has built a hospital completely without windows, like some kinds of structures which have been built, although with modern techniques and engineering it is entirely possible to produce (achieve) a set of " necessary conditions " including complete control over atmospheric conditions, such as heat, light, humidity, air cleanliness, etc without the use of windows. Undoubtedly, people like fresh air and natural light. It is an extremely important psychological factor because light affects the emotions of both patients and hospital workers. Indeed, a suitable natural lighting design in hospital may help patients to develop the happy emotions which in turn produce curative effects. It can also improve the working atmosphere for the employees.

To narrow the subject to hospital design, good daylighting is of great import to hospitals for three following reasons :

1. PProper Vision ;

It is important in the hospital to be able to read a thermometer accurately and to see abnormalities in colour of skin, lips finger-nails, wounds, pus and all other symptoms in terms of which the most elementary clinical procedures are taught and practiced.

2. Psychological Effect ;

The psychological factors are also very important. A morbid patient may be beyond caring whether the sun shines or not, although this is not always true. A very sick patient may at times prefer a low level of illumination, however the average patient and particularly the long-term patient who must spend many weary days, weeks or even months in a hospital, craves the cheerful play of daylight and a view of the sky.

3. Protection from cross-infection ;

Early in the bacteriological era, the bacteriologists showed that respiratory bacteria when coughed or sprayed into indoor atmospheres spread for only a relatively short distance in the air, three or four feet, and quickly settled to the ground. After leaving the body these bacteria deteriorate quite rapidly with a simultaneous loss of ability to infect another individual. A person in close contact with a sneeze might contract infection while one who entered a room shortly after a sneeze would have little chance of contracting it. In the nineteenth centery, the bacteriologists discovered that not only could disease organisms be readily spread through the air of institutions for relatively great distance, but that these germs could be recovered from the air and floor dust in great numbers. Sometimes they survive for days and weeks, apparently without loss of their ability to produce disease. Therefore, it is important to prevent diseases from spreading through the air.

Daylight is germicidal to pathogenic bacteria floating in the air or settling out in the dust. Therefore it must not disregarded in the hospital design particularly in the wards, surgical rooms, and clinics, since it prevents the spread of respiratory infections.

Both filtered and unfiltered daylight are believed to be germicidal. The bactericidal effects of unfiltered daylight are much better than that of filtered ones. A series of experiments by Dr. Leon Buchbinder on germicidal effectiveness of indoor daylight showed that diffuse daylight was a patent lethal agent. The lethal effects of daylight depended on both its quantity and quality. Diffuse daylight from blue skies exerted a maximal effect while overcast skies produced a minimal one. However, the total lethality even under overcast skies was still significant. Direct sunlight through glass was about ten times as potent as diffuse daylight. Therefore we can conclude that good natural lighting is a factor in preventing the atmospheric spread of infection in hospital and that :

a. This effect improves as the quantity of indoor daylight increases;

b. Sunlight is quicker to take effect than light reflected from the sky or clouds;

c. The less filtering daylight is subjected to in entering a room, the better, but light from overcast skies, even though filtered through two thicknesses of ordinary glass, is still germicidal. (C-20)

Since hospitals require more daylight, a greater expanse of glass area is needed, and building orientation becomes very important. In Section A.6 of this Part, Fig. 3-6. shows several diagrams of building shapes which, when properly orientated, will exploit sunlight to the maximum although most of them are not suitable for hospital designs. The architect Isadore Rosenfield found that the T-shape, shown in Fig.3-46, is ideal for most general hospitals, up to about 700 beds. In this case the nursing units are placed at the head of the T facing southeast, while the stem accommodates the various diagnostic and therapeutic facilities. The L-shape is also very good; some designs for hospital buildings of 1,000 beds or more are a combination of L's. This design is used at

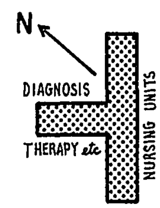


Fig. 3-46 T-shape, adapted to hospital layout.

the hospital building for bedridden custodial chronics on Welfare Island, N. Y. shown in Fig. 3-47. While the T-shaped building would have two nursing units per floor, the double L has four nursing units, one is

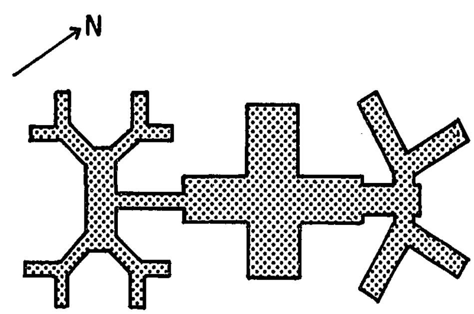


Fig. 3-47 The multiple L-shape, hospital building for bed-ridden chronic patients, Welfare Island, N.Y.

each leg of each L. Another building shape, the Y-shape, like the Sea View Hospital for Tuberculosis, shown in Fig. 3-48, has three nursing units per floor. In all these examples the patients can be exposed to the sun for at least part of day while such services as bethrooms, utility

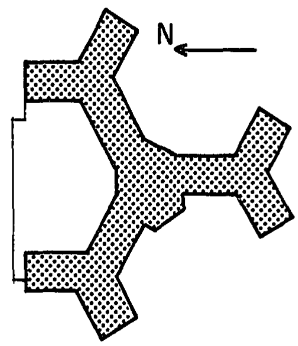


Fig. 3-48 Y-shape, Sea View Hospital for Tuberculosis.

rooms, serving kitchens, etc., occupy the sides of the corridor least likely to get direct sunlight. The Goldwater Memorial Hospital, shown in Fig. 3-49, which is located on a narrow island that is considered undesirable because of its great heights, is an interesting example of

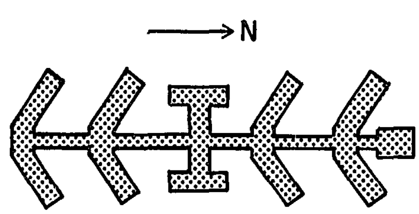


Fig. 3-49 Chevron shape, a series of flattened L's, Goldwater Momorial Hospital.

the simultaneous exploitation of orientation and view for a hospital of about 1,600 beds for chronic sick. In order to give patients a river view on either side of the island, wards are disposed in four chevron shaped buildings, each four stories high, with two nursing units per floor per chevron.

Although a U-shape plan is not very satisfactory for hospital building from the point of view of internal organic arrangement, many hospitals are U-shaped because a good feature in one type of building is not necessarily good in another. Therefore, orientation alone can be a factor but not be a determining one in shaping a building.

The window itself, the width and position, and the brightness of the ceiling and walls around it always affect the daylight quality and germicidal effects. Usually a wide window is recommended with its width greater than or equal to 1/4 the length of the wall. A bigger window gives a deep view outside and more powerful germicidal effect because the organisms are concentrated near the bed and diminish in number around windows particularly at the southern end of the room. From the point of view of eye comfort a bigger window gives less brightness contrast since a bigger window results in smaller area of wall around it. If the window reached from partition to partition, the darkness would disappear entirely from either side of the window, and, as a result no annoying brightness contrast would be produced. As the window head rises near the ceiling, the dark strip between them would be entirely eliminated (Fig. 3-50, 3-51). A brighter the ceiling and wall decreases their contrast with the window. (C-21)

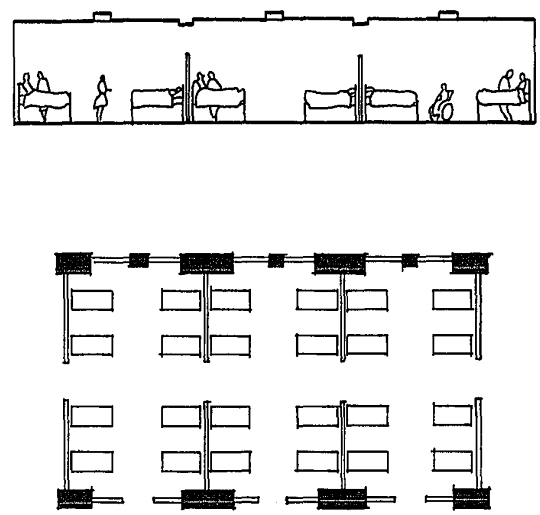


Fig. 3-50 Typical 24-beds ward.

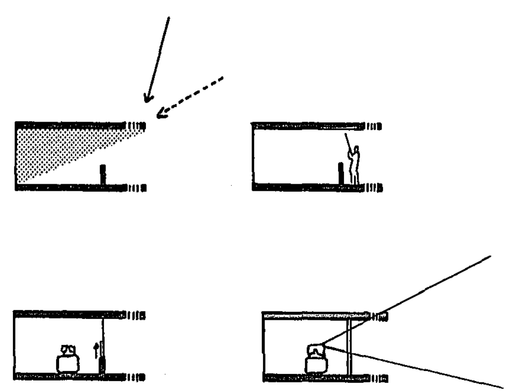


Fig. 3-51 Typical patients room free from glare, and unpleasant contrast but plenty of sunlight.

Well planned wards and rooms are required if the patient is to receive adequate daylighting without discomforting brightness contrasts. The traditional hospital usually is a perimeter type known as a barracks plan, such as Park Hospital of London, England, (Fig.3-52). The beds are

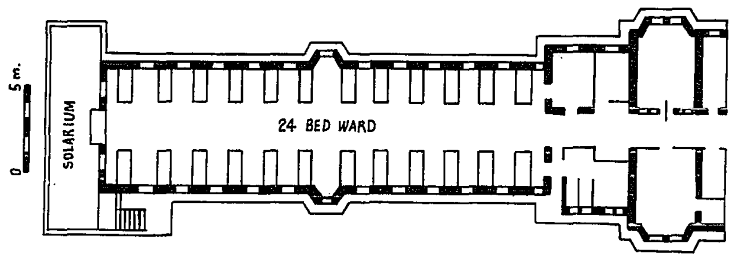


Fig. 3-52 Park Hospital, London, plan of typical pavilion.

placed with the patient's head pointing to the outside wall and each bed has a seperate window. The light is good for reading and medical examinations but it presents the worst possible condition of glare and brightness contrast because the patient is confronted by the windows across the ward. Some patients, such as those who are bedridden, may find it very difficult to adjust their position in order to avoid this uncomfortable condition. A better arrangement of beds would place the patient parallel to the outside wall instead of perpendicularly to it, as shown in Figs. 3-50, 3-51. If he likes to look outside he has only to turn his head. (C-22, C-23)

Since big windows and glass are frequently used in hospitals, the control of strong sunlight becomes important when it is not wanted. Usually the protection from direct sunlight provided by shelves, fixed fins or canopies is better than that of venetian blinds or curtains because the latter may harbour dirt and shut off outside beauty (Fig.3-51). Blinds and curtains cannot be adjusted by bedridden patients, and nurses cannot be expected to judge what setting will be best for each patient, because of the sun's continual motion. Outside shading can also provide a foothold for window cleaners thereby avoiding the dislodged dirt which blows into the ward if windows were cleaned from indoors. (C-24)

Besides the importance of daylight in the ward, the value of daylight in keeping down cross-infection, at least in operating and delivery rooms, infant nurseries, pediatric wards, communicable disease wards, surgical supply, pre-operation, formula rooms, and laboratories must not be overlooked. For these areas ample daylight becomes a must.

In actual hospital designs many architects overlook the important germicidal effects of natural lighting and ventilation and as a result place services such as kitchens, laundries, shops and even dining rooms in basements or sub-basements. When food is prepared and served, and the patient's laundry is cleaned in unhealthy conditions, the patient as well as the workers suffer, for bacteria lingering in kitchens, dining rooms or laundries are very likely to be carried to the patient. Therefore, providing them with ample daylight is essential. (C-25)

C.3 Residential buildings and houses

It is axiomatic that good housing in the city must have direct sunlight. This sunlight should fall on every wall not actually turned away from the sun for a reasonable span of time every day, and especially in the winter. Sunlight is important in the dwelling because it has physiological and germicidal effects. Health statistics show that flu, pneumonia, sinus troubles, sore throats, and general run-down conditions flourish in February and during the early spring. There is no doubt that the scarcity of sunlight in winter is one important cause of lowered resistance to these ills. For this reason, the avoidance of shadows, that is, the best utilization of the available sunlight, must be considered essential for good housing.

In dwelling designs, a simple shaped building is recommended for better natural lighting because a complex shape or structure always produces shadows. For this reason most dwellings are planned to be long and narrow, and without projecting wings. Any wing projecting on the sunny side of a building will cast a shadow on the neighbouring wall, or receive a shadow from it during some part of every day. In winter, when the sun is lower, this shadow will extend from the angle of roof line in the upper right corner, to a point about twice as far away from the wing. Wings on the north side of a building, although they may not cast a shadow on a wall, since the adjoining wall may be already in shade, nevertheless, cast an additional shadow on the ground, and tend to create a dark, and often icy or damp area. (C-26)

It has already been shown in section B.1 in Fig.3-15 and 3-16 that given equivalent building volumes, tall blocks ensure better daylight penetration. Another diagram, shown as Fig.3-53, from a study by Walter Gropius demonstrates how tall buildings provide equivalent accommodation and more free ground area than low structures and, how the control of height and form is determined by the light angle. (C-27) In Fig.3-53 the degrees of all light angles are the same but their distances apart from each other are different. For the apartment buildings

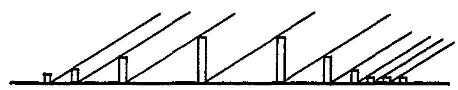


Fig. 3-53 The control of height and Form by the light angle.

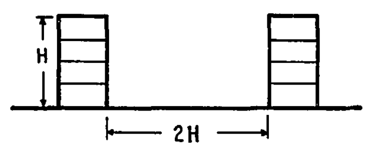
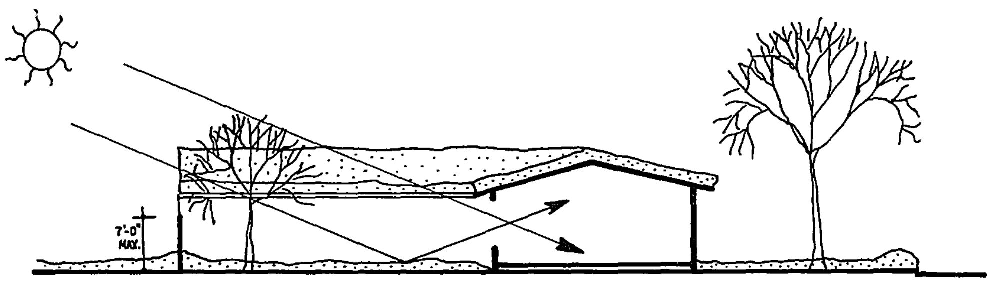


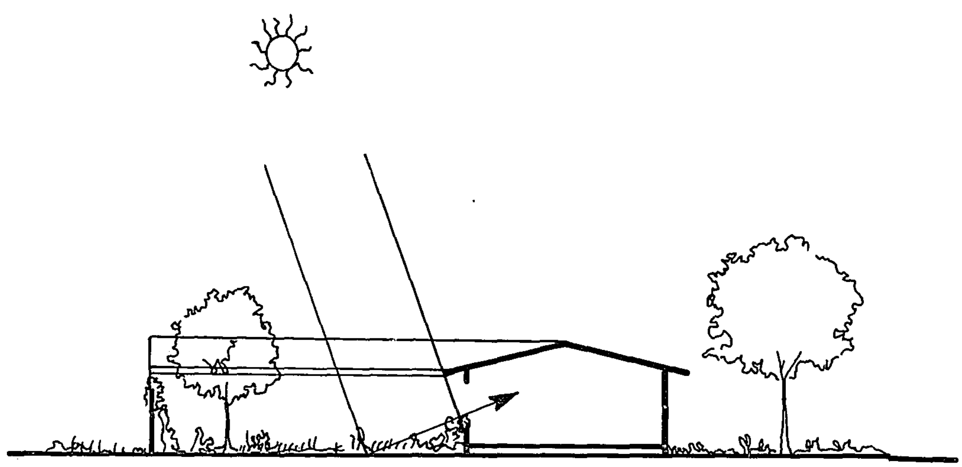
Fig. 3-54 The width of garden court between two apartment buildings.

a simple reasonable standard for determining this distance, leaving space for a garden court, entails making the width of the court equal to the building height (see Fig.3-54). (C-28)

A court garden house provides good daylight conditions. By concentrating the fenestration about the interior court, a greater amount of sunlight and daylight can be gained within the house by reflections from light-coloured ground surfaces and walls. During the summer, when the sun is high a narrow eve will exclude undesirable heat rays and excessive light in a court garden house, as figure 3-55 shows. In winter a clean, undisturbed snowblanket in the court will reflect a great deal of light into rooms, particularly on a sunny day. Since in the higher latitudes (Canada) the sun travels as low angle in the sky for a considerable part of the year, it becomes necessary to keep the height of the freestanding court walls less than seven feet. For obtaining maximum sunlight in the court area, a southern exposure is imperative. (C-29)



(a) REFLECTION OF SUNLIGHT IN WINTER



(b) EXCLUSION OF HEATRAYS IN SUMMER

Fig. 3-55 Good daylighting in court-garden house.

It is a apparent that pitched roofs opposite the windows obstruct sunshine and daylight much more than flat roofs. In the following picture (Fig. 3-56), the first house on the left has its windows completely in the shadow of the pitched roof opposite it, while

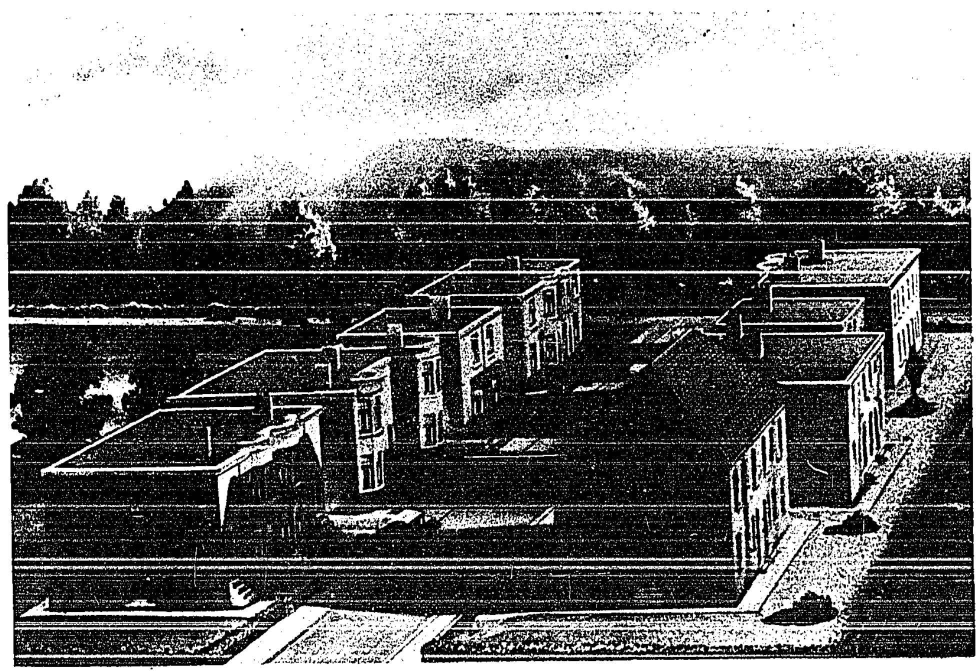


Fig. 3-56 Pitched roof opposite the windows obstruct sunlight and daylight much more than do flat roof.

at the same instant the other three houses on the left, being opposite flat roofs, are bathed in sunshine. Fig.3-57 shows a section diagram of three rows of houses spaced at a common distance interval, As the diagram illustrates, when the sun is rising or setting, a flat roof impedes the sunlight much less than does the pitched roof on a building with the same height of eaves. With streets of equal width (70 feet) and with the same height of eaves for two-storey buildings laying on the street direction from North to South at the latitude 56° N, calculations show that the number of hours with direct daylight entering the windows is nearly two hours different every day in the year between the case of

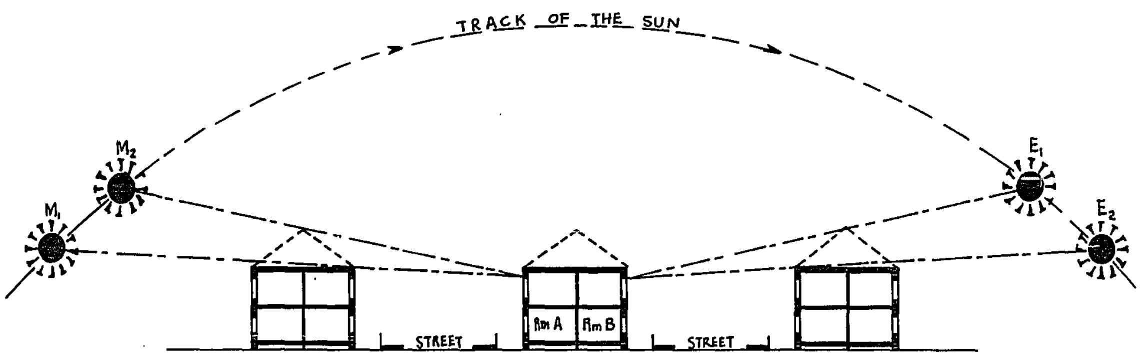


Fig. 3-57 A diagrammatic section through three rows of houses, with streets between running north to south.

"flat roofs opposite" and the "pitched roofs opposite." In other words the old pitched roofs houses cut off 21 per cent of the total possible sunshine throughout the year. (C-30)

In housing designs, each dwelling should be oriented to obtain the optimum sunlight exposure and all living quarters should face towards south as much as possible. A description of the fundamentals of orientating or planning living areas to face the sun has been given in A.6 of this part and is shown in diagram Fig.3-7. The various orientations for different rooms are given in Fig.3-8. A carefully chosen orientation may receive better lighting on the same building site than other orientations. For example, Fig.3-58 shows three possible orientations for groups of apartment houses on the axis of Fifth Avenue in New York City. Plan A is perpendicular to the avenue; C is parallel to it; and B is oblique to the avenue and facing to the south. The direction of the noonday sun is indicated on each example. Cross-sections showing the line from the midwinter, noonday sun to the sill of the first storey window are presented on the right of each diagram. Thus, the orientation

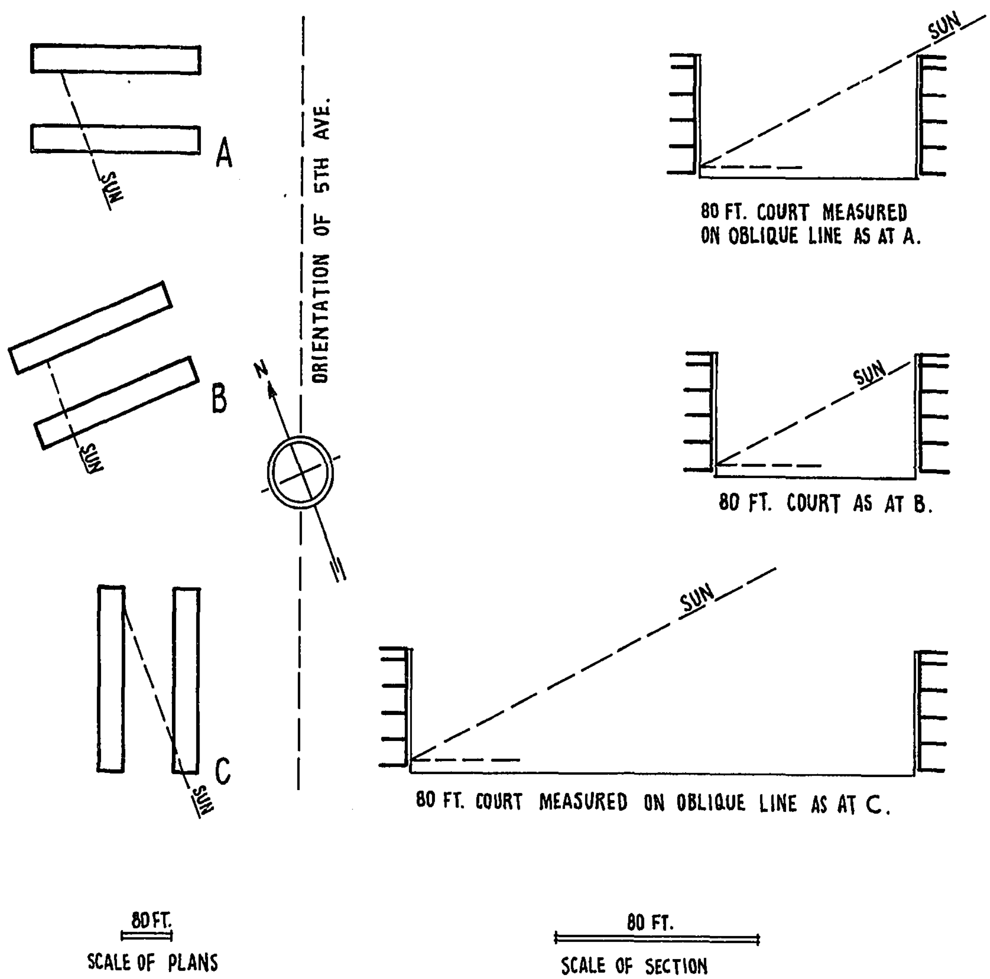


Fig.3-58 Noonday sun in winter for 4-storey apartment houses.

C permits the noonday sun to shine high over the opposite roof, but in a position oblique to the plan of the window and at a sharp angle to the right. With orientation B, the noonday midwinter sun will be entirely hidden from the lowest window sills, behind the cornice of the opposite house. (C-28)

After considering the obstruction from other buildings, the effects of the projecting parts of the building itself on the daylight penetration into the rooms must also be evaluated. A 10-ft. wide veranda

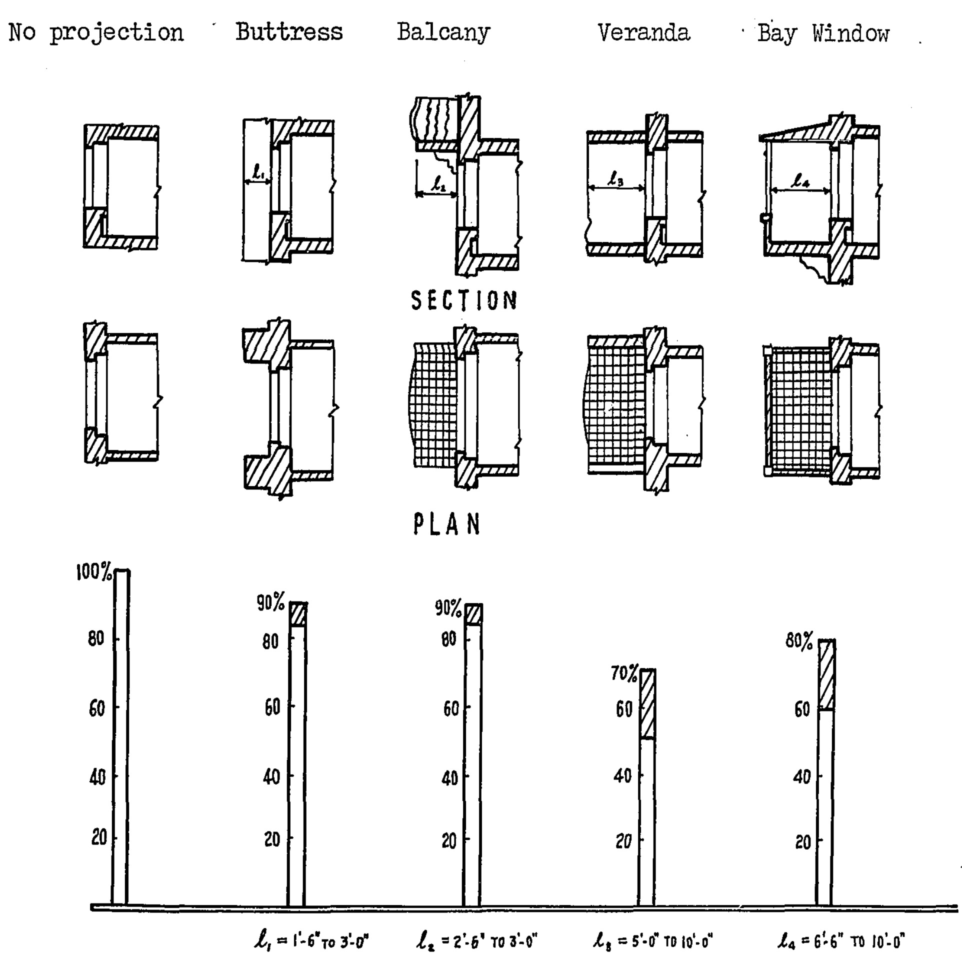


Fig. 3-59 The projection on the window decreases interior illumination

may decrease the room illumination of sky component to 50% of the window without any projection. Fig.3-59 shows that the buttress or column, balcony, veranda and bay window all decrease the interior illumination. (C-31)

The different room diminsions can also affect the interior illumination. Fig.3-60 illustrates the values obtained by changing the proportion of the room. In order to obtain adequate daylight penetration some glass area standards have been devised by local authorities. Table III-6 is an example of these standards. (C-32) Broadly speaking

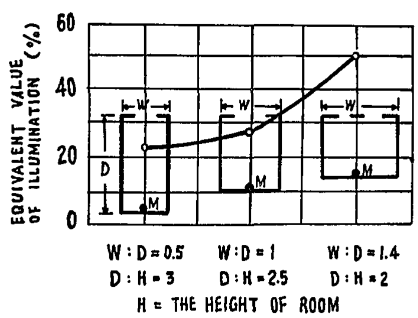


Fig.3-60 Illumination changes for rooms of different proportions.

Table III-6 Glass Area Sunlight Standards

Room	Room size (sq.ft.)	Window		
		Width	Glass area (sq.ft.)	% Floor area
Kitchen	up to 100	4'-9"	19	19
	101 - 120	6'-0"	24	20
Living Rm.	up to 150	4'-3"	16	11
	151 - 200	7'-3"	30	15
Bedroom	up to 110	2'-9"	11	10
	111 - 150	4'-3"	16	11

the area of the window may determine the penetration. Fig.3-61 shows the Daylight Factor contours for four arrangements of the same area of glazing. (C-33)

Skylight always provides good lighting in the dwelling. It can light the dark interior areas, such as the central service core where the kitchen, bath and heater room are grouped around compact utilities. It can also brighten the inside stairwell and center halls.

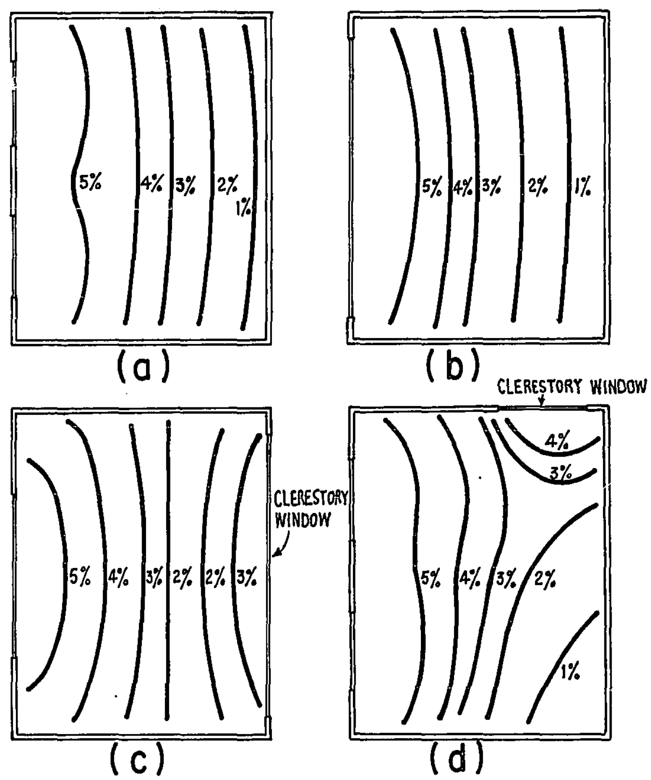


Fig. 3-61 Daylight Factor four arrangements of the same area of glazing.
(a) predominantly vertical; (b) predominantly horizontal;
(c) two-side (opposite); (d) two-side (adjacent).

For a good visual environment, many experiments of daylighting have been carried out in schools and in industry. Little experimentation has been devoted to daylighting residential construction. A good example of a researched residential design is the "daylight research house" which was designed by architect Harris Armstrong for the daylight-researcher Robert A. Boyd. This design gives a brightness controlled house in which comfortable daylighting is achieved by good window arrangements and overhead lighting (see Fig.3-62). Toplite glass block panels were used

Fig. 3-62(a) Daylight Research House, architect Harris Armstrong.

as wall fenestration in one bedroom, the outside bathroom, the kitchen and a clerestory in the living room incorporated the same prismatic light-rejecting principle as the overhead panels. In this house there are no dark corners. The daylight illumination is adequate but the brightness ratios are very low, so that glare in this house has been controlled. (C-34)

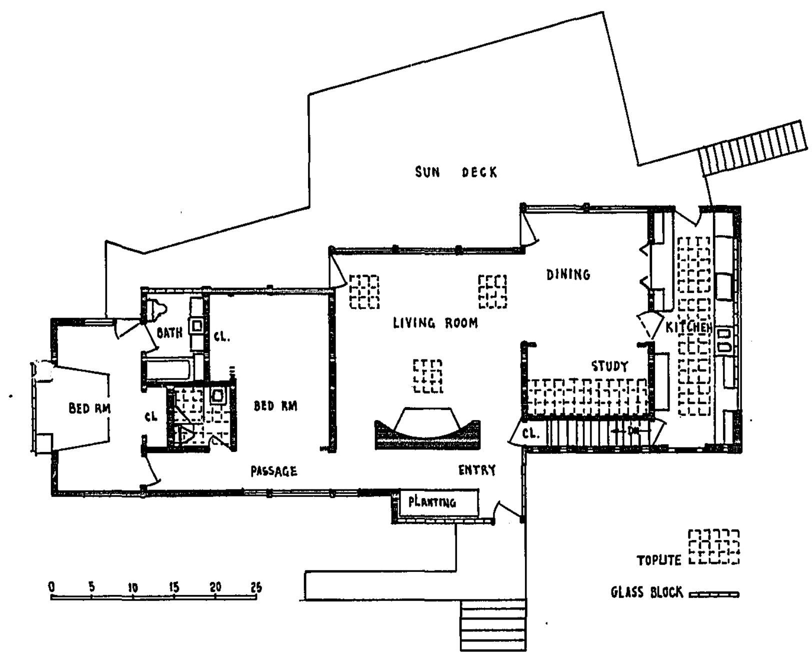


Fig. 3-62(b) Plan, Daylight Research House.

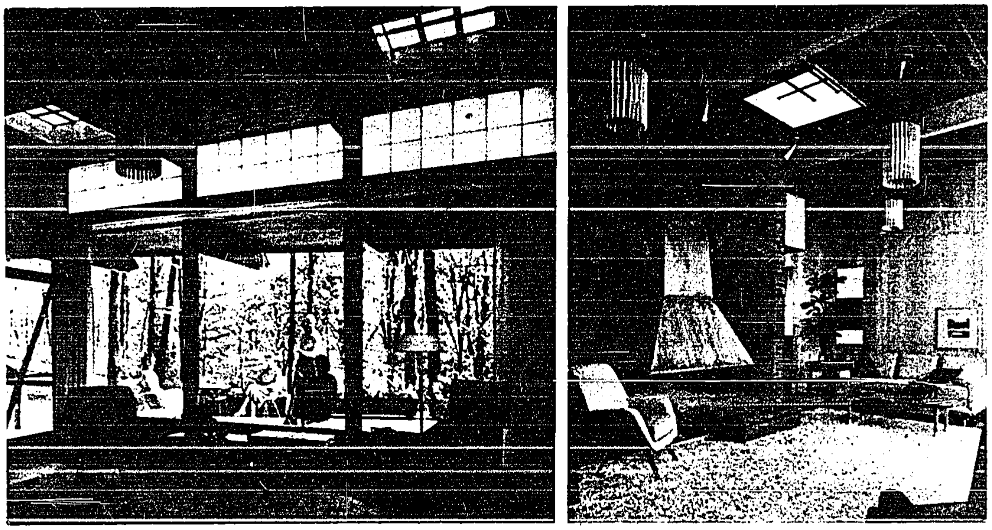


Fig. 3-62(c) Living room, Daylight Research House.

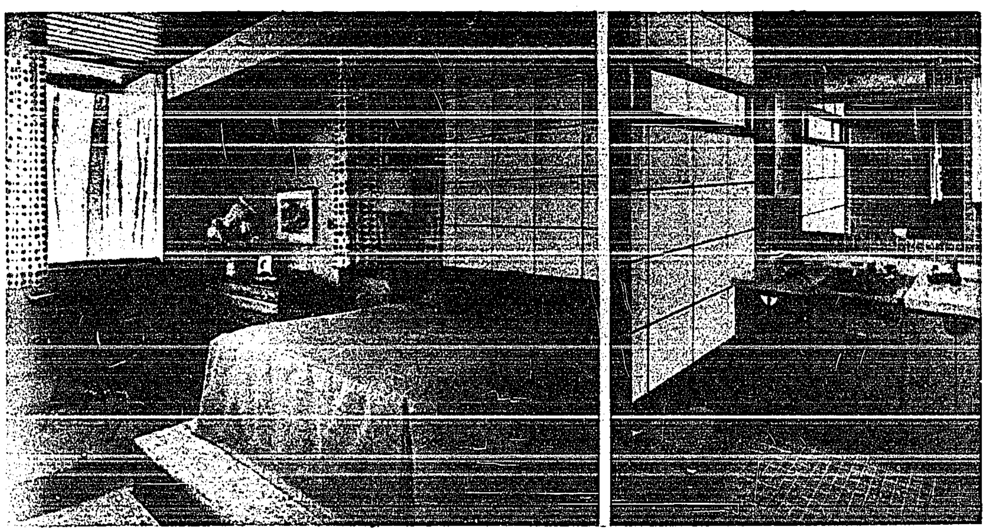


Fig. 3-62(d) Bedroom and bathroom,
Daylight Research House.

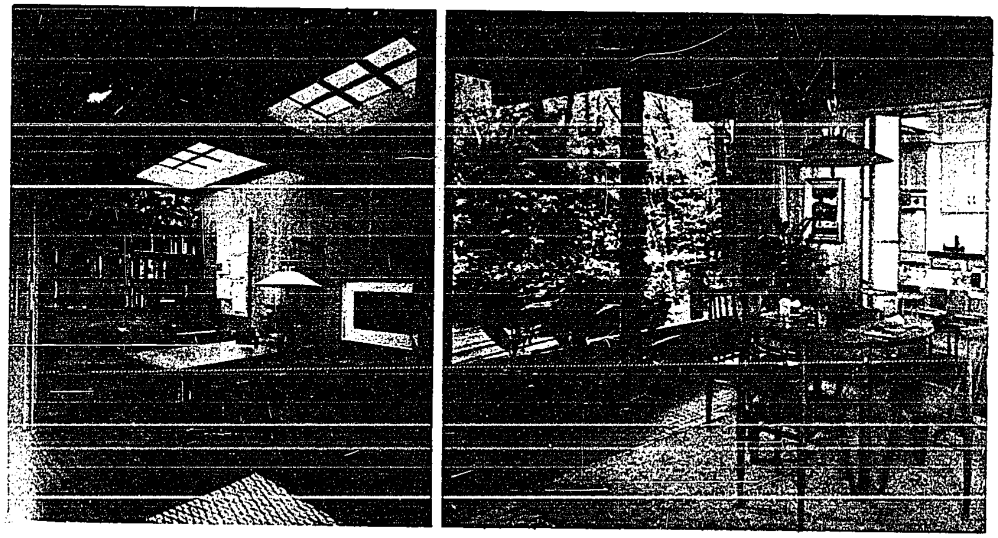


Fig. 3-62(e) Study and dining room,
Daylight Research House.

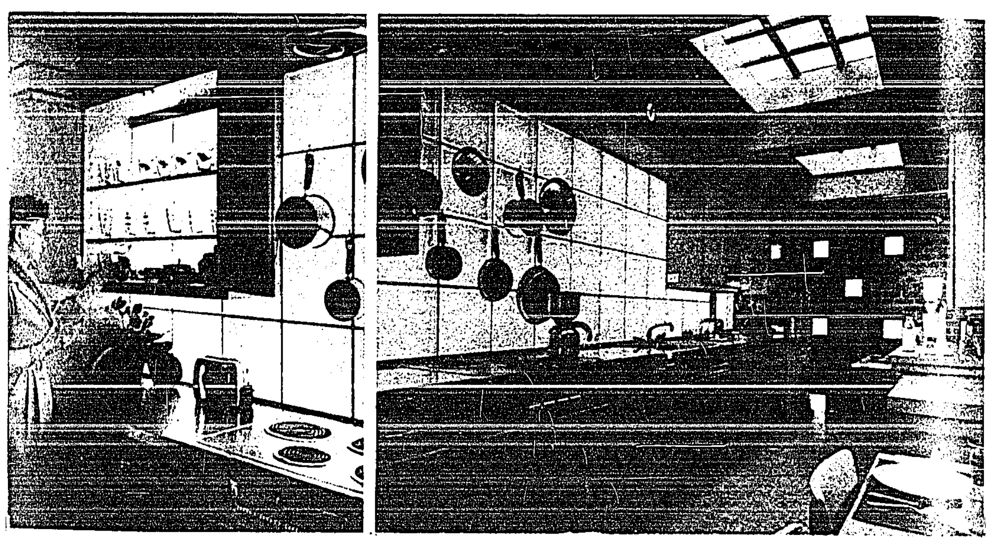


Fig. 3-62(f) Kitchen, Daylight Research House.

C.4 Churches

" The two main determinants of excellence in church architecture are the quality of its enclosed space and of its natural light. " said G.E. Kidder Smith. (C-35) Although it cannot be over emphasized that the sources and flow of daylight are among the most important factors in the success or failure of a church, there are frequent examples where fine spaces have been ruined by cruel light. As an example, on the left picture of Fig. 3-63 it can be seen that the columns are "cut in half" by badly located light sources and that the ceiling design cannot be seen

Fig.3-63 Two approaches to lighting the Mansion House, London.

properly because of the bright sources of light. On the right, an attempt has been made to light the space without destroying the architectural detailing and eliminating glare. (C-36)

Light or light and shadow combinations are one of most effective design tools in church architecture. The ingenious design of lighting in the building always reveals fresh delicate forms and textures and, more important it helps to create a spiritual (emotional) atmosphere. (C-37) In the M I T chapel (The chapel of Massachusetts Institute of Technology) the lighting plays a crucial role and, its

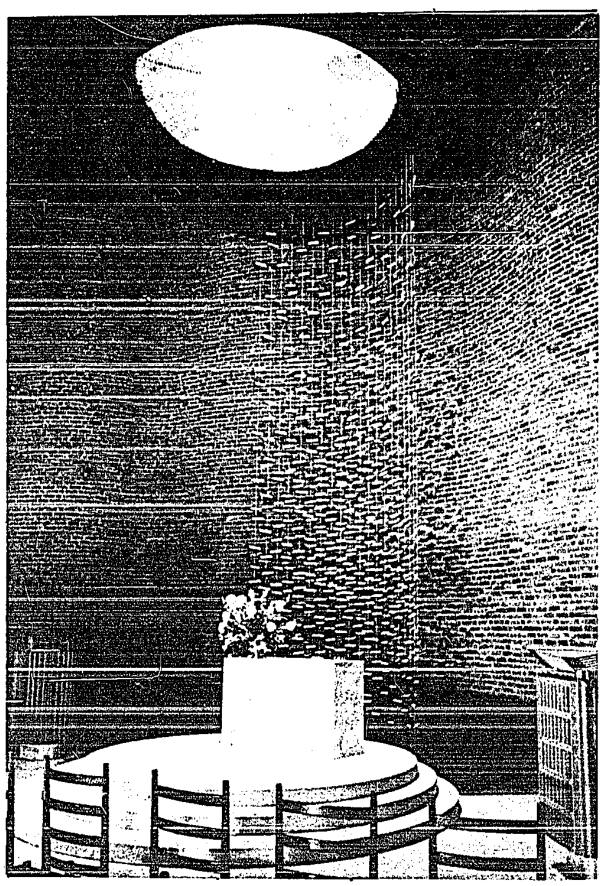


Fig. 3-64 The M I T chapel.

interior fosters contemplative withdrawal. As shown in Fig.3-64 the light from both natural and artificial sources filters down through a central oculus in the roof onto a metal screen. Additional light is provided from simple recessed down-lighting units in the remaining ceiling, and light is added at low level by means of openings that admit light refracted through the water of the moat surrounding the perimeter. Additional impact to the chapel is gained from the approach through an entrance cloister with walls of black glass, which admits only a low level of light as a transition to the space beyond. This design was created by some basic thinking on the particular "feelings" that should be inspired and, it was sucessful in achieving the appropriate religious atmosphere without recourse to the religious symbolism associated with any individual faith.

Every architectural program will call for a distinct emotional response based upon the purpose of the building. In church the emotional response is of a heightened nature. An appropriate lighting system with the judicious placing of colour should assist in the creation of this particular feeling. The place of worship can be constructed to instill a feeling or desire to reach out to something beyond the normal sphere of life, a sense of the infinite, and this feeling should be present in both the small parish church as well as the largest cathedral. (C-38)

Some diagrams follow that illustrate several ways of admitting natural light into the worship space. Fig. 3-65 shows lighting for general illumination and Fig. 3-66 emphasis lighting to focus attention on the chancel. Besides considering the creation of a spiritual atmosphere, the designer must also pay careful attention to providing adequate amounts

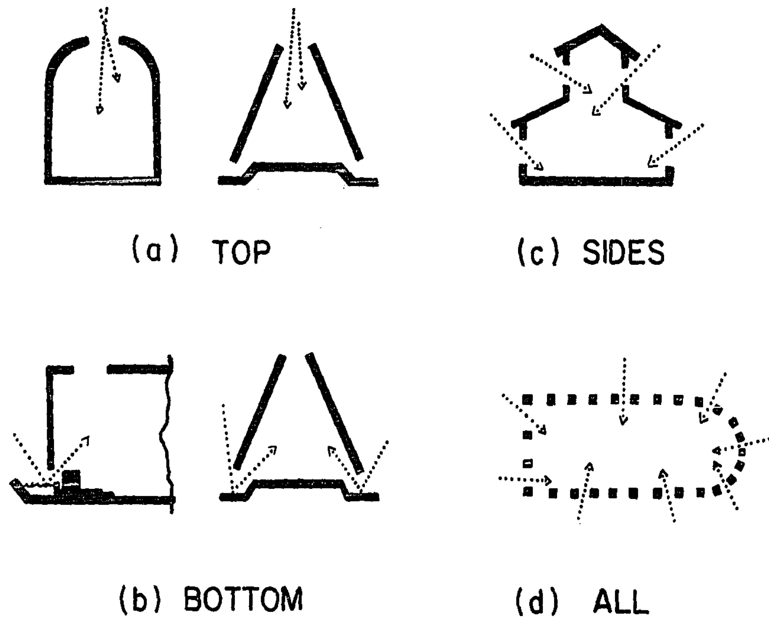


Fig.3-65 General lighting for church

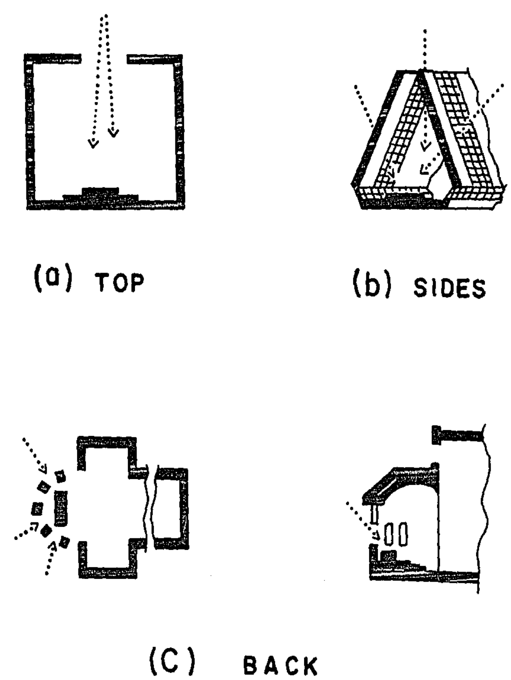


Fig.3-66 Altar lighting

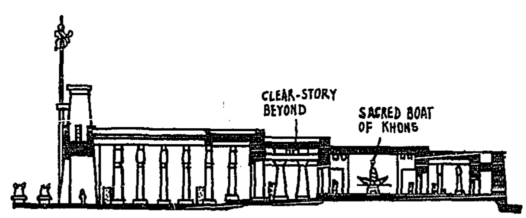
of good quality light. The tools he has to use are window size, heights of windows in walls, relationships between windows and wall space, and the use of stained or clear glass. (C-37)

For the non-liturgical type of service, daylight should be planned to reveal the face of the preacher and horizontal daylight factors must be sufficient for reading hymnals in all parts of the church. Where the emphasis is on liturgical action, the natural lighting should be designed accordingly, to focus attention on the altar and the sanctuary. The illumination in other areas should be coordinated for this purpose, and "topped up" by artificial lighting when occasion demands. Light should be directed at the vertical faces of the altar. Its horizontal surface will be almost hidden from the congregation, so light from directly above is largely wasted. In churches with a central altar and worshippers on all sides, care must be taken to highlight the altar without exposing the congregation to excessive glare since no congregation can be expected to look into glare and like it. An alternative treatment in an axial church is to light the wall behind the altar as brightly as possible, by windows in the side walls. The altar is then revealed in dramatic silhouette, though sculptured and coloured finishings will loose their clarity. Windows behind the altar are a source of distraction and, from a lighting point of view, quite misplaced. Interestly enough, the Gothic architects often provided direct apsidal windows facing the people. (C-35, C-39)

Stained glass is always used in church windows to avoid glare to create a religious feeling. In Medieval architecture especially, the stained glass was used in the openings with deeper colour and darker tones at the lower or aisle levels, with lighter tones in the upper or clerestory levels. In order to keep the primacy of the altar as the major attraction, the windows at the sanctuary were larger and more translucent. In modern church designs, stained glass is not used in the traditional sense, but its colour and resultant aesthetic patterns will continue to be used. However, stained glass is best seen from a darkened interior. If it is to be used its demands must have precedence over all other lighting considerations because any light from other windows reaching the surface or surrounds of the strained glass will detract from its brilliance. (C-39, C-40)

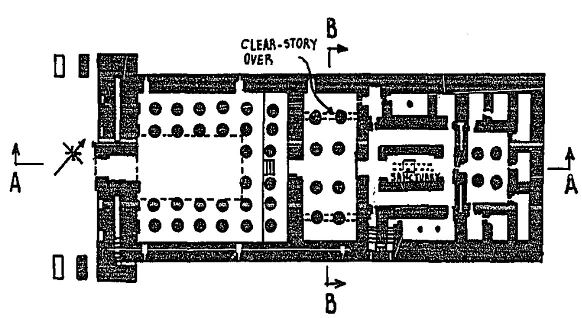
The investigation of historic architecture, has shown that various natural lighting methods were utilized consciously to illuminate the interiors and to ingeniously create a spiritual feeling and emotion. There are several example shown in the following.

1. TEMPLE OF KHONS : Karnak — EGYPIAN ARCHITECTURE, is a good example for utilization of natural light. The light was admitted

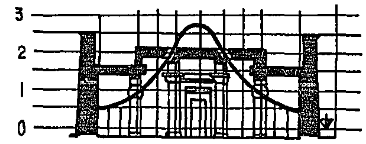


SECTION A-A

Fig. 3-67 Temple of Khons, Karnak.



PLAN

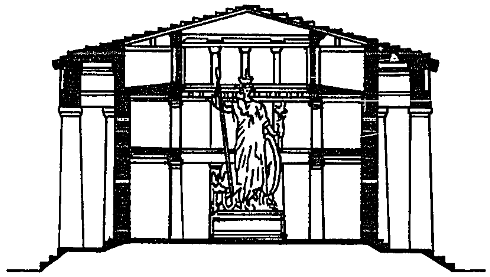


SECTION B-B

into the hypostyle hall by a clearstory formed by the increased height of the columns of the central aisles as shown in Fig.3-67. Its characteristic daylight curve descended rapidly from the centre of temple downwards to each sides and from the entrance downwards to the sanctuary. This resulted in a feeling with vast space in the temple. (C-41)

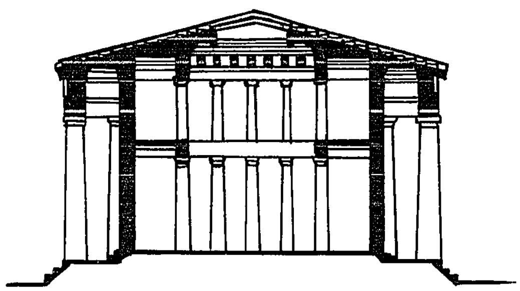
2. THE PARTHENON, ATHENS ___ Greek Architecture, is also an important example. There were two suggestions showing how to light the naos where the famous statue of Athena Parthenos stood. Fergusson thought that the naos was lighted by a clearstory and a translucent roof of white marble (see Fig.3-68a.). Another suggestion forwarded by Bötticher, stated that the light was admitted into the naos from a central opening (see Fig.3-68b.). The results of another investigation using a model showed that the idea of natural lighting illuminating the naos through the translucent roof was more sensible because it would provide better lighting conditions for the marvellous spectacle of statue Athena. (C-42)

3. THE PANTHENON, ROME, ---- ROMAN ARCHITECTURE, is quite interesting both in lighting design and architecture. The lighting of the building is effected by one circular unglazed opening, 27 ft. in diameter, in the crown of the dome. The area of the lighting opening is 4% of the floor area. The illumination of the inside temple is much lower than that outside. This increase results in a feeling of "concentration" and peace. Through the opening, sunlight illuminates inside of the dome and distinguishes the prominent decorations and details of the semi-gloomy interior. Although there are many prominent decorations, they do not produce a bright contrast of shade and shadow



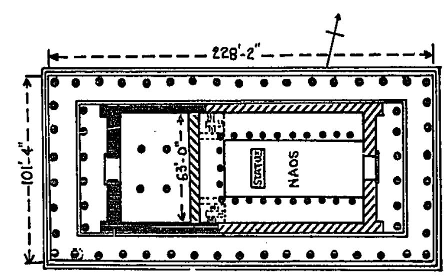
(a)

a. method of lighting
by clerestory (Fergusson)



(b)

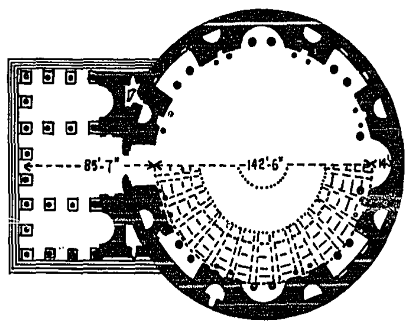
b. method of lighting
by skylight (Bötticher)



(c) PLAN

Fig. 3-68 The Parthenon, Athens.

when the interior lighting is imperturbable. This method of lighting produces a solemn and impressive effect and emphasizes the feeling of vast space inside the temple. (C-43, C-44)



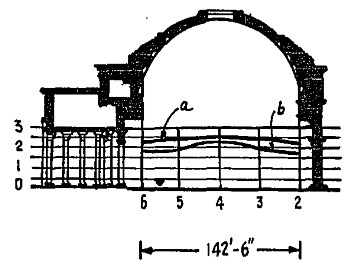


Fig.3-69 The Panthenon, Rome.

a. surveying curve
b. calculating curve.

4. ST. SOPHIA : CONSTANTINOPLE —— BYZANTIN ARCHITECTURE is also interesting in lighting design. Its lighting is partly effected by forty small windows in the lower part of the dome and by twelve windows grouped in the spandrel walls north and south under the great

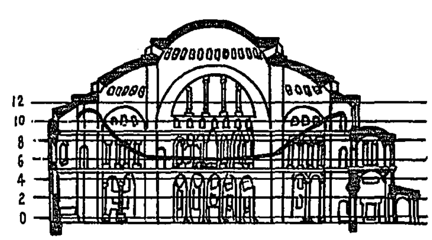


Fig.3-70 St. Sophia, Constantinople.

arches which support the dome, while there are windows in the lower part of the domes of the exedrae and of the apse. (see Fig.3-70) In the semicircular arches, the large semicircular headed openings have many small and elaborate windows inside which are divided into six by columns at two heights, between which marble lattice screens admit light through glazed openings about 7 ins. square. The dome of central plane and the main space of church are divided by the windows inlayed in the recesses of the walls. When the sun shines in, it creates the feeling that the dome is flying upwards in the sky. St Sophia admits a large quantity of light, which, when reflected by the bright surfaces, fills the church with light and allows the decorations on the ceiling and walls to be clearly seen. (C-45)

5. ST. PETER: ROME —— ITALIAN RENAISSANCE, is a good example of an architect utilizing boldly visual sensation in church design, and especially emphazing the visual sensation of the dome in the centre of the church. When the visitors enter the church walking longitudinally to the centre it appears that light diffuses unequally and the illumination decreases. Fig. 3-71 shows that the daylight factor at the plane of eye

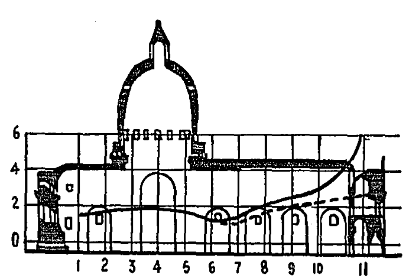


Fig.3-71 St. Peter, Rome.

level is about 2%. In the condition of low brightness for the ceiling and walls the low level lighting in the interior can provide a gloomy feeling. In this atmosphere, the top of the dome filled with sunlight is emphazied. Through the windows at the bottom of the dome, only a little light streams to the top of the dome, therefore the dome looks very high and the spiritual feeling is stronger. (C-46)

C.5 Office buildings

Side windows cannot provide sufficient illumination in an office to dispense with artificial lighting for most of the hours of daylight unless the office depth is severely limited. Good lighting should provide sufficient quantities of quality light. Although the quantity of lighting is easy to obtain the quality of lighting in an office depends on the demands of the emotions, visual comfort, the light source, and the economics of the building.

Emotions are strongly affected by the quality of light. In an office a happy mood can provide a stimulated and comfortable environment which will reduce mental and physical tension, stimulate people and assist them in completing their work.

Bad lighting conditions result in eye fatigue. A good lighting design should have the working plane in the best lit part of the room and it should make the task the brightest object in the field of view. For visual comfort, high levels of illumination are required, but strong contrasts should be avoided, sunlight should be controlled and glare should be eliminated. The levels of illumination vary to suit different needs, for example, the desk worker wants limited contrast since too much light makes sustained work uncomfortable, the computer operator needs more in order to hold his attention against other movements in his field of vision, and the draftsman needs a high level of illumination over a large area. However an pleasant office should have a "rest centre" for the eye needs. It can be made from a long view across the room, or a view out of a window or an area of light colour.

The light source must be designed to eliminate the discomfort and the disability caused by glare. A glare from a light source that is much brighter than its surroundings may distract or dazzle the eye. Therefore, the immediate surroundings of the source must have an intensity gradient in order to eliminate sharp contrasts, and the source must be kept out of the field of vision (between 45° and 60° from the line of sight). All strong sources must be small, and horizontal rather than vertical shapes if supplementary artificial lighting is used.

The subject of economy in an office building has to be considered. First of all, daylight is one of the amenities that the building user is buying or leasing, and it is becoming more valuable, daily. In choosing the daylighting system, the expenses for areas of window greatly affect the cost of external walls and, more importantly, the capital and running costs of heating and cooling the office must be compared to the capital and running costs of artificial lighting. However, meeting the psychological and physiological requirements, creating a surrounding of happy emotion, and making the building more luxurious and comfortable for the working people although increasing the capital and running costs, can pay off in the longterm. (C-47)

In general, for administrative convenience, many people share a single large office where side windows cannot hope to provide sufficient daylight for everybody. Although the deep offices are virtually inevitable and the artificial light has made it acceptable, most of employees prefer to work in smaller offices, and supervisors may want their own office with a window. (C-48) In America many office buildings are planned with the daylit private offices arround periphery of a deep block while the larger windowless internal areas are given to less senior staff. Social consquences inevitably affect the shape of new office buildings more than the other factors governing daylighting. (C-49)

The orientation of an office building largely determines what light is available. If the axis of the building runs north-south it allows direct sunlight on both sides of the building however the sun will shine into the eyes of people when it is low in winter, and it will lead to an accumulation of heat in summer. A sun control treatment, such as a screen of vertical louvres should be installed to overcome this problem. If the building axis runs east-west, a small projection over the window is enough to keep out the hot summer sun. On small sites where such a design may not be possible, the shape and orientation of the building is determined by building lines and the availability of light. The lighting problem is often modified by the presence of surrounding buildings. (refer to Part III Sect. B)

Internally, the window is the source of natural light, and therefore the size and height of windows affect the penetration of daylight. The floor space can generally be divided into three zones of light; natural light, reaching about 12 ft. into the room; a further 10 ft. where supplementary artificial light is needed; and a zone of total artificial light which in the normal shallow slab block would be used for storage, circulation, and ancillaries only. (C-51)

In the case of the board room and committee room, the table should be placed perpendicular to the window wall and the chairman seated facing the window at one end of the table. (C-51)

The standards of lighting vary greatly from country to country. The British I. E. S. Code, recommended a minimum daylight factor value of 1 per cent for office buildings and a normal minimum illumination for the interiors of building of 15 lm/sq.ft. The recommended standards for working areas of office are shown as Table III-7.

Table III-8 shows the comparisons of recommended illumination values for general offices in different countries. (C-52)

Since the type of glass affects the quality and distribution of the light admitted, many office buildings use it to reducing sky glare, diffuse and re-direct the bright sky light, and absorb sun radiating heat. One must be careful to use the proper type of glass otherwise it may become a glare source in the room and spoil the lighting surroundings. (C-53)

Table III-7 Levels for Daylight and Artificial Light in Offices

Room	Recommended illumination lumens/sq.ft.
Entrance hall and reception	15
Conference room, executive offices	30
General offices	
Reading, writing, filing, indexing, mail-sorting - prolonged close work, stenographic work, typing, accounting and book-keeping	30
Business machine operation	45
Drawing offices	
General	30
Boards and tracing	45
Photocopying	15
Corridors and lifts	7
Stairs	10
Lift lobbies	15
Telephone exchanges	
Manual exchange rooms on desk	20*
Main distribution frame rooms	15

* Special lighting will be required for switchboard.

Table III-8 Comparisons of Recommended Illumination Values for General Offices in Different Countries

Country			lumens/sq.ft. approx.
France 1961	minimum		30
	recommended		60
Germany (draft 1962)			12 to 25
Britain	1961		30
Sweden	1962		30 to 100
U. S. A.	1959		100 to 150
U. S. S. R.	1959	fluorescent	20 to 30
		incandescent	7.5 to 15

C.6 Museums and Art Galleries

The principle factor in the lighting designs of museums and art galleries is the quality of light. Although, all objects of arts and sculptures need adequate light to display their colour and appearance, the relative brightness of objects, contrast, and glare resulting from direct sunlight are the most important problems. As ultra violet light tends to deteriorate most items on display in museums and art galleries, it would seem important to work with low illumination levels and to make certain that these are maintained for the short time intervals. It also suggests that all natural light sources should be capable of being obscured so that daylighting can be moderated when it becomes excessive and if necessary totally excluded. (C-54) It is difficult to give a "safe" level of illumination for sensitive materials because any light may cause some deterioration. To some extent the limit imposed on the illumination level must be arbitrary and dependent on the object being illuminated. In France a maximum illumination of 50 lumens per sq.ft. is prescribed for the artificial lighting of oil paintings, and 30 lumens per sq.ft. for pastels, water colours and other critical materials. In the Natural Gallery, London, and in recent galleries in Portugal and Australia, the illumination on pictures is restricted to 15 lumens per sq.ft. (C-55)

The quality of light obtained from north-facing openings has long been considered as the best, however other factors may make it impossible to obtain light with "north" light qualities. Whenever directional daylight is used in museum, the opening admitting it should

C.6 Museums and Art Galleries

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The quality of light obtained from north-facing openings has long been considered as the best, however other factors may make it impossible to obtain light with "north" light qualities. Whenever directional daylight is used in museum, the opening admitting it should be designed so that the light is graded and glare avoided by excessive contrast of dark objects with the incoming light. Openings should also be placed in such a position or screened in such a manner, that the eye will not see the sky or other bright areas, such as white paving or sunlit buildings, after it has adjusted itself to the lower levels of illumination found inside. (C-56, C-57)

Generally, daylighting in museums is always provided by using elevated opening and clerestorys. The diagrams shown as Fig.3-72 demonstrate the different natural lighting system of large museums in the world. They all use high openings and clerestorys. Fig.3-73 is an example where sunlight has been excluded from a room in the museum.

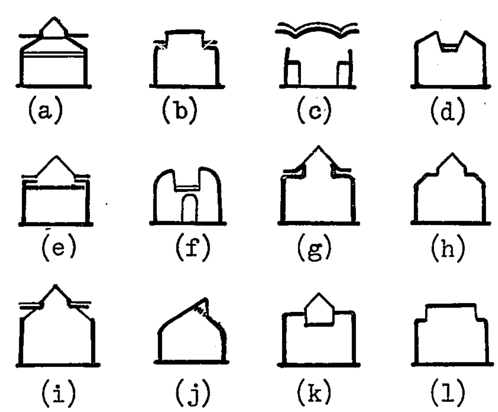

Fig. 3-72 The natural lighting system of museum

This reflected lighting system may provide better visual conditions without sunshine. (C-58)

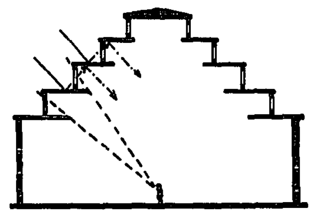

Fig. 3-73 A reflected lighting museum.

Ultraviolet radiation can damage textiles, paintings, leather and paper, so the amount of light striking these materials must be severely limited. However sculptures are best seen in sunlight and, jewellery and metalwork are enhanced by an abundance of daylight. If a sculpture must be exhibited indoors the lighting should aim to simulate the directional qualities of sunshine. A large side window can be satisfactory (see Fig.3-74) but a roof light directly overhead is a very poor substitute. (C-59, C-60)

Art gallery lighting should aim to emphasize the paintings. The background of the whole exhibition room should be slightly darker than the paintings themselves. Since clerestory lighting above the paintings would be distracting and side windows facing the paintings would reflect light into the observer's eyes, roof lights should be carefully designed to light the pictures, rather than the floor, and to avoid all unwanted reflections. (C-55, C-61) Fig. 3-75 shows four possible modes of natural lighting in an art gallery. From their comparison, structures (c) and (d) are more economical because the height of rooms required to eliminate contrast is lower. (C-62)

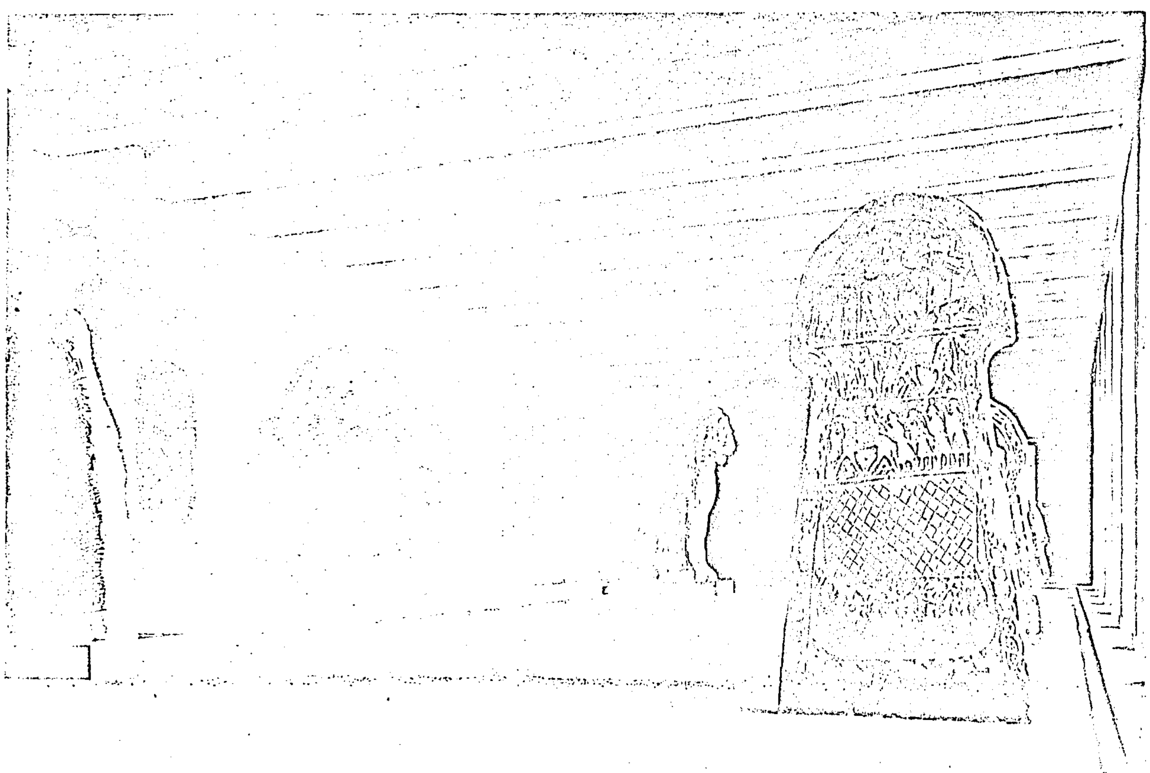

Fig. 3-74 Large side window lights the sculptures of indoor exhibition.

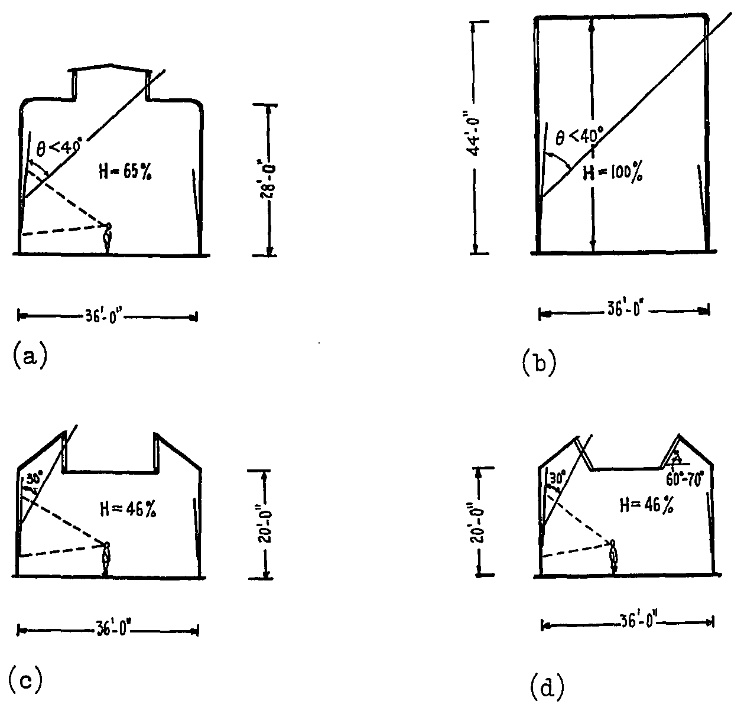

Fig. 3-75 The comparison of four possible natural lighting methods in art galleries.

Finally since illumination levels and daylight factors inside an art gallery must be kept low it is important to provide a smooth gradation of lighting from the entrance to the interior space to prevent an impression of gloom on entering the gallery.

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CONCLUSION

The theory of daylighting in architectural design represents the application of physics to the problem of obtaining the best effect for utilizing natural lighting and, providing the most suitable environment with adequate and comfortable illumination and healthy living conditions. The quality of both the exterior and interior of building depends on the availability of natural light. The planning, forms, elevations, orientation and the window design affect the daylight penetration and illumination; the interior and exterior forms and the selection of colour in decorations are dependent on the existing natural lighting conditions.

Daylight design in architecture requires a consideration of both the quantity and quality of natural light, the problem being to provide adequate wanted light to the interior and to exclude unwanted light from the room. The quantity of natural light is determined by the size and positioning of the fenestration. Numerical estimate can be obtained from many computational techniques. The best method for computing daylight has been devised by the Building Research Station of England, but the methods of single-stage calculation of total daylight are more simplified and conveniently used by the architects. The quality of daylight in architectural design is important because good lighting can provide a pleasant and comfortable working environment and enjoyable living to human beings. Eliminating glare and providing diffused light are the two most important objectives in providing high quality daylighting.

It is difficult to provide criteria for daylighting in all building designs but, as a general approach to the effect of daylight design in architecture, the following points must be considered essential:

1. Provide as much indoor daylight as possible, however ensure that it is glare-free;
2. Avoid strong sunlight sources which would become sources of glare discomfort;
3. Control glare by using the proper type of glass, curtains, blinds or louvres and interior colour rendering;
4. Ensure that the main visual task can be distinguished from its surroundings by being brighter, or more contrasting, or more colourful, or all of three;
5. Provide the suitable orientation capable of improving the daylight conditions of a building;
6. Consider the design and purposes of the building and evaluate the criteria of good and effective lighting relative to the total environment.

Daylight design in city planning should include investigations of the effects of neighbouring obstructions. On the same building site with equivalent building volume, the multiple storey buildings benefit from better natural light. Different shapes of buildings provide various illuminations and penetrations for individual rooms. The best results for daylight design for town planning can be obtained from the Waldram Diagram or Permissible Height Indicators both which were devised and ultilized in England.

Daylight in building design must depend upon the main purpose of the individual building as well as considerations of local climate and the speciality of visual work. Daylight design in schools, hospitals and housing is most important.

In modern school design, lighting provides pleasant environment thereby generating the interest and enthusiasm necessary to stimulate children's learning. Large quantities of daylight and suitable sunshine in the classroom are recommended because lighting in school affects not only seeing but also the health and growth of school children.

Daylight is important in hospital design. Besides its germicidal benefits, it provides the proper vision for nursing procedures and psychological therapeutic effects for the patients. A suitable and adequate lighting design in a hospital may prevent the spread of respiratory infections and thereby help patients to develop the pleasant emotions that can produce good curative effect.

Daylighting in dwellings is very important because qualified good housing requires sufficient sunlight penetration. A simple shaped narrow, long building without projecting wings with proper orientation to the sun is the basic design characteristic of dwellings with sufficient natural light.

In churches, daylight design governs emotional responses and create an inspirational religious atmosphere.

Although side windows cannot provide sufficient illumination to light the deep internal areas of a large office building, most of employees prefer to work in a office with a window. The essential problem of natural lighting design in the office building is to produce a pleasant and stimulating environment for as many people as possible.

Since ultraviolet radiation can deteriorate most items on display in museum and art gallery, low illumination levels are recommended. While sculptures, jewellery and metalwork all need direct daylight to enhance their appearances, natural light on the other objects particularly the paintings must be severely restricted. Elimination of contrast and glare from the surface of paintings is another important lighting problem in art galleries.

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