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ABSTRACT

Research gathered by the Functional Efficiency Division of the National Building Research Institute, South Africa, is aimed at providing lighting conditions under which the school child can produce his maximum effort with the least strain and fatigue. These favorable conditions are outlined along with specific examples of their realization in design solutions. Nine sections comprise the report--(1) Introduction, (2) Lighting Requirements, (3) Design Considerations, (4) General, (5) Conclusions and Recommendations (6) References, (7) Appendix I--Tables for Determining the Number and Sizes of Lamps Required to Deliver a Predetermined Illumination Level on the Working-Plane, and (8) Appendix II--A Bibliography on School Lighting, containing over one-hundred and fifty entries dealing with child development, color, vision, luminance control, natural lighting, artificial lighting, and codes. Photographs, charts, and diagrams appear through the text. (KK)

SCHOOL LIGHTING

TECHNICAL REPORT BY THE NATIONAL BUILDING RESEARCH INSTITUTE ON AN ASPECT OF SCHOOL BUILDINGS RESEARCH **10**

SCHOOL LIGHTING

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FOREWORD

Before the School Buildings Committee began its work, there existed a guide to architects called *Suggestions concerning the planning of school and hostel buildings* in which, under the heading 'Orientation of Buildings', it is hinted that buildings should face south because: 'In addition direct sunlight striking through the exposed window space upon pupils and their desks in schools has to be screened off by means of blinds and curtains. . . It is necessary to emphasize that southern lighting if adequately provided for imposes far less severe eye-strain on the children'. Except for a casual reference here and there where windows are mentioned, this is all it had to say on the subject of lighting.

How to provide adequate light was the problem which the School Buildings Committee had to solve, but it was privileged to be able to consult the Functional Efficiency Division of the National Building Research Institute. Members of the Division visited schools to study the problem at first hand and therefore could write: 'The poor daylighting that is encountered in many schools is sufficient proof that proper lighting design was almost completely neglected in the past owing to the fact that, until fairly recently, no rational method existed for designing buildings for daylighting'.

The Division took up the challenge but the problem, which seemed so simple to the layman, was so involved that years were needed to design measuring instruments, to experiment with models and to test the prognostications in actual classrooms. The result is this report which gives 'a more rational and scientific approach to the problem of daylighting design'.

This report is written in such a way that it can be understood by the layman without impairing the scientific validity of its findings. A glance at the table of contents shows what a wide field it covers. Minimum standards are suggested, and the sizes and positioning of windows to ensure this illumination are given. The effect of ceiling heights and the planting of trees or the laying down of concrete outside the classroom are discussed. Artificial lighting installations are suggested. How the quality of light is affected by colour schemes, direct sunlight, glare, etc., is examined. For the architect this report is invaluable but, as many of the factors influencing the problem of adequate lighting fall under the control of the principal, everyone connected with schools should make a careful study of the recommendations embodied in this report.

The aim of the research was to provide lighting conditions under which the child could produce his maximum effort with the least strain and fatigue. It is only necessary to walk into the classrooms which conform to the norms laid down here to feel the soothing effect of the proper distribution of light and the elimination of glare, and to realize that this research has been of immense value to the child.

The School Buildings Committee is very pleased that it initiated the research and is proud to have been associated with this work.

T. LE ROUX
Chairman, School Buildings Committee

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INTRODUCTION

Since the prime function of a school building is to stimulate the educational process in its broadest sense, every effort should be made to provide schoolchildren with a suitable and stimulating educational environment. In this respect the importance of good lighting to the child's development, by the conservation of his eyesight, cannot be overemphasized. Ensuring efficient vision in every way possible is a means to this end.

Research conducted in America[14, 15] has shown that an unbalanced lighting pattern in the child's visual field can produce both physical and physiological distortions such as one-sided positioning, curved spinal development and distorted vision. Distortions such as these arise from the child's unconscious and automatic adjustment to the stresses and strains to which he is subjected by inadequate lighting conditions.

Light not only helps the child to see and recognize objects but also prepares his mind and body to respond to action, so that he can adapt himself to any task he is called upon to perform. The better the light, the more easily and quickly will the task be accomplished, and the less will be the strain on the eyes.

Basically, lighting is adequate when both its quality and quantity create a general luminance which is agreeable and beneficial to the user, and when it makes possible a high degree of efficiency in seeing the necessary tasks with a minimum of effort. The purpose of this report is to outline the basic requirements of good lighting and to show how these requirements can be realized in practice.

Before doing this it is necessary to review a few of the fundamental concepts of lighting and to define some of the more important terms used when discussing illumination.

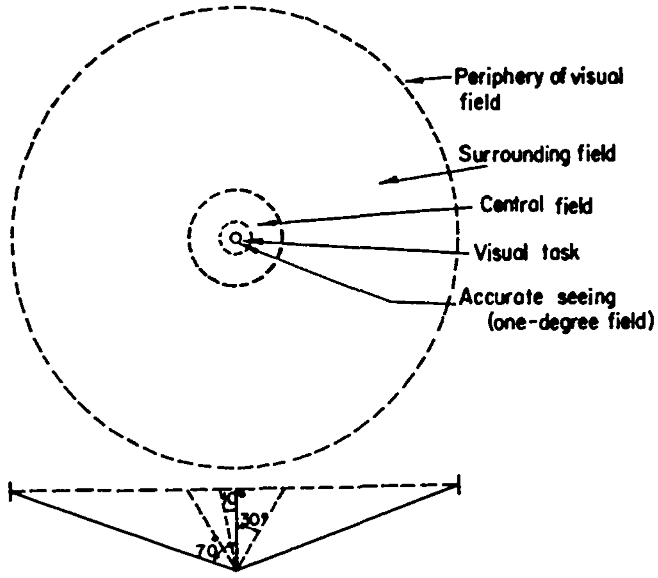


FIGURE 1(a)
Diagrammatic presentation of the visual field

LIGHTING CONCEPTS AND ILLUMINATION TERMINOLOGY

1. VISUAL FIELD

The human eye is sensitive not only to light in the direct line of sight but also to that in the field of vision surrounding it. The field of vision consists of a cone of about 70° (shown schematically in Figures 1 (a) and 1 (b)[2]).

The visual field comprises:

(a) an inner cone of about 1° wide, which is the *area of precise vision*;

(b) the *visual task field*, a cone of approximately 10°, which circumscribes (a) and takes up the task object itself, a book, for instance;

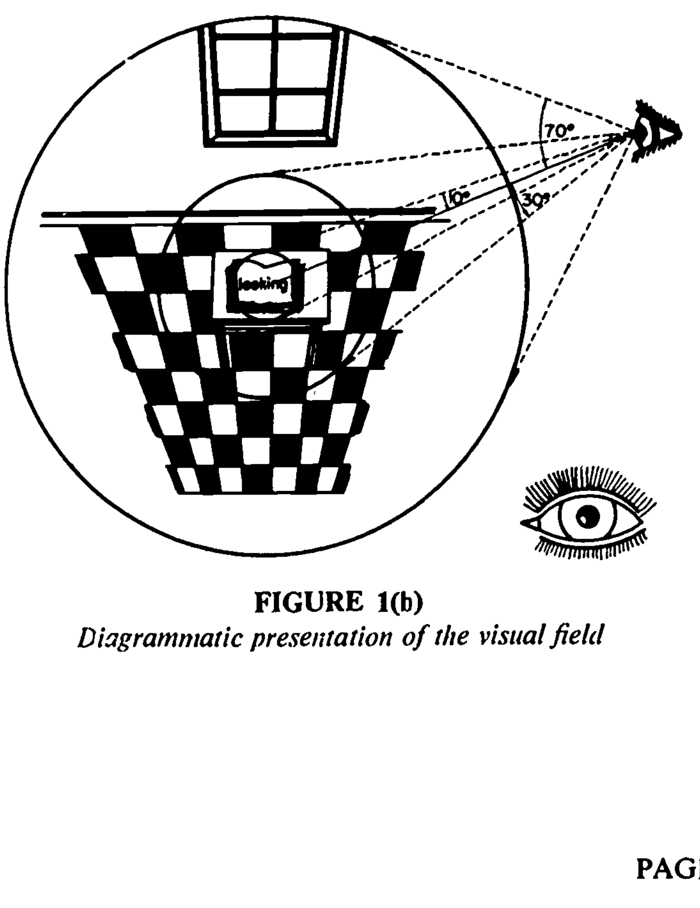


FIGURE 1(b)
Diagrammatic presentation of the visual field

(c) the field surrounding the task object up to and including a cone of about 30° which is usually referred to as the *central field*, the lighting of which should be of good quality for easy seeing and visual comfort;

(d) the remainder of the visual field, which is generally referred to as the *surrounding field*, usually consists of the background to the task, e.g., floors, walls, furniture, etc. Although the lighting of the surrounding field is of least importance, it should, nevertheless, be taken into account in the lighting design for comfortable seeing.

2. LIGHTING OR ILLUMINATION

In order to recognize any particular object, a certain amount of illumination is necessary. The application and use of light for certain tasks and its relationship to the environment is called illumination, or lighting.

3. INTENSITY OF LIGHT

The intensity of light is measured in footcandles, or lumens/sq ft. One lumen/sq ft is the illumination at a point on a surface which is one foot from, and perpendicular to, a uniform point source of one candle-power[38]. This unit of light quantity, which can be measured by an illumination or footcandle meter or by a visual photometer, is basic to the evaluation of conditions of seeing.

4. SKY- AND DAYLIGHT-FACTOR

The term sky-factor as used in daylighting studies refers to the computed ratio of the level of daylight at any reference point in a room to the coincident level outdoors under an unobstructed sky, exclusive of direct sunlight[9]. A shortcoming of the concept of the sky-factor is that it does not take into account the contribution of light reflected by external and internal surfaces and is thus not a true reflection of lighting indoors. In order to overcome this disadvantage a new concept, the daylight-factor[35], was introduced which, in principle, is the same as the sky-factor, except that it allows for the contribution of reflected light components.

5. REFLECTION-FACTOR

The reflection-factor is the ratio, or percentage, of the light reflected by a surface to the incident light. The reflection-factor of a surface may vary considerably according to the direction and nature of the incident light and the texture of the surface. The reflective quality of a surface is generally compared with a 'pure white surface', e.g., magnesium-oxide, which is taken as having a reflection-factor of 100 per cent.

6. LUMINANCE OR BRIGHTNESS

Luminance, or brightness, is produced by the light reflected from a surface. It may be defined as the luminous intensity of a surface, or as the product of the illumination falling on a surface and the reflection-factor of the surface. Luminance is expressed in footlamberts, e.g., if a surface with a reflection-factor of 100 per cent is illuminated to one lumen/sq ft, its luminance is one footlambert. Luminance, or brightness, can also be associated with the direct transmission of light as, for example, from a light-fitting itself or from the sky through a window.

The latest findings in regard to illumination indicate that it is luminance, and not illumination intensity, that contributes most to comfortable seeing conditions.

7. LUMINANCE RATIO

The term luminance ratio is defined as the ratio of the luminance of the central field to that of the surrounding visual field.

8. LUMINANCE CONTRAST

Luminance contrast refers to the difference between the luminance of the focal object, i.e., object to be observed, and that of its background, e.g., black ink on white paper.

A balance between the luminances of the focal object and its background is the key to comfortable seeing. Excessive luminance ratios may result in glare.

9. GLARE

Glare cannot be defined in precise terms; it is easier to illustrate its effect on vision. For example, a bright light-source in the field of vision such as a window viewed against a bright sky, can reduce the ability to see clearly. This is because the eye does not readily adapt itself to so wide a difference in the luminances in the field of vision. This effect is known as 'disability glare'.

Another type of glare, called 'discomfort glare', causes discomfort but not a total inability to see. It is caused, for example, by a light-source of high light-output and high luminance in the field of vision, or by a bright task against dark surroundings. The degree of both these types of glare is influenced by such factors as luminance conditions, gradation of luminances, the apparent size of the source of light relative to the field of view, and the position and shape of the source.

A third type of glare which causes eye-strain and discomfort is 'reflected glare'. This occurs when the image of a light-source is reflected from a shiny surface into the eye.

LIGHTING REQUIREMENTS

1. VISUAL TASKS IN THE SCHOOL

From the point of view of lighting, the visual tasks of the schoolchild can be divided into two main categories:

firstly, close-up visual tasks such as reading, writing, painting, sewing, etc., and, secondly, visual tasks at more distant focal points such as those on chalk- and pinning-boards, models, displays, or distant objects. Each of these calls for certain lighting.

In general, the visibility of a task or an object depends on its size, its contrast with its background, and how detailed it is. All these factors are interrelated, but the size and contrast with background are inherent to the task itself and are, as a rule, unalterable.

As far as size of printing is concerned, experience has shown that, in the case of close-up tasks, 10-12 point type in the new roman type-face is the most legible and suitable for schoolchildren. Visibility is also improved when the contrast with the background is increased to the maximum, i.e., black on white.

In the case of more distant tasks, research conducted in England[17] has shown that, in order for children in the back rows to see lettering on chalk- and display-boards clearly, the letter should be at least one inch high and not more than about 25 ft away. It should also be borne in mind that children sitting in the back row will be about three times as far away from the chalk- and display-boards as those in the front row, with the result that to them the visual or apparent size of the objects of attention will appear to be a third of their true size.

From the foregoing it is clear that a child's eyes function under constantly varying conditions, such as seeing things close to or at a distance, or the changes that occur in luminances and contrasts, so that unless good lighting is provided, a child's eyesight may very easily be impaired.

2. ILLUMINATION STANDARDS

It has been shown in the previous paragraph that the proper illumination of the various tasks that confront schoolchildren requires special attention. This means that the illumination must be adequate both in quantity and in quality.

(a) Quantity of illumination

The minimum amount of illumination required for the performance of any specific task must take into account not only the efficiency with which the task is performed but also such factors as fatigue, physiological and psychological effects and economics. Unfortunately it is not practical to study the influence of all these factors because the characteristics of visual tasks are too variable. Consequently, attention has so far been devoted mainly to a study of the relationships between the level of illumination and visual efficiency in terms of the speed and accuracy with which work is performed[11, 26, 39, 7].

The minimum illumination standards prescribed in the British Illuminating Engineering Society Code[19, 25, 8] are based on Weston's[40] work in which a level of performance of about 90 per cent is assumed as the desir-

TABLE 1

Summary of illumination levels (lumens/sq ft) recommended for schools by overseas authorities

Country and Authority / Application	America			England			Sweden	France	Holland	
	Illuminating Engineering Society[2]	Illuminating Engineering Society[22,10]	U.S. Dept. of Education[34]	Illuminating Engineering Society[23] 1958	Illuminating Engineering Society[23] 1961	Ministry of Education[17]	See ref. 20	See ref. 20	Very good lighting[28]	Good lighting[28]
Classrooms .. Chalk-boards ..	30	30–70 150	30	15	30 20–30	10	15	20–25	23	12
Laboratories .. Study halls	30	100 70		3–15 depending on task	15–30 depending on task					
Drawing-offices .. Typing and needlework	50	100 150	40	20	45–70		30	30–50	47	23
Wash-rooms ..	10	30			15					
Manual training: Fine .. .. Ordinary .. Rough	50	500 100 50		50 10 7	70 30 15 depending on trade					

able objective. The Americans, on the other hand, work on a level of performance of between 90 and 100 per cent[12, 22]. Consequently, their lighting standards call for much higher levels of illumination. The minimum standards adopted for current recommended lighting practices in various countries are compared in Table 1.

Although the values given in this table are minimum values, they do not exclude the use of higher illumination levels. However, it will be found that, although visual acuity increases with an increase in the illumination level, the rate of improvement in visual acuity is much slower than the rate of increase in illumination level.

The proposed minimum illumination levels (in lumens/sq ft) for South African schools are given in Table 2.

TABLE 2

Proposed minimum illumination levels recommended for South African schools

Application	Illumination level (lumens/sq ft)
Classrooms .. .. / Chalk-boards	20
Laboratories .. .. / Libraries (reading-tables)	20
Drawing-offices .. .. .. / Typing and sewing	30
Gymnasiums	10
Wash-rooms	5
Manual training:	
Fine	30
Ordinary	20
Rough	10
Children with defective vision ..	Special lighting

In principle, the illumination values given in Table 2 are based on the British recommendations[19] except that allowance has been made for the decrease in illumination intensity when a room is occupied. Laboratory tests and measurements in schools in the Cape Province during term time have indicated that a 17-27 per cent decrease in intensity can be expected if a classroom is occupied by children wearing variegated school uniforms. In actual fact the values were rounded off to the nearest increment of 5 lumens/sq ft. This resulted in an average increase over the British standards of between 25 and 33 per cent.

The illumination of classrooms for children with defective vision should receive special attention. Generally speaking, such children require higher illumination intensities, although lower intensities are necessary in those cases where the children's eyes are over-sensitive to light.

The recommendations listed in Table 2 refer to rooms for teaching purposes only. For rooms other than these, Table 3 should be consulted.

TABLE 3

Minimum illumination levels recommended for rooms other than teaching-rooms

Application	Illumination level (lumens/sq ft)
Assembly halls as halls ..	10, special lighting
Assembly halls as classrooms ..	15—20
Dressing-rooms	7+local lighting
Study halls	20 general, or 10+local lighting
Bedrooms	5+local lighting for studying
Bathroom	5
Kitchen and laundry	10
Halls, passages and stairs ..	3
Living-rooms	7
Administrative offices	20

Apart from providing the minimum recommended illumination levels throughout the rooms as well as on the chalk- and pinning-boards, it is just as important for the light to be evenly distributed in order to avoid high contrasts. The ratio of maximum to minimum illumination level should not exceed 3 : 1; a ratio of 2 : 1 would, however, be preferable[36].

(b) **Quality of illumination**

(i) *Glare*

It was mentioned previously that the provision of adequate illumination implies far more than merely providing the minimum illumination levels; the quality of the light plays just as important a role. Lack of luminance control in the field of vision can result in glare in one way or another. The sense of glare is determined largely by the luminance ratios or luminance differences in the field of vision. Turning the eyes from an area of high luminance to one of lower luminance will not only temporarily impair vision but also affect performance. The only possible way of eliminating this harmful effect is to ensure that the luminances for all areas in the field of vision are not much in excess of that of the task. This can normally be achieved by ensuring that the luminance ratios in the field of vision do not exceed the values recommended in Table 4[2].

TABLE 4

Recommended limiting luminance ratios in classrooms

Field	Luminance ratio
Between task, e.g., book and immediate surround, e.g., table-top	1 to $\frac{1}{3}$
Between task and more remote surround, e.g., floor and walls	1 to 1/10
Between task and more remote brighter surface	1 to 10
Between light-fittings or windows and surfaces adjacent to them	20 to 1

It must be stressed that shadow patches in classrooms should be avoided as far as possible. Shadows on the upper surfaces of desks can be very distracting and can accelerate eye-fatigue. Similarly, shadows cast by objects may cause excessive luminance contrasts. Lighting should, therefore, be well diffused and the positioning of light-sources, including windows, should receive careful attention. This applies particularly to art-rooms where predominantly directional lighting is required.

In order to prevent reflected glare it is recommended that all surfaces in the field of vision should have a matt texture, as shiny surfaces result in specular reflection.

(ii) *Colour*

Another aspect closely related to the quality of lighting is the use of colour for interior decoration. Different colours not only have different psychological and emotional effects on people, but also determine the luminous reflectances of surfaces.

Generally speaking, blues and greens tend to produce a feeling of coolness and an illusion of space and distance. Reds, oranges and yellows, on the other hand, tend to induce a feeling of warmth and cosiness[13].

For good observation of an object it is recommended that warm colours be applied in close proximity to the centre of attention, and cool colours to the more remote surroundings. This arrangement of colours creates a centre of attention to which the eye automatically returns.

Chalk-boards are traditionally black in colour and are generally viewed against a background of white or cream, so do not form a centre of attraction. A white or yellow board with black chalk lettering would be better, but, because this is rarely practicable, chalkboards have retained their dark colours. Experiments carried out in England[16] have shown that the chroma of chalk-boards is relatively unimportant when the reflection-factor is 15 per cent. Furthermore, if illuminated to less than 10 lumens/sq ft, glare is no serious problem. If, on the other hand the board has a reflection-factor of the order of 25 per cent or more, care must be exercised in the choice of colour. This seems to indicate that the colours used for chalk-boards should have reflection-factors varying between 15 and 25 per cent. Although the actual choice of a suitable colour will depend on the colour scheme of the classroom, the chroma should be borne in mind. The following colours, with their Munsell notations, have, for instance, been found suitable for chalk-boards[16]:

Blue (7.5 PB)
Blue-green (2.5 BG)
Yellow-green (10 GY)
Orange (10 YR)
Red (2.5 R)

Here again, as mentioned previously, it must be stressed that the chalk-board surface should be perfectly matt in order to avoid specular reflections.

In conclusion it should be mentioned that in the same way that the indoor environment affects people psychologically so may the outdoor environment affect the occupants within a building, and it, too, can be turned to account in the creation of a pleasant atmosphere. Well laid out grounds and interesting topographical features such as hills can be exploited with advantage to contribute towards a restful visual environment, just as they can be used to control sky glare.

DESIGN CONSIDERATIONS

Having established the minimum standards of illumination desirable, the next step is to indicate how these minimum requirements can be met in practice. In this respect, attention will be devoted chiefly to design considerations that will ensure adequate light for children with normal vision.

What cannot be over-emphasized is that provision of adequate illumination in classrooms does not mean that the services of the eye specialist will no longer be required. Regular examinations and screening tests are essential for the early diagnosis of any eye trouble. Consequently, it is strongly recommended that periodic eye examinations by properly trained personnel should be made compulsory in all schools and that a record should be kept of the condition of every child's eyes. Those pupils whose visual deficiency cannot be corrected by the specialist require special illumination, for they are affected more noticeably by both the quality and quantity of light than people with normal vision. The responsibility for providing schoolchildren with the best possible lighting conditions is, therefore, shared by the architect, the illuminating engineer and the eye specialist.

The two main sources of light are daylight and artificial light. As it is generally more natural, comfortable and economical to work by daylight, daylighting will be given prime consideration.

A. QUANTITY OF LIGHT

1. DAYLIGHTING

The provision of adequate daylighting is an integral part of the planning of a building and as such must be given consideration from the earliest stages of a design. The amount of daylight that can be provided indoors depends on an assessment in the early stages of planning of the illumination levels out of doors, the size, arrangement and positioning of windows, the type of glass used, the size and shape of the room, the internal decoration, the orientation of the building, sun control devices, and external surroundings and obstructions.

The poor daylighting that is encountered in many schools is sufficient proof that proper lighting design was almost completely neglected in the past owing to the fact that, until fairly recently, no rational method existed for designing buildings for daylighting. During recent years, however, serious attention has been given to developing a more rational and scientific approach to the problem of daylighting design. Various methods have been proposed but they all have their limitations. Probably one of the best approaches is that followed by Hopkinson, Longmore and Graham[18]. Reports on their research findings are published in the form of a series of Tables from which sky-components, sky-factors and internal reflected components can be determined.

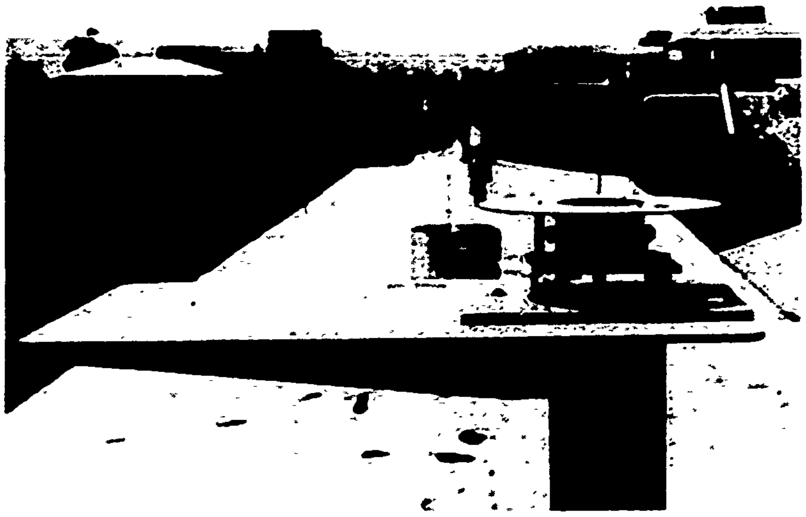


FIGURE 2
Total daylight meter

(a) **Outdoor design considerations**

Owing to the fact that climatic conditions in this country differ appreciably from those experienced overseas, the first stage in the development of a design procedure for daylighting in this country was to determine the values of outdoor illumination under different sky conditions for different regions of the country. For this purpose total outdoor illumination, sky illumination, and the distribution of sky luminance were measured in Pretoria over a period of three years[33]. Some of the instruments used for recording these are shown in Figures 2, 3 and 4.

FIGURE 3
Skylight meter

FIGURE 4
Sky luminance meter

TABLE 5

Frequency analysis of the mean hourly horizontal outdoor illumination values for overcast conditions for Pretoria, between the hours 8 a.m. and 2 p.m. for the period Jan. 1951 to Dec. 1953
(percentages)

Lumens/sq ft			0-249	250-499	500-749	750-999	1 000-1 249	1 250-1 499	1 500-1 749	1 750-1 999	2 000-2 249	2 250-2 499	2 500-2 749	2 750-2 999	3 000-3 249	3 250-3 499	3 500-3 749	3 750-3 999	4 000-4 249	4 250-4 499	4 500-4 749	4 750-4 999	5 000-5 249	5 250-5 499	5 500-5 749	5 750-5 999	6 000-6 249
Month	Total hours	Hours over-cast																									
January ..	635	52	—	—	—	0.2	0.2	0.5	0.2	0.6	0.6	0.8	0.2	0.8	0.3	0.5	0.2	0.3	0.3	0.8	—	0.5	0.3	0.3	0.3	0.2	0.3
February ..	407	72	—	0.2	1.0	0.5	1.2	1.2	1.5	1.0	0.2	2.5	1.0	0.2	1.2	0.7	0.7	0.5	0.5	—	0.5	1.2	0.7	0.5	0.5	—	—
March ..	590	79	—	—	0.5	0.5	1.9	0.3	0.8	1.0	0.7	0.3	1.2	0.3	1.2	1.4	0.2	0.7	0.5	0.7	0.2	0.8	—	—	—	0.2	—
April ..	554	68	0.2	0.5	1.3	0.5	1.3	0.7	1.6	0.5	0.7	1.1	0.9	0.5	0.4	0.4	0.4	0.4	0.2	0.2	—	—	0.2	0.4	—	—	—
May	515	52	0.6	1.0	0.6	1.2	1.0	1.2	1.4	0.4	0.8	0.4	0.8	0.2	—	0.4	—	0.2	0.2	—	—	—	—	—	—	—	—
June	365	6	—	—	0.3	—	—	0.3	—	—	0.5	0.3	—	—	0.3	—	—	—	—	—	—	—	—	—	—	—	—
July .. .	604	25	0.2	0.3	0.2	0.8	0.5	0.2	—	0.2	0.5	0.5	0.5	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—
August ..	608	19	0.2	0.5	0.2	0.5	—	0.2	0.3	0.2	—	0.2	0.5	0.3	0.2	—	—	—	—	—	—	—	—	—	—	—	—
September..	539	20	—	0.4	0.4	—	—	0.6	0.4	0.4	1.1	0.2	0.2	—	—	—	—	0.2	—	—	—	—	—	—	—	—	—
October ..	592	96	—	0.2	1.7	1.5	2.0	1.4	2.4	1.2	1.2	1.0	0.3	—	—	0.5	0.3	0.7	0.2	0.7	0.2	0.3	0.2	0.2	—	0.2	—
November..	578	111	—	0.5	1.2	1.0	1.2	0.7	3.1	0.5	0.7	1.0	0.7	1.0	0.3	1.0	0.7	1.2	0.7	0.9	0.2	0.3	0.9	0.2	0.7	—	0.3
December..	565	89	—	0.2	0.4	0.9	0.4	1.1	0.2	1.6	1.1	0.7	0.9	1.1	0.7	0.5	0.2	0.7	0.5	0.7	0.9	0.4	0.7	0.4	0.2	0.4	1.2
Total .. Averages ..	6 552	689	0.1	0.3	0.6	0.7	0.8	0.7	1.0	0.6	0.7	0.7	0.6	0.4	0.4	0.5	0.2	0.4	0.3	0.4	0.2	0.3	0.2	0.2	0.1	0.1	0.2
Accumulative percentages			0.1	0.4	1.0	1.7	2.5	3.2	4.2	4.8	5.5	6.2	6.8	7.2	7.6	8.1	8.3	8.7	9.0	9.4	9.6	9.9	10.1	10.3	10.4	10.5	10.7

In order to determine the sky illumination value for school building design, the mean hourly illumination values for overcast conditions were determined and recorded daily during the school hours 08.00 to 14.00. The values were then analysed on a percentage frequency basis for each month, to show the number of occasions, expressed as a percentage of the total number of hours recorded, when the mean hourly illumination fell between the limits 0 to 249, 250 to 499 and so on, in steps of 250 lumens/sq ft as shown in Table 5.

Because these observations give the minimum levels of illumination and because in practically every case these levels of illumination will be exceeded by all other conditions of the sky, it was considered safe to base the design for interior illumination on overcast sky conditions. The reason for this is that the contribution of light reflected from bright or partly sunlit ground and other exterior surfaces will be greater even though the actual sky luminance may be lower than the corresponding contributions under overcast conditions. This is substantiated by measurements of illumination levels in a particular room under the conditions of both an overcast and a clear sky of 1 000 lumens sq/ft as illustrated in Figure 5. Under the clear sky condition, the intensity of the direct sunlight on the horizontal plane was 5 800 lumens/sq ft.

The choice of the appropriate design sky conditions must necessarily be an arbitrary one. A reasonable and practical choice for South African schools is considered to be one in which the minimum levels of interior illumination will be exceeded for 96 to 98 per cent of the normal school hours in the average year. On this basis it would seem, from Table 5, that a reasonable choice for the Pretoria area would be a sky illumination of 1 000 lumens/sq ft. If this value were used lighting levels in the classrooms would be below the recommended minimum requirements for only 20 to 30 out of a total of about 1 000 school hours during the average year, which is negligible.

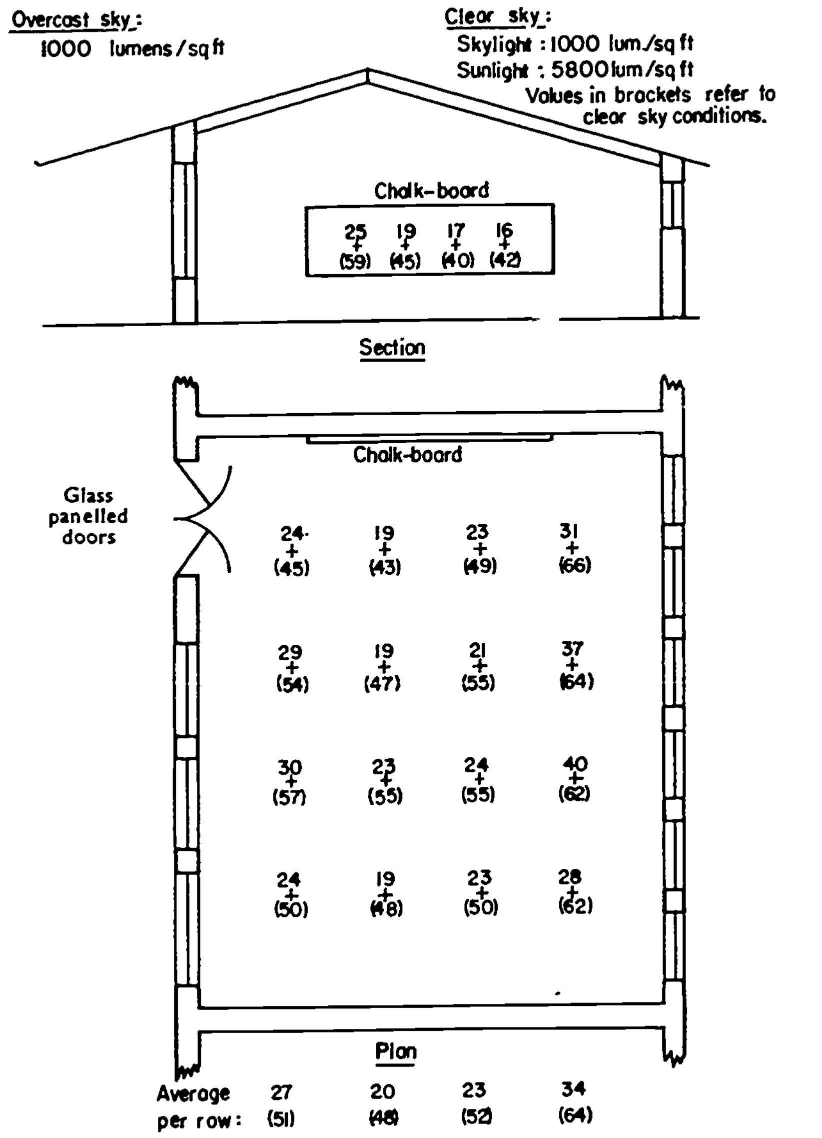


FIGURE 5

Comparison of measured illumination values in lumens/sq ft for overcast and clear sky conditions in an actual classroom

Although outdoor illumination values have been recorded only for Pretoria, it is possible, from these measurements, to assess corresponding design values for other towns or areas in South Africa by making use of the relationship between illumination and sky radiation intensities for overcast sky conditions, i.e., 7 010 lumens/sq ft=1 gramme calorie/minute[33]. Total and sky radiation fluxes are measured by the Weather Bureau at different centres in South Africa.

The frequency analysis for outdoor illumination values for Cape Town converted from radiation data is summarized in Table 6. Using the same arguments as for Pretoria, it would appear that an assumed value of 750

TABLE 6

Frequency analysis of the mean hourly horizontal outdoor illumination values (converted from solar radiation data) for overcast sky conditions for Wingfield, between the hours 8 a.m. and 2 p.m. for the period Jan. 1952 to Dec. 1955 (percentages)

Lumens/sq ft			0-249	250-499	500-749	750-999	1 000-1 249	1 250-1 499	1 500-1 749	1 750-1 999	2 000-2 249	2 250-2 499	2 500-2 749	2 750-2 999	3 000-3 249	3 250-3 499	3 500-3 749	3 750-3 999	4 000-4 249	4 250-4 499	4 500-4 749	4 750-4 999	5 000-5 249	5 250-5 499	5 500-5 749	5 750-5 999	6 000-6 249
Months	Total hours	Hours over-cast																									
January ..	868	14	—	—	—	—	—	—	0.1	0.1	0.1	0.3	0.2	0.1	—	0.1	—	0.1	0.1	—	0.1	0.1	—	—	—	—	—
February ..	791	47	—	0.1	0.1	0.5	0.4	0.5	0.5	0.5	0.6	0.5	0.4	0.1	0.6	0.1	0.1	—	0.3	0.1	0.1	—	0.1	0.1	—	—	—
March ..	868	69	—	0.1	0.2	0,2	0.8	0.5	0.2	0.7	0.5	1.5	0.7	0.3	0.5	0.5	0.3	0.5	0.2	—	0.2	—	—	—	—	—	—
April ..	840	145	0.2	1.1	2.6	1.9	1.1	1.5	1.4	1.3	1.2	1.5	0.8	1.0	0.4	0.4	0.6	—	0.1	0.1	—	—	—	—	—	—	—
May	868	202	1.8	3.7	2.3	1.5	2.6	2.3	1.7	1.8	1.3	2.3	0.7	0.8	—	0.3	—	—	—	—	—	—	—	—	—	—	—
June	840	123	2.3	1.9	1.0	1.0	1.8	0.6	1.3	1.1	1.2	1.7	0.4	0.4	0.2	—	—	—	—	—	—	—	—	—	—	—	—
July	868	258	3.9	4.8	3.7	2.4	2.8	2.3	1.5	1.8	2.2	2.0	0.9	0.8	0.3	0.2	—	—	—	—	—	—	—	—	—	—	—
August ..	868	197	1.0	2.6	1.5	1.7	2.0	2.2	2.1	2.4	1.8	1.0	1.3	1.0	0.8	0.6	0.1	0.3	0.1	—	—	—	—	—	—	—	—
September .	840	113	0.1	0.1	1.3	1.1	1.4	1.1	1.2	1.0	1.0	1.5	0.5	0.4	0.7	0.6	0.6	0.2	—	0.4	0.1	0.2	—	—	—	—	—
October ..	868	106	—	0.2	—	0.5	0.8	0.8	1.0	0.8	0.9	1.4	0.7	0.8	0.8	0.3	0.5	0.5	0.7	0.2	0.2	0.1	0.3	—	0.2	0.3	—
November..	840	85	—	0.1	0.1	0.8	0.2	0.8	0.5	1.0	0.7	0.7	0.5	0.6	0.7	0.5	0.2	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
December	868	77	—	—	—	0.1	—	0.3	0.1	0.6	0.5	0.9	1.0	1.0	0.3	0.2	0.8	0.5	0.2	0.5	0.6	0.5	0.1	0.1	0.1	0.1	0.2
Total .. Averages ..	10 227	1 436	0.8	1.3	1.1	1.0	1.2	1.1	1.0	1.1	1.0	1.3	0.7	0.6	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	—	—	0.1	—
Accumulative percentages			0.8	2.1	3.2	4.2	5.4	6.5	7.5	8.6	9.6	10.9	11.6	12.2	12.6	12.9	13.2	13.4	13.6	13.7	13.8	13.9	14.0	14.0	14.0	14.1	14.1

lumens/sq ft would be a reasonable design value for conditions in the South Western Cape.

It was, unfortunately, not possible to extend this analysis to other centres in South Africa, but from observations and experience it is estimated that the design value of 1 000 lumens/sq ft for an overcast sky is applicable to practically the whole of the summer rainfall area in the country. It is only in the south western to south eastern coastal areas, i.e., roughly from Cape Town to East London, that it is felt that a design sky illumination of 750 lumens/sq ft should be used. In the case of Durban, with its high percentage of fog and smog, a design sky of 750 lumens/sq ft should also be used. Should further radiation and illumination data become available a more detailed analysis will be undertaken.

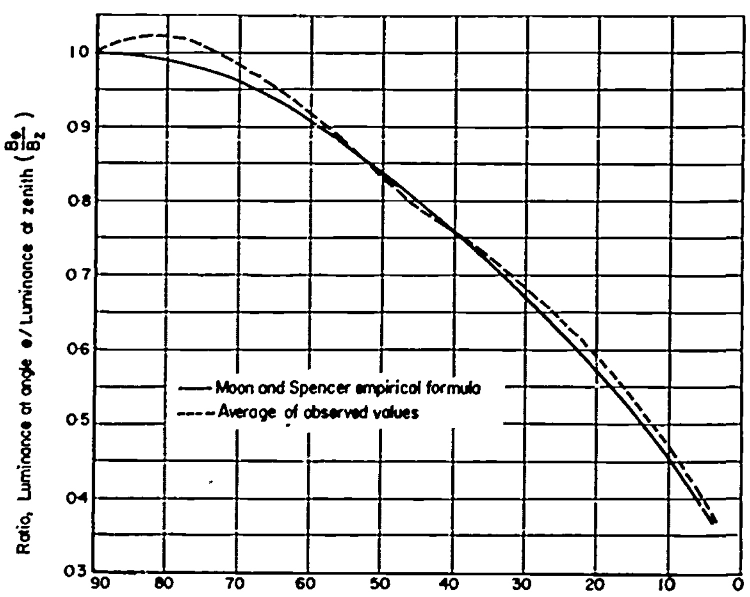
Under overcast sky conditions the orientation of the windows does not play an important part in the design of schools, as the lighting available from an overcast sky is more or less the same in every direction. However, overcast sky conditions are experienced for only about 11 per cent of the total number of school hours in the year in Pretoria and for about 14 per cent in Cape Town. Consequently, for most of the time there will be direct sunlight because the sky will be either clear or intermittently cloudy. This presents serious glare problems which can only be eliminated effectively and economically by the correct orientation and planning of classrooms. This aspect will be dealt with in detail later in the report.

Equal in importance to the sky illumination value in the lighting design of a building is the sky luminance distribution which controls the penetration of daylight into a room. Sky luminance distributions for Pretoria were, therefore, also noted during the three years when daylight was being measured.

Average luminance distributions deduced for Pretoria for overcast and clear sky conditions are given in Figures 6, 7 (a) and 7 (b). Spot readings taken in Cape Town under both summer and winter conditions have shown that these distributions apply equally well in the

FIGURE 6

Comparison of average measured luminance distribution for overcast skies with the empirical distribution given by the moon and Spencer formula



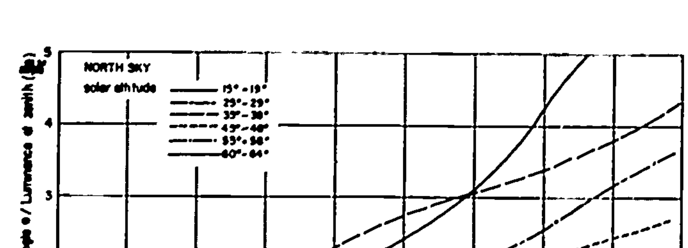


FIGURE 7(a)

Average clear sky luminance distribution curves for the northern half of the sky with the sun at different altitudes

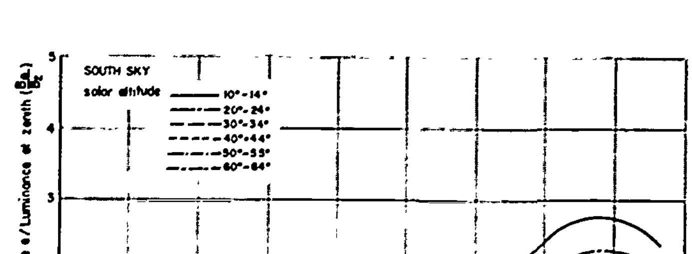


FIGURE 7(b)

Average clear sky luminance distribution curves for the southern half of the sky with the sun at different altitudes winter rainfall area. From this it seems reasonable to infer that the distributions determined for highveld conditions can be applied with a fair degree of accuracy to all regions in the country.

It will be observed from the results plotted in Figure 6 that the luminance distribution found for overcast sky conditions agrees fairly well with the distribution calculated from the Moon and Spencer empirical equation[24] which has been adopted internationally.

(b) **Relationship between outdoor and indoor illumination**

The next step in the lighting design of buildings is to establish the relationship between outdoor and indoor illumination. In this connection it is customary to express indoor illumination at any point in a room in terms of the coincident outdoor illumination. The ratio of indoor to outdoor illumination, expressed as a percentage, is generally referred to as the daylight-factor[35, 24]. The most convenient form for expressing this factor is:

$$K = \frac{E_i}{E_{ov}} \times 100 \quad \ldots\ldots\ldots\ldots \quad (1)$$

where

K =daylight-factor, percentage,

E_i =internal illumination at any point in a room, expressed in lumens/sq ft, and

E_{ov}=total outdoor illumination on a vertical plane measured at the centre of the window also expressed as lumens/sq ft.

For a more accurate determination of indoor illumination, however, the total outdoor illumination on the vertical window-plane should be separated into its two components, viz., sky illumination only, E_{ovs}, and the component reflected from the ground, E_{ovg}. The daylight-factor can then be expressed in the form:

$$K = \frac{E_i}{E_{ovs} + E_{ovg} \times 100} \quad \ldots\ldots\ldots\ldots \quad (2)$$

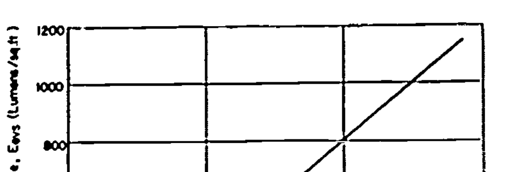


FIGURE 8

Average relationship between illumination on a horizontal surface (E_{oh}) and on a vertical surface (E_{ovs}) for overcast sky conditions

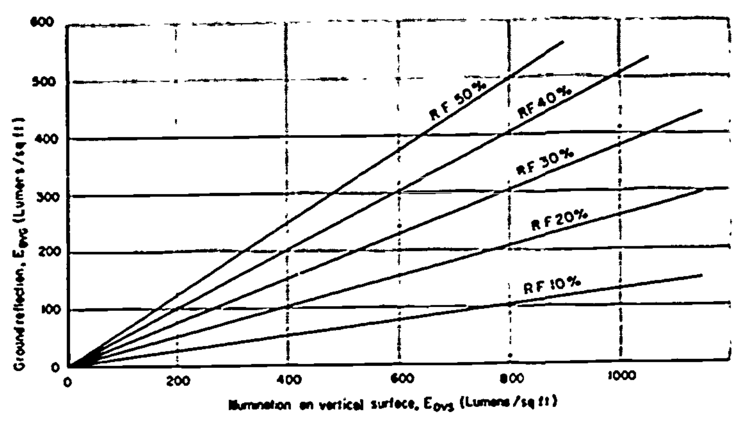


FIGURE 9

Relationship between illumination on a vertical surface (E_{ovs}) and the light reflected from the ground (E_{ovg}) with different surface reflection-factors (R.F.) for overcast sky conditions

The outdoor illumination intensities used in equations (1) and (2) refer to the intensities measured in the vertical plane, whereas the design sky illumination values refer to those measured in a horizontal plane. For an overcast sky the relationship between the illumination values on a horizontal plane and those on a vertical plane has been determined experimentally for Pretoria and is given in Figure 8. In the same way the relationships between the vertical sky component, E_{ovs}, and the ground component, E_{ovg}, have been determined for different ground surfaces and are given in Figure 9.

It will be seen that the ground component increases linearly with the sky component and that the rate of increase is determined by the reflection-factor of the ground surface. The higher the reflection-factor, the greater the contribution of light reflected from the ground. Examples of the reflection-factors of a few typical surfaces are listed in Table 7.

TABLE 7

Reflection-factors of ground surfaces

Surface	Reflection-factor (per cent)
Soil, dark-brown sandy loam	10—12
Tarmac	10—13
Grass, green	13—18
Grass, dry (in winter)	23—28
Soil, yellow sandy loam	25—29
Concrete paving	45—53

In this connection it is interesting to note that, in the case of single-storey buildings, it is only the ground within a distance of about 80 ft from the windows that contributes significantly to the interior illumination on the horizontal working-plane.

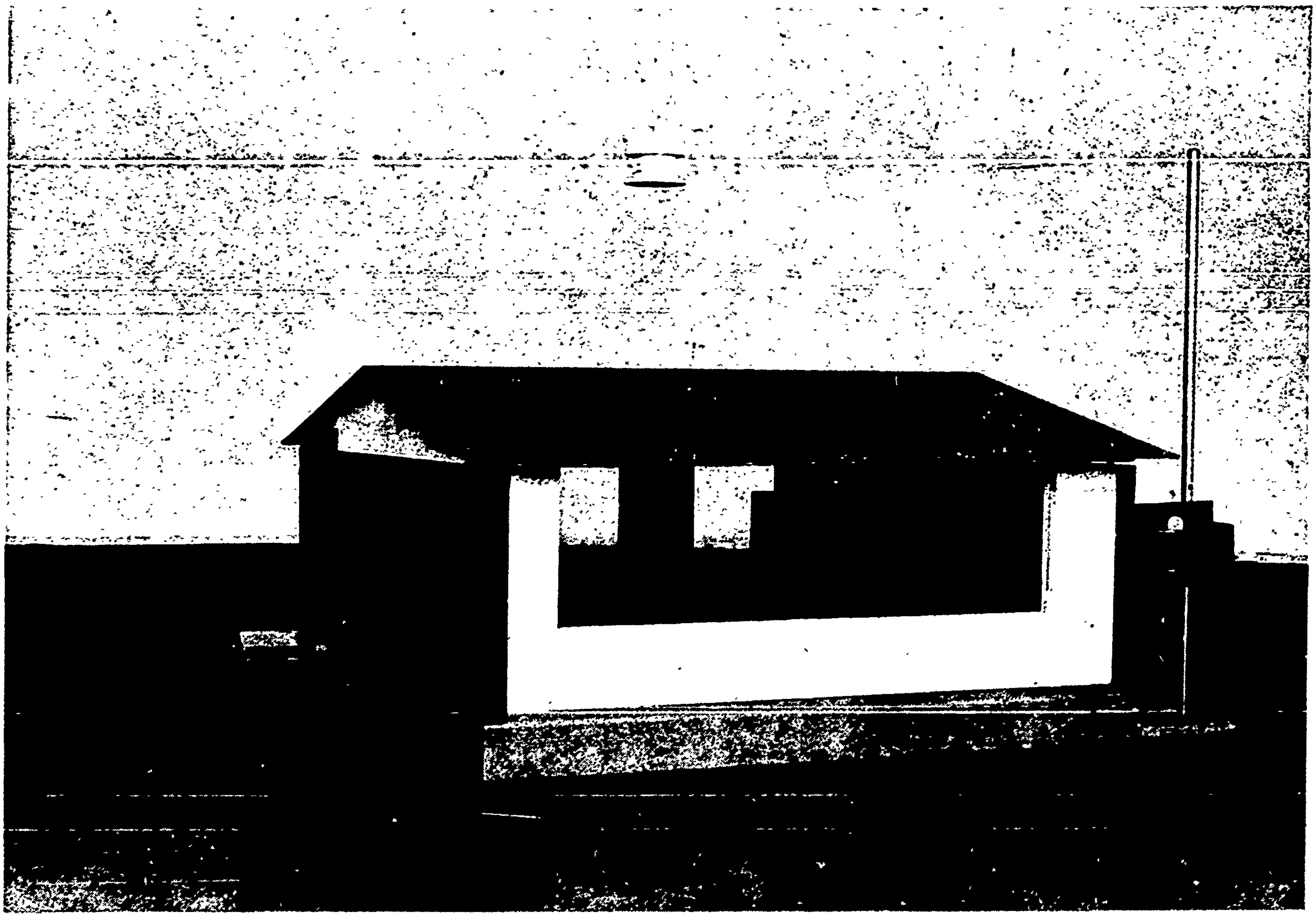


FIGURE 10
Scale model of classroom under artificial sky

(c) Scale model studies

An extensive series of measurements was carried out on scale models under the artificial sky[29], as well as on full-scale buildings under natural sky conditions, in order to determine the influence, on interior illumination levels and distribution, of such factors as size, shape and position of windows, ceiling height, and external obstructions in the form of adjacent buildings, trees and various sun control devices.

A typical scale model used for these tests is shown in Figure 10. This particular model, in which the window openings were glazed with 24-oz clear glass for all tests, represents a classroom 22.5 ft wide by 27 ft long and 9 ft high with an 8-ft roof-overhang on one side and a 2-ft overhang on the other. The model was also modified to represent either the open type of corridor classroom typical in the Transvaal and Orange Free State, or the closed-in type generally found in schools in the Cape Province. The internal surfaces of the model were painted in the different colours, the reflection-factors of which are indicated in Table 8.

TABLE 8

Reflection-factors of different colours used in scale model classroom

Surface	Colour	Reflection-factor (per cent)
Ceiling	White	80
Window walls	White	80
Back wall	White	80
Chalk-board wall ..	Light green	50
Chalk-board	Dark green	17
Floor	Dark grey	20
"Ground"	Dark green	20

(i) *Influence of window size, shape and position on interior illumination*

To determine the influence of window size on indoor illumination, the area of each of the main and corridor window openings was varied independently. During the first series of tests the window opening in the corridor wall was blocked off, whilst the area of the main window was varied from a maximum size of 20 ft wide by 6 ft high to a minimum size of 12 ft wide by 4 ft high. There-

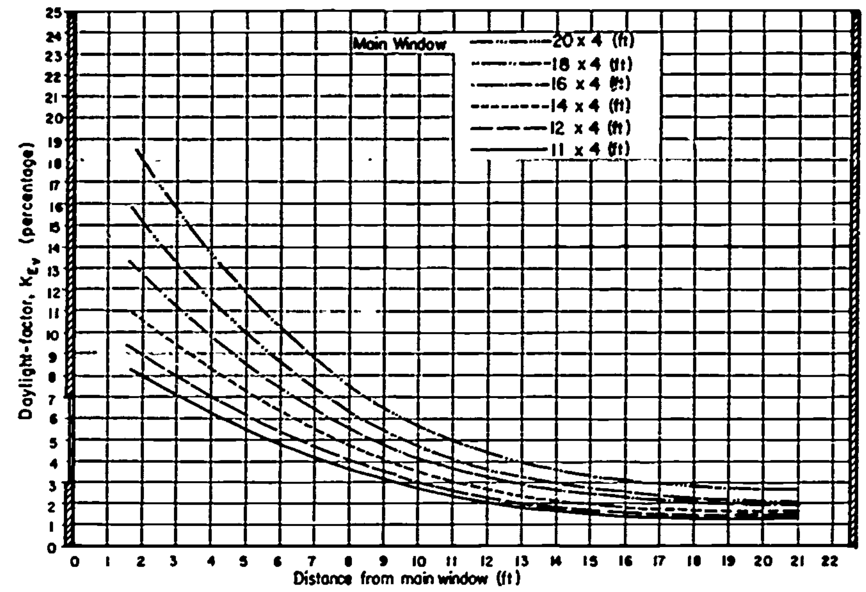


FIGURE 11(a)

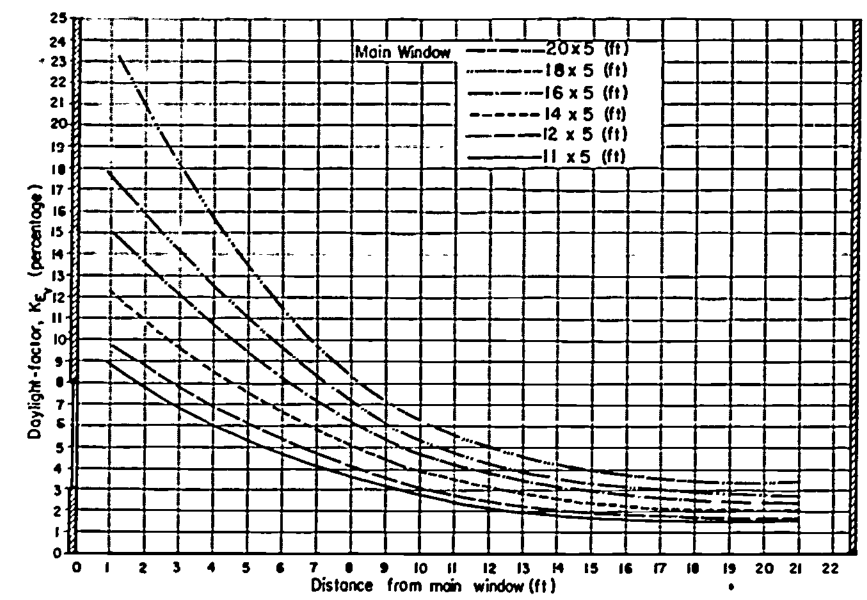


FIGURE 11(b)

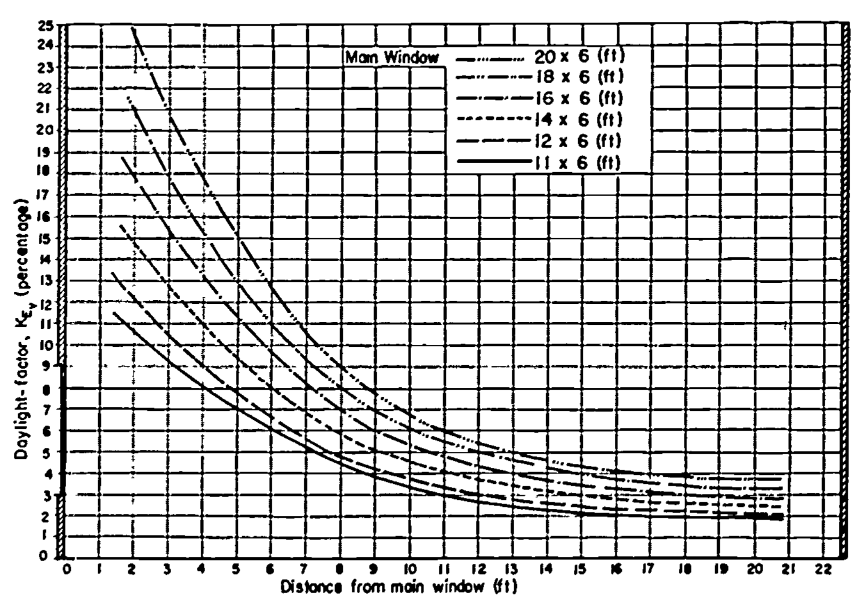


FIGURE 11(c)

FIGURES 11(a), 11(b), 11(c).

Variation of daylight-factor with distance from window for different sizes of main window in both open and closed-in corridor type classrooms, 22 ft 6 in wide

FIGURE 12(a)

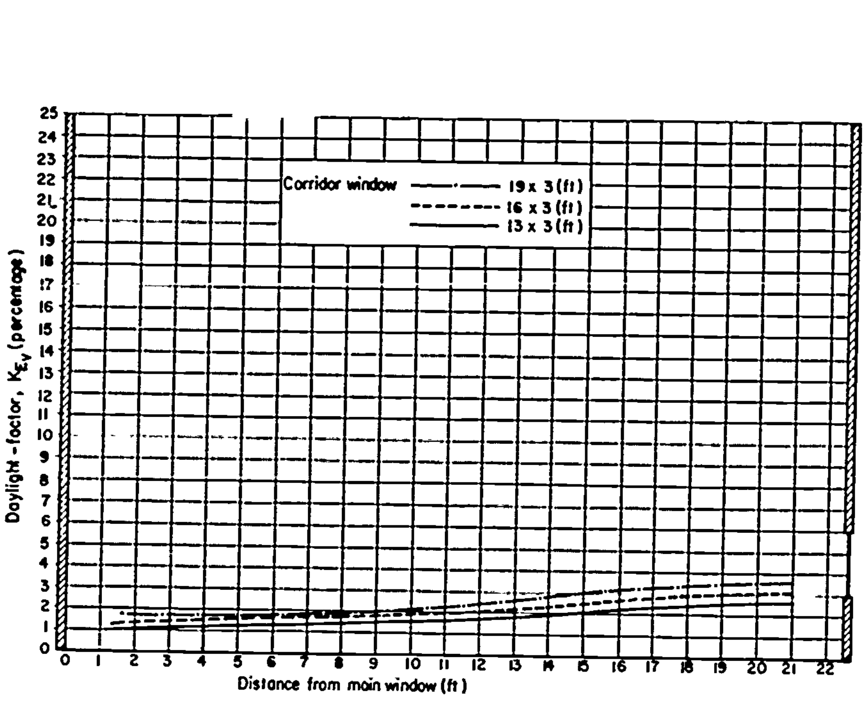


FIGURE 12(b)

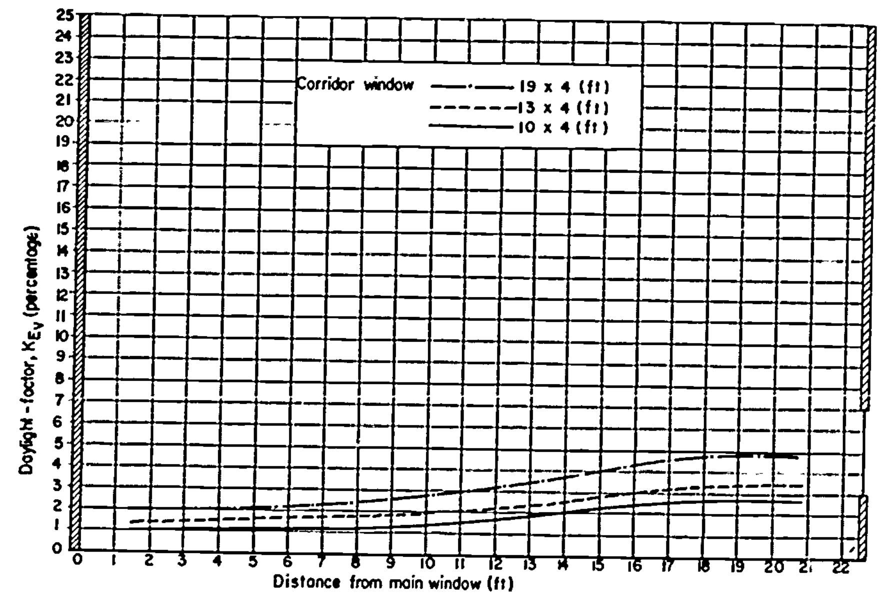
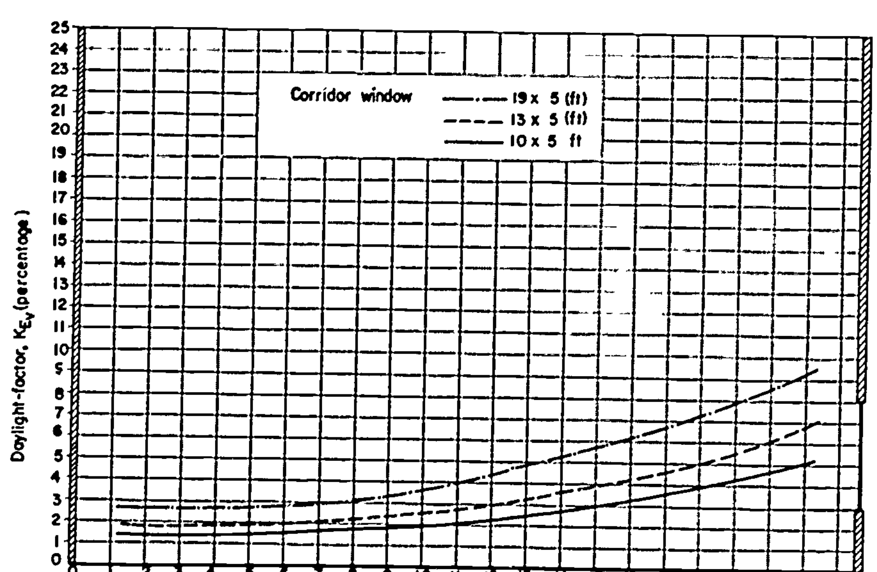


FIGURE 12(c)



FIGURES 12(a), 12(b), 12(c).

Variation of daylight-factor with distance from window for different sizes of corridor window in open corridor type classrooms, 22 ft 6 in wide after the main window was blocked off and the same procedure was repeated for the corridor window. In this case the window size was varied from 19 ft wide by 5 ft high to 13 ft wide by 3 ft high. The results of these tests are reproduced in Figures 11 (a), (b) and (c) and 12 (a), (b) and (c), respectively. In these figures the daylight-factor at desk-level is plotted against the distance of the point of observation from the particular window.

Similar tests were conducted on a closed-in type of corridor classroom, but here it was only necessary to vary the areas of the internal and external corridor windows independently of each other since the results given in Figures 11 (a), (b) and (c) for the main window in the open type of corridor classroom still applied. All the results of this investigation are given in Figures 13 (a) to (i).

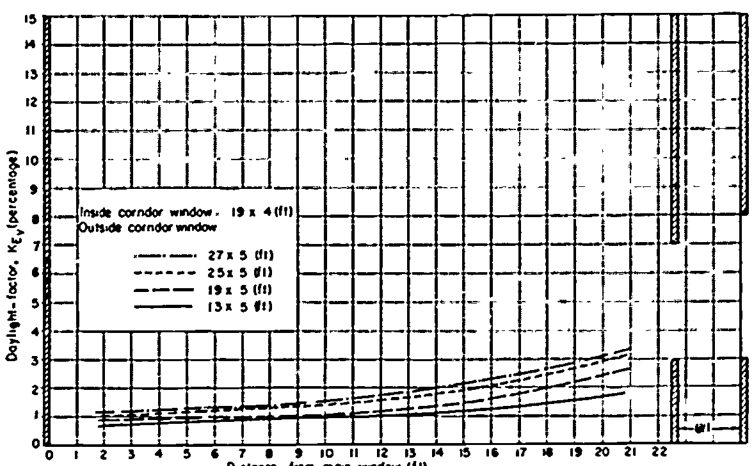


FIGURE 13(a)

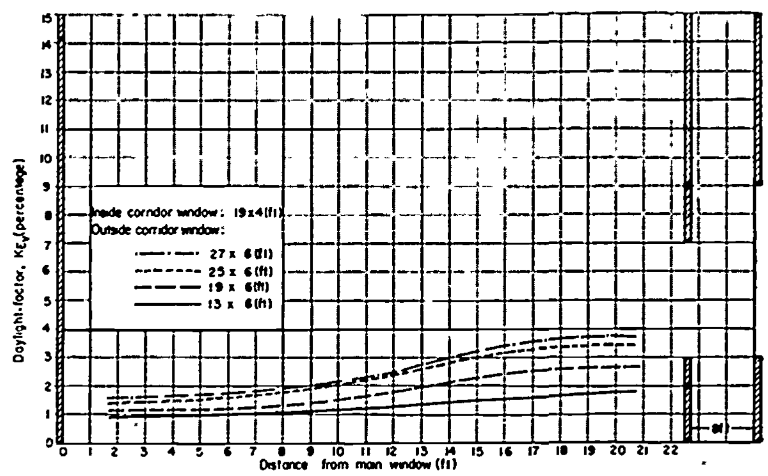


FIGURE 13(b)

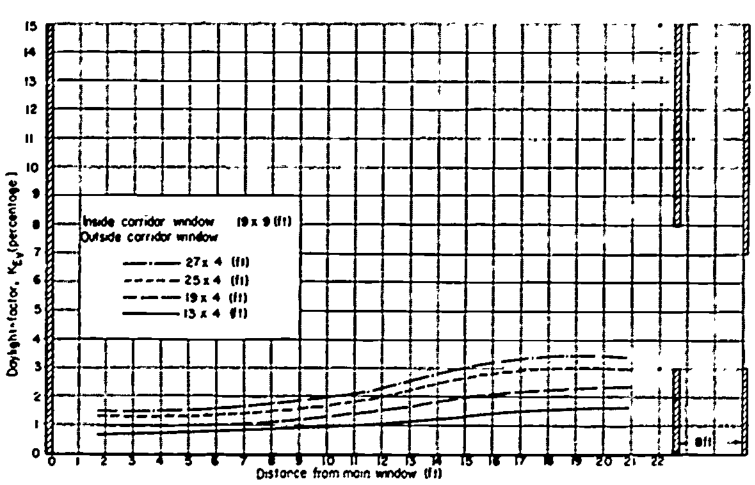


FIGURE 13(c)

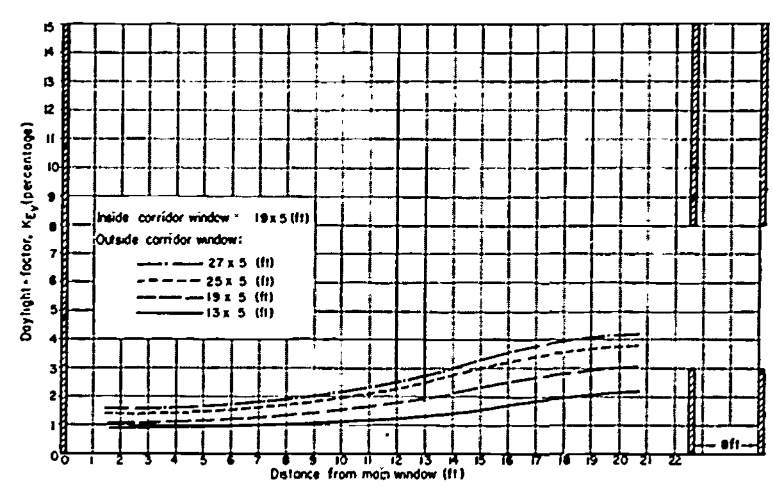


FIGURE 13(d)

FIGURES 13(a)—13(e).
Variation of daylight-factor with distance from window for different sizes of corridor windows in closed-in corridor type classrooms, 22 ft 6 in wide

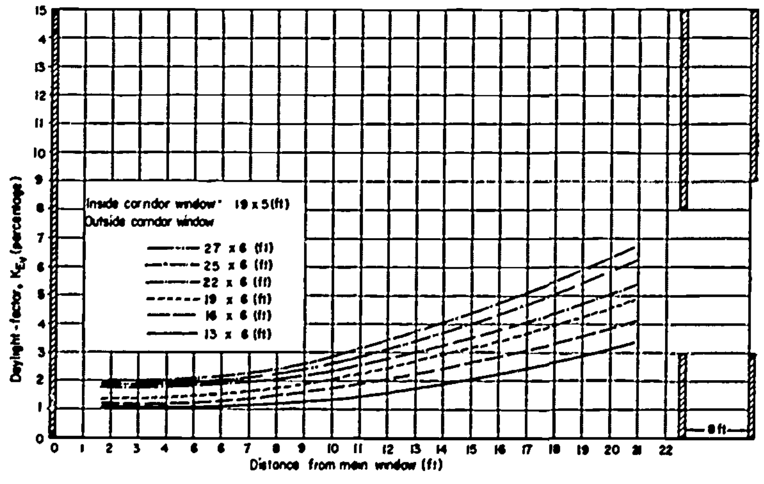


FIGURE 13(e)

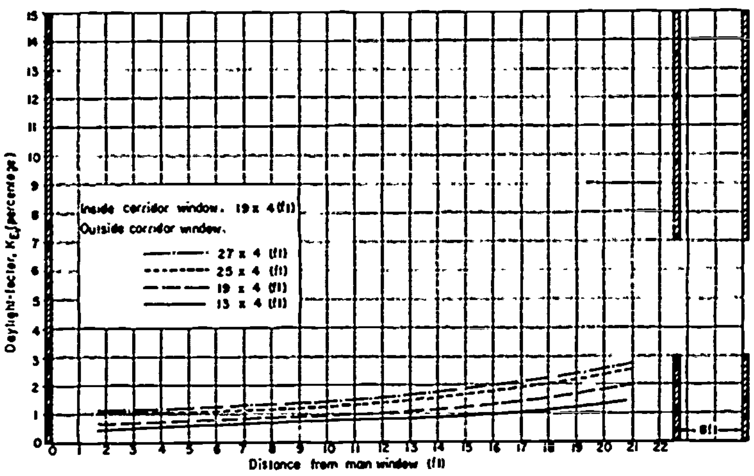


FIGURE 13(f)

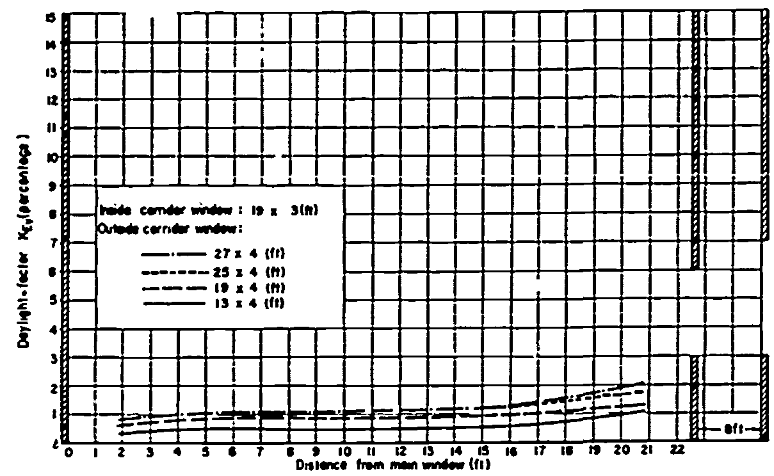


FIGURE 13(g)

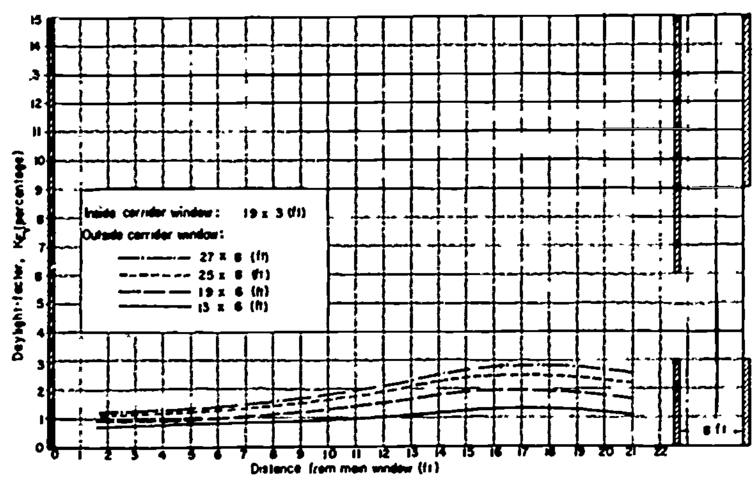


FIGURE 13(h)

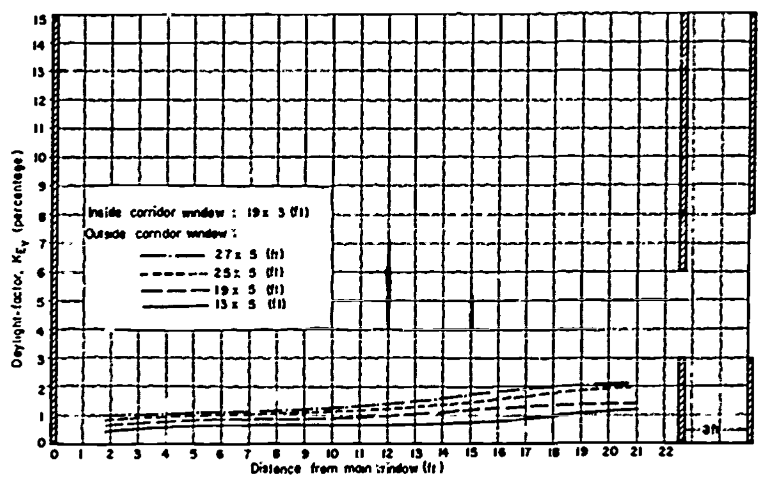


FIGURE 13(i)

FIGURES 13(f)—13(i)

Variation of daylight-factor with distance from window for different sizes of corridor windows in closed-in corridor type classrooms, 22 ft 6 in wide

Although the curves given in these Figures were obtained with a model representing a classroom 22.5 ft wide, the curves can be extended with a good degree of accuracy to cover rooms wider than this.

An example will now be worked out in order to illustrate how the information given in Figures 11 to 13 can be used in practice for the daylighting design of classrooms.

Consider an open type of corridor classroom, 22.5 ft wide, requiring a minimum illumination level, anywhere in the classroom excluding the first 2 ft from the outer walls, of not less than 20 lumens/sq ft and a distribution of maximum to minimum illumination of not more than 3 : 1. The first 2 ft are excluded because there will be no desks within this distance from the walls.

The corresponding daylight-factor can be calculated from equation (2) by substituting the appropriate values for E_{ovs} and E_{ovg} as given in Figures 8 and 9 respectively. For instance, for a ground reflection of 20 per cent and a design sky illumination value of 1 000 lumens/sq ft, the corresponding daylight-factor amounts to 4 per cent.

From Figure 11 (a) it will be seen that none of the window sizes tested will provide a daylight-factor of 4 per cent throughout the classroom. The best that can be achieved is a daylight-factor of 4 per cent up to a depth of just over 16 ft with a main window of 20 ft wide by 6 ft high. Even then, the distribution of maximum to minimum illumination will be far in excess of the maximum permissible ratio of 3 : 1. It is thus evident that the minimum lighting requirements cannot be obtained with unilateral lighting only. Windows will have to be provided in the corridor wall as well.

Superimposing the contribution of the corridor windows given in Figure 12 (a) on that of the main windows given in Figure 11 (a), the total contribution of various

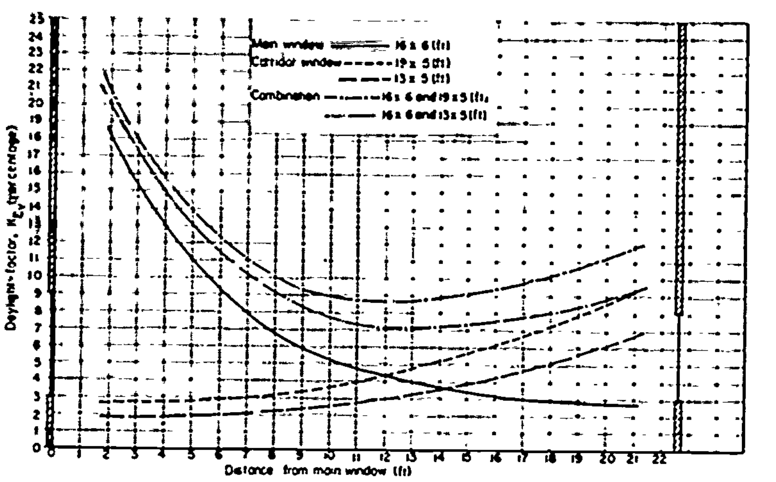


FIGURE 14

Variation of daylight-factor with distance from window for combinations of main and open corridor windows

combinations of main and corridor windows can easily be determined. The procedure is illustrated in Figure 14 in which case the size of the main window is fixed at 16 ft wide by 6 ft high, whereas two sizes of corridor window are considered, viz., 19 ft wide by 5 ft high and 13 ft wide by 5 ft high, respectively. Adding the respective contributions of main and corridor windows shows that both combinations, i.e., a main window 16 ft × 6 ft together with a corridor window 19 ft × 5 ft, and a main window 16 ft × 6 ft together with a corridoi window 13 ft × 5 ft, more than satisfy the minimum illumination requirement of a daylight-factor of 4 per cent. In fact, the minimum daylight-factor with the first combination exceeds 8 per cent and with the latter combination 7 per cent, which means that the minimum illumination intensity will be of the order of 40 and 35 lumens/sq ft, respectively, as compared with the minimum requirements of 20 lumens/sq ft. The distribution of maximum to minimum illumination amounts to 2.4 : 1 and 2.8 : 1, respectively, for the two window combinations under consideration. Both ratios fall within the requirement, i.e., a maximum ratio of 3 : 1. The lower ratio would, however, be given preference.

Reference has been made to the fact that the lighting of the chalk-board should also conform to certain minimum standards, viz., an absolute minimum illumination level of not less than 20 lumens/sq ft and a ratio of maximum to minimum illumination not exceeding 3 : 1. Both combinations of windows considered above comply with these requirements. In the case of the 16 ft × 6 ft main window together with the 19 ft × 5 ft corridor window the illumination levels on the chalk-board were found to vary from 42 lumens/sq ft near the main window to 30 lumens/sq ft on the corridor side. With the 16 ft × 6 ft and 13 ft × 5 ft combination, the corresponding variation was from 40 to 26 lumens/sq ft. Comparing the illumination levels on the chalk-board surface with those on the horizontal surface, it will be seen that the latter values are on the average about 25 per cent higher. This emphasizes the very important fact that, unless this is unavoidable, window sizes should not be selected merely to comply with minimum illumination requirements on the desks because, if they are, the chalk-board lighting will be inadequate under design sky conditions. This could, however, be overcome by supplementary artificial illumination of chalk-boards which will be discussed in subsequent paragraphs.

In order to simplify the design procedure, suitable combinations of main and corridor window sizes are listed in Tables 9, 10 (a) and 10 (b) for standard* open and closed-in type corridor classrooms 22.5 ft wide by 9 ft high, respectively. The window sizes, ranging from maximum to minimum sizes of main window or corridor window(s), given in these Tables were selected to give adequate illumination not only on the horizontal working-plane but also on the chalk-board surfaces under the respective design overcast sky conditions, viz., 1 000 lumens/sq ft in the case of the open corridor type classroom used so extensively in the Transvaal, Orange Free State and other inland areas, and 750 lumens/sq ft in the case of the closed-in corridor type classroom favoured in the winter rainfall areas of the Cape Province.

For rooms wider than 22.5 ft, larger window areas will, of course, be required. As a general rule it is recommended that window sizes be increased by 5 per cent, preferably in height, for every foot increase in room width up to a maximum width of approximately 30 ft. Rooms wider than 30 ft will require special attention. An increase in room length requires a corresponding increase in window areas.

It should be borne in mind that the window sizes given in these Tables refer to overall sizes or total glass area. In practice, it would be better from the point of view of light distribution to split the single widths into different smaller units which can be distributed more evenly over the wall lengths. The shape of the individual units is not very important except that glazing-bars should be as slender as possible and limited in number because, if they are not, they will affect lighting detrimentally and result in excessive luminance contrasts. The positioning of windows in relation to the chalk-board wall is extremely important. No window should be less than about 2 ft from the wall containing the chalk-board. This does

* By 'standard' is meant an 8-ft roof-overhang in the case of the open corridor classroom, and a corridor width of 6 to 7 ft in the case of the closed-in corridor type classroom.

TABLE 9

Suitable window sizes (in ft) for Transvaal and Orange Free State schools (classrooms 22 ft 6 in wide, and no external obstructions)

(Design sky 1 000 lumens/sq ft)

Main window	Corridor window
22×6	19×5
21×6	19×5
20×6	19×5
	16×5
19×6	19×5
	16×5
18×6	19×5
	16×5
	13×5
17×6	19×5
	16×5
	13×5
	19×4
16×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
15×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	19×3
14×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	10×4
	19×3
	16×3

Main window	Corridor window
13×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	10×4
	19×3
	16×3
12×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
11×6	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
22×5	19×5
21×5	19×5
	16×5

Main window	Corridor window
20×5	19×5
	16×5
	13×5
	19×4
19×5	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
18×5	19×5
	16×5
	13×5
	10×5
	16×3
	16×4
	13×4
	10×4
	19×3
	16×3
17×5	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	10×4
	19×3
	16×3
16×5	19×5
	16×5
	13×5
	10×5
	19×4

Main window	Corridor window
16×5	16×4
	13×4
	10×4
	19×3
	16×3
	13×3
15×5	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	10×4
	19×3
	19×4
	13×3
14×5	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
13×5	19×5
	16×5
	13×5
	19×4
	16×4
	19×3
12×5	19×5
	16×5
	13×5
	19×4

Main window	Corridor window
12×5	16×4
	19×3
11×5	19×5
	16×5
	13×5
	19×4
	16×4
22×4	19×5
	16×5
21×4	19×5
	16×5
	19×4
20×4	19×5
	16×5
	13×5
	19×4
	16×4
19×4	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	19×3
18×4	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
17×4	19×5
	16×5
	13×5
	10×5

Main window	Corridor window
17×4	19×4
	16×4
	13×4
	19×3
	16×3
16×4	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
15×4	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
14×4	19×5
	16×5
	13×5
	10×5
	19×4
	16×4
	13×4
	19×3
	16×3
13×4	19×5
	16×5
	13×5

Main window	Corridor window
13×4	19×4
	16×4
	19×3
12×4	19×5
	16×5
	13×5
	19×4
	16×4
	19×3
11×4	19×5
	16×5
	13×5
	19×4
	16×4
	19×3

TABLE 10 (a)

Suitable window sizes (in ft) for schools in the Cape Province (classrooms 22 ft 6 in wide, and no external obstructions)
(Design sky 1 000 lumens/sq ft)

Main window	Inside corridor window	Outside corridor window
19×6	19×5	27×6
18×6	19×5	27×6
		25×6
17×6	19×5	27×6
		25×6
		22×6
16×6	19×5	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
	19×4	27×6
15×6	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		27×4
	19×4	27×6
		25×6
14×6	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
14×5	19×4	25×6
		22×6
		19×6
		27×5
		25×5
		22×5
		27×4
	19×3	27×6
		25×6
	15×3	27×6
13×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
		27×3
	19×4	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
	19×3	27×6
		25×6
12×5	19×5	27×6
		25×6
		22×6
		19×6

Main window	Inside corridor window	Outside corridor window
14×6	19×4	27×6
		25×6
		22×6
13×6	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
	19×4	27×6
		25×6
		22×6
		27×5
12×6	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		13×6
		27×5
		25×5
		22×5
		19×5
		16×5
		27×4
		25×4
		22×4
		27×3
	19×4	27×6
12×5	19×5	16×6
		27×5
		25×5
		22×5
		27×4
		25×4
	19×4	27×6
		25×6
		22×6
		27×5
	19×3	27×6
11×5	19×5	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
		22×5
		27×4
	19×4	27×6
		25×6
	19×3	27×6
22×4	19×5	27×6
		25×6
		22×6
		19×6
		27×5
21×4	19×5	27×6
		25×6
		22×6
		19×6
		27×5
20×4	19×5	27×6
		25×6

Main window	Inside corridor window	Outside corridor window
12×6	19×4	25×6
		22×6
		19×6
		27×5
	19×3	27×6
11×6	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		16×5
		27×4
		25×4
		22×4
		27×3
	19×4	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
	19×3	27×6
		25×6
22×5	19×5	27×6
		25×6
21×5	19×5	27×6
20×5	19×5	27×6
		25×6
19×5	19×5	27×6
		25×6
20×4	19×5	22×6
		19×6
		27×5
	19×4	27×6
19×4	19×5	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
	19×4	27×6
		25×6
18×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		27×4
	19×4	27×6
		25×6
17×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4

Main window	Inside corridor window	Outside corridor window
19×5	19×5	22×6
		19×6
		16×6
		27×5
		25×5
		22×5
	19×4	27×6
18×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
	19×4	27×6
		25×6
		22×6
		27×5
17×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		27×4
		25×4
	19×4	27×6
		25×6
17×4	19×4	27×6
		25×6
		22×6
16×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		13×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
		22×4
	19×4	27×6
		25×6
		22×6
		19×6
		27×5
	19×3	27×6
15×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		19×5
		27×4
		25×4
		27×3
	19×4	27×6

Main window	Inside corridor window	Outside corridor window
17×5	19×4	22×6
		27×5
16×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		13×6
		27×5
		25×5
		22×5
		19×5
		16×5
		27×4
		25×4
		22×4
		27×3
	19×4	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
	19×3	27×6
15×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		13×6
		27×5
		25×5
		22×5
		19×5
15×4	19×4	25×6
		22×6
		19×6
		27×5
		25×5
		27×4
14×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		27×4
		25×4
	19×4	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
13×4	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		27×4
		25×4
	19×4	27×6

Main window	Inside corridor window	Outside corridor window
15×5	19×5	16×5
		27×4
		25×4
		22×4
		19×4
		27×3
	19×4	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		27×4
		25×4
		22×4
	19×3	27×6
14×5	19×5	27×6
		25×6
		22×6
		19×6
		16×6
		27×5
		25×5
		22×5
		19×5
		16×5
		27×4
		25×4
		22×4
		27×3
		25×3
	19×4	27×6
13×4	19×4	25×6
		22×6
		27×5
12×4	19×5	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
		22×5
		27×4
	19×4	27×6
		25×6
11×4	19×5	27×6
		25×6
		22×6
		19×6
		27×5
		25×5
		27×4
	19×4	27×6
		25×6

TABLE 10 (b)

Suitable window sizes for schools in the Cape Province (classrooms 22 ft 6 in wide, and no external obstructions)
(Design sky condition 750 lumens/sq ft)

Main window	Inside corridor window	Outside corridor window	Main window	Inside corridor window	Outside corridor window	Main window	Inside corridor window	Outside corridor window	Main window	Inside corridor window	Outside corridor window	Main window	Inside corridor window	Outside corridor window
19×6	19×5	27×6	13×6	19×5	27×5	18×5	19×4	27×6	14×5	19×5	27×6	18×4	19×5	27×4
18×6	19×5	27×6			25×5			25×6			25×6		19×4	27×6
		25×6		19×4	27×6			22×6	13×5	19×5	27×6			25×6
17×6	19×5	27×6	12×6	19×5	27×6			27×5			25×6	17×4	19×5	27×6
		25×6			25×6	17×5	19×5	27×6	12×5	19×5	27×6			25×6
		22×6			22×6			25×6	22×4	19×5	27×6			22×6
16×6	19×5	27×6			27×5			22×6			25×6			27×5
		25×6		19×4	27×6			19×6			22×6			25×5
		22×6	11×6	19×5	27×6			27×5			19×6		19×4	27×6
		19×6			25×6			25×5			27×5	16×4	19×5	27×6
		27×5	22×5	19×5	27×6			22×5	21×4	19×5	27×6			25×6
		25×5			25×6			27×4			25×6			22×6
	19×4	27×6	21×5	19×5	27×6		19×4	27×6			22×6			27×5
15×6	19×5	27×6	20×5	19×5	27×6			25×6			19×6			25×5
		25×6			25×6			22×6			27×5		19×4	27×6
		22×6	19×5	19×5	27×6	16×5	19×5	27×6	20×4	19×5	27×6	15×4	19×5	27×6
		19×6			25×6			25×6			25×6			25×6
		16×6			22×6			22×6			22×6	14×4	19×5	27×6
		27×5			19×6			19×6			19×6			25×6
		25×5			16×6			27×5			27×5	13×4	19×5	27×6
		27×4			27×5			25×5		19×4	27×6			
	19×4	27×6			25×5			22×5	19×4	19×5	27×6			
		25×6			22×5			27×4			25×6			
14×6	19×5	27×6		19×4	27×6		19×4	27×6			22×6			
		25×6	18×5	19×5	27×6			25×6			19×6			
		22×6			25×6		19×3	27×6			27×5			
		19×6			22×6	15×5	19×5	27×6			25×5			
		27×5			19×6			25×6		19×4	27×6			
		25×5			16×6			22×6			25×6			
		27×4			27×5			19×6	18×4	19×5	27×6			
	19×4	27×6			25×5			27×5			25×6			
		25×6			22×5			25×5			22×6			
13×6	19×5	27×6			19×5			27×4			19×6			
		25×6			27×4		19×4	27×6			27×5			
		22×6			25×4			25×6			25×5			

not, of course, apply to fanlights above doors, because these are normally protected by large roof-overhangs. In fact, fanlights are very useful for increasing the lighting intensity on chalk-boards, particularly if they can be extended right up to the chalk-board wall.

It must be stressed again that, although the orientation of windows is not very important under overcast conditions, it is of prime importance under cloudy or clear sky conditions. Unless the main windows can be protected from direct sunlight, it is preferable for them to face either south or, if the room is not occupied during the afternoon, west. Furthermore, the minimum window areas given in Tables 9, 10 (a) and 10 (b) only apply to cases where there are no external obstructions. The extent to which these minimum areas should be increased to allow for the effects of obstructions will be discussed later.

The recommended minimum window sizes for rooms other than classrooms, such as offices and the different rooms encountered in school hostels, are given in Table 11. In this connection it should be pointed out that the proper distribution of daylight may not always be feasible and that in many instances artificial lighting will have to be considered. Nevertheless, this does not imply that the quality of the lighting can, or should, be overlooked. For instance, particular attention should still be given to the control of glare.

TABLE 11

Minimum recommended window sizes for rooms, other than classrooms, work-rooms and laboratories

Room	Window sizes given as a percentage of the floor area
Bedrooms, dining-rooms	10
Living-rooms..	15
Bathrooms	10
Kitchens and laundries	15
Study halls	20
Offices	20

(ii) *Influence of ceiling height on interior illumination*

The influence of ceiling height on interior illumination under overcast conditions is illustrated in Figures 15 (a) and 15 (b) for the two combinations of window

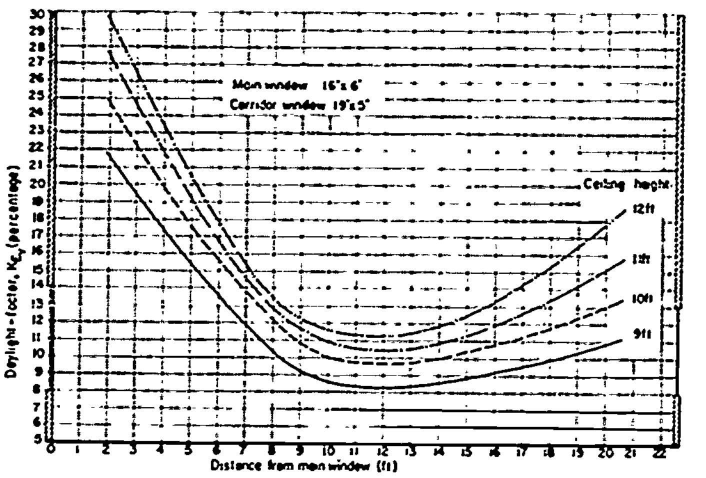


FIGURE 15(a)

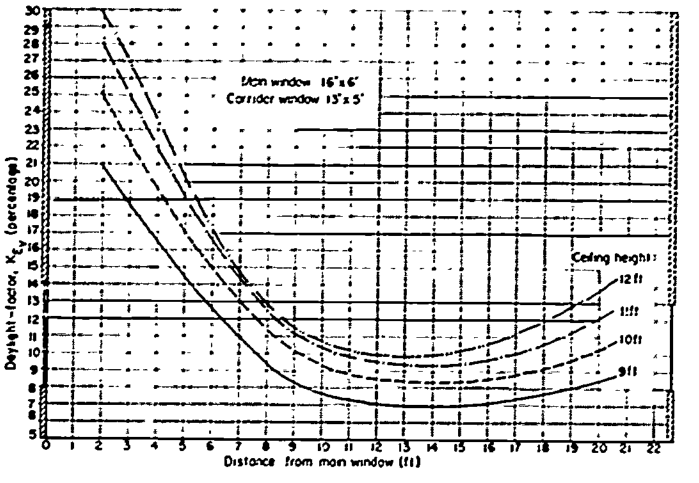


FIGURE 15(b)

FIGURES 15(a), 15(b).
Influence of ceiling height and overhang height on interior illumination for two different combinations of main and corridor windows

sizes considered previously, viz., main window 16 ft× 6 ft and corridor window 19 ft×5 ft, and main window 16 ft×6 ft and corridor window 13 ft×5 ft, respectively. The results plotted in these Figures were obtained under the artificial sky with the model open corridor classroom on a dark green base. The positions of the windows remained unaltered during all tests and only the heights of the ceiling and overhangs were changed.

It will be seen that ceiling heights and, more particularly, overhang heights have a pronounced influence on interior illumination. A change in the heights of the ceiling and overhang from 9 ft to 12 ft resulted, for instance, in an increase in illumination in the centre of the classroom of about 36 and 42 per cent, respectively, for the two combinations of window sizes tested. This is explained not only by the fact that the higher the ceiling the greater the contribution of light reflected from the ground adjacent to the window walls but also by the more significant fact that the screening effects of roof-overhangs dwindle the higher the overhangs are above the windows. It was shown that, when the ceiling was raised but the overhang height kept constant, the indoor illumination increased far less proportionately than it did when both ceiling and overhang heights were raised. This proves that the expense involved in having a higher ceiling is not warranted on the grounds of improved indoor illumination. As has been pointed out elsewhere[37], a ceiling height of 9 ft is considered more than adequate for classrooms of normal size.

(iii) *Influence of external obstructions and various sun control devices on interior illumination*

Typical examples of the pronounced screening effects of external obstructions, in the form of neighbouring

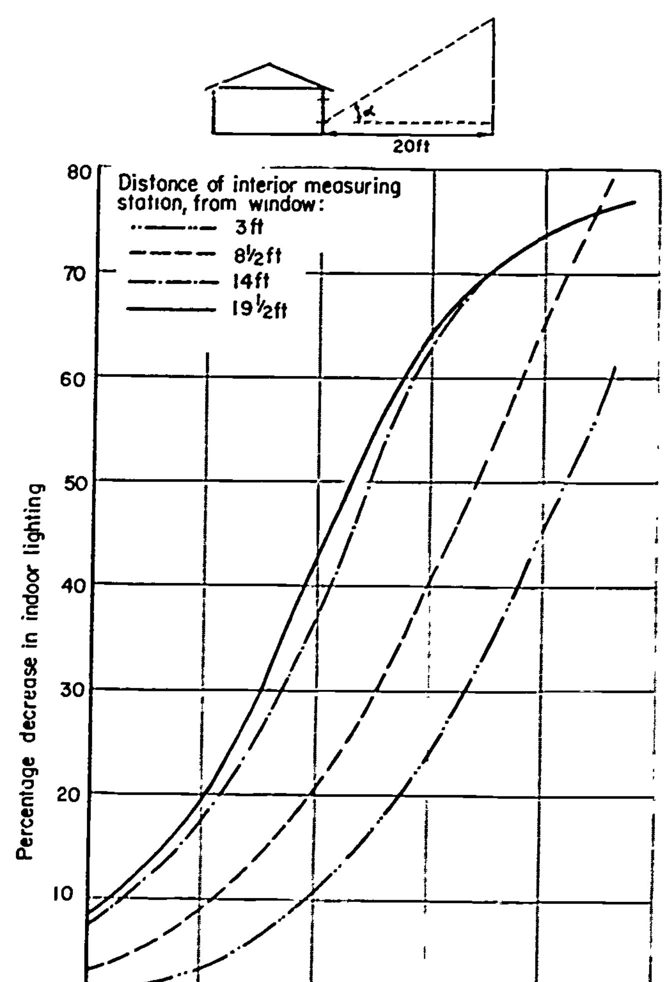


FIGURE 16
Influence of external obstructions in the form of a neighbouring building, 20 ft from window wall, on indoor lighting under overcast conditions

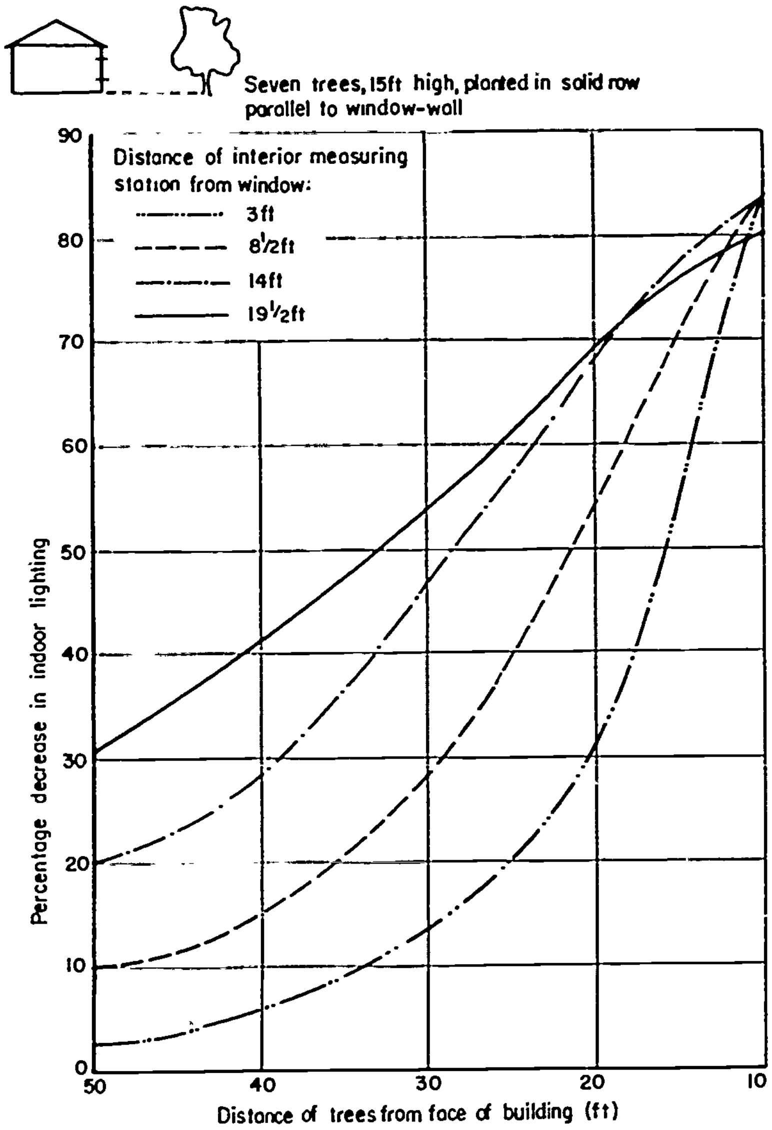


FIGURE 17

Influence of external obstructions in the form of trees on indoor lighting under overcast conditions

buildings and trees, on interior illumination on the horizontal working-plant in the case where windows are provided in the wall facing the obstruction only, are shown in Figures 16 and 17, respectively.

The extent to which window areas should be increased to compensate for the average loss in lighting intensity throughout a classroom due to solid external obstructions is given in Figure 18 for open corridor type classrooms with a roof-overhang of 8 ft on the corridor side. Although not strictly applicable, it is felt that, in practice, the same corrections may be applied to closed-in corridor type classrooms.

Since trees can serve a very useful purpose in controlling sky luminance and in providing shade in warm areas[37], they should preferably be planted in rows at right angles to the window walls and not parallel to them. If planted in this manner, their adverse effect on both lighting and natural ventilation will be limited. Similarly, right-angled screen walls have very little influence on indoor lighting.

Roof-overhang. The influence of roof-overhang on interior illumination under overcast conditions is illustrated in Figure 19.

As can be expected, the length of the overhang is of far greater importance than the colour of the overhang, although the lighter the colour the higher the indoor lighting intensities will be.

Sun-control Devices. In cases where control of direct sunlight is essential, the effect of the specific sun control device on interior illuminations should be taken into account because it can lead to serious reductions in indoor illumination. The many ways of controlling sunlight make it quite impossible, however, to lay down

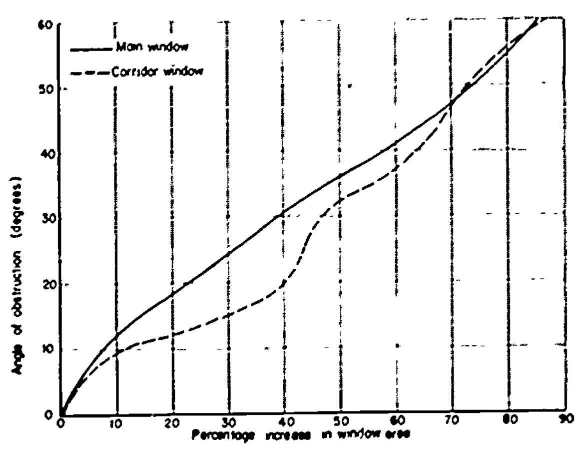


FIGURE 18

Increase in window sizes to allow for average decrease in indoor lighting due to external obstructions in the case of open corridor type classrooms 9 ft high, with an 8-ft roof-overhang on the corridor side

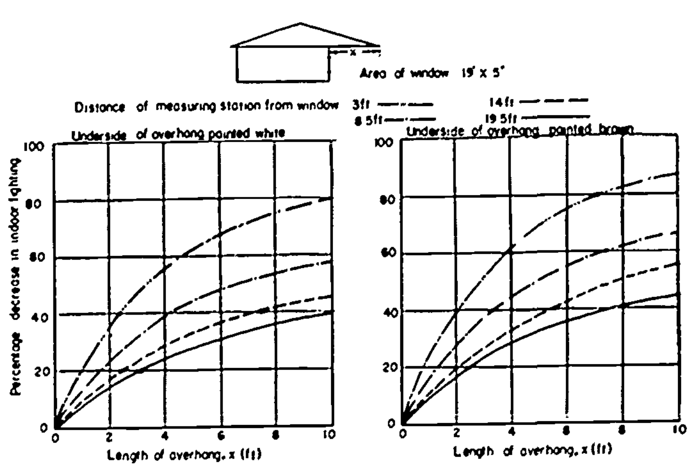


FIGURE 19

Influence of length and colour of roof-overhang on indoor lighting for overcast conditions even general rules as to the extent to which window areas should be increased to compensate for the effects of such devices on lighting. Each case must be dealt with individually.

Figure 20 illustrates the extent to which sun control devices in the form of external horizontal louvres can influence indoor illumination under overcast conditions. The results plotted in this Figure were obtained with the model open-corridor classroom under the artificial sky. Only unilateral lighting was considered and each of the three equally spaced windows, measuring 5 ft high × 6 ft wide, was fitted with six horizontal louvres as shown in the Figure.

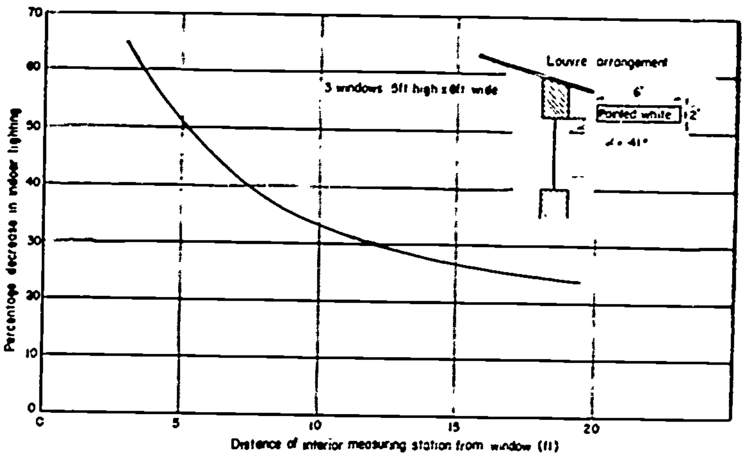


FIGURE 20

Influence of horizontal louvres on average indoor lighting for overcast conditions

It will be observed that, as with roof-overhangs, the maximum reduction in indoor lighting occurs near the wall containing the windows.

Even if configurated, prismatic, louvred, diffusing and other heat-absorbing glasses are used as sun control devices, allowance should be made for the reduction of light-transmission through such glasses.

2. ARTIFICIAL LIGHTING

As has already been indicated, it is impossible in practice to ensure adequate natural indoor lighting under all weather conditions. The best that can be achieved is to provide sufficient light for about 96 to 98 per cent of the school hours during the year. Consequently, there will be at least 2 to 4 per cent of the school hours during which indoor lighting conditions will not conform to minimum requirements, but it is doubtful whether so small a percentage would warrant the installation of a full-power artificial lighting system.

Judging from measurements conducted in well-designed schools, it would appear as though the provision of such an installation were unnecessary. A lighting system capable of giving a maximum of 10 lumens/sq ft would, in most circumstances, be more than adequate for supplementing daylighting under adverse weather conditions and also, perhaps, in densely built-up areas. In areas where external obstructions are limited, the advisability of providing even a supplementary installation is questionable. Local lighting of chalk-boards is, however, considered essential, the reason being that, while it is possible to read and write for short periods with a lighting intensity of as low as 5 to 10 lumens/sq ft on the desks, it is generally impossible for the children to read writing on the chalk-board under such conditions. Chalk-board lighting should, therefore, be so designed as to give a lighting level of not less than 10, but preferably 20, lumens/sq ft to supplement daylighting.

If, on the other hand, classrooms are to be used for evening classes or lectures or for purposes of study at night, a full-strength lighting installation would be essential.

In cases where artificial lighting installations are considered necessary, it would be advisable to consider the use of an automatic photo-electric on-and-off switching device, so that the control of lighting will not be dependent upon the judgment of teachers or children.

The design considerations to keep in mind in the design of artificial lighting systems are discussed in subsequent paragraphs.

(a) General lighting

In the design of an artificial lighting system for classrooms, the engineer or architect should ensure that it not only presents a pleasing appearance but also delivers enough light on the desks and chalk-board to comply with minimum recommendations. The quantity of illumination in a given area depends on the type of light-source, the wattage of the source, the size of the room and its decoration. The quality of the lighting is governed by the type of lamp and the design and arrangement of the fittings selected. The selection of the best type of lighting system for any particular room should, therefore, receive careful attention and should be considered in the early stages of design.

General lighting systems are usually classified into five main groups, depending on the manner in which the light is distributed from the fitting[36]. The various groups are illustrated in Figure 21. The approximate percentages of light distributed upwards and downwards from the fittings of the five main groups are given in Table 12.

The merits of each of the five main groups of lighting may be summarized briefly as follows:

(i) *Direct lighting*

In a direct lighting system undesirable luminance ratios may result if some means of illuminating the ceiling is not provided. It is, furthermore, desirable to use light-coloured materials and finishes throughout the room. Although it is easy enough to design a direct lighting system that will provide the desired illumination, it is, as a rule, not so easy to design one that does not cause disturbing shadows, particularly if filament lamps are used. Moreover, the area taken up by the lighting units required is often large, while direct and reflected glare can be distressing if the relative luminances are not kept within the recommended limits. In view of the foregoing, it is felt that direct lighting with incandescent lamps is not suitable for classrooms. Certain types of direct lighting fittings with fluorescent tubes may, however, be used with advantage to give adequate illumination without the danger of glare. Suitable units normally consist of recessed troffers fitted with louvres or of ceiling-mounted direct reflector equipment with a proper cut-off angle.

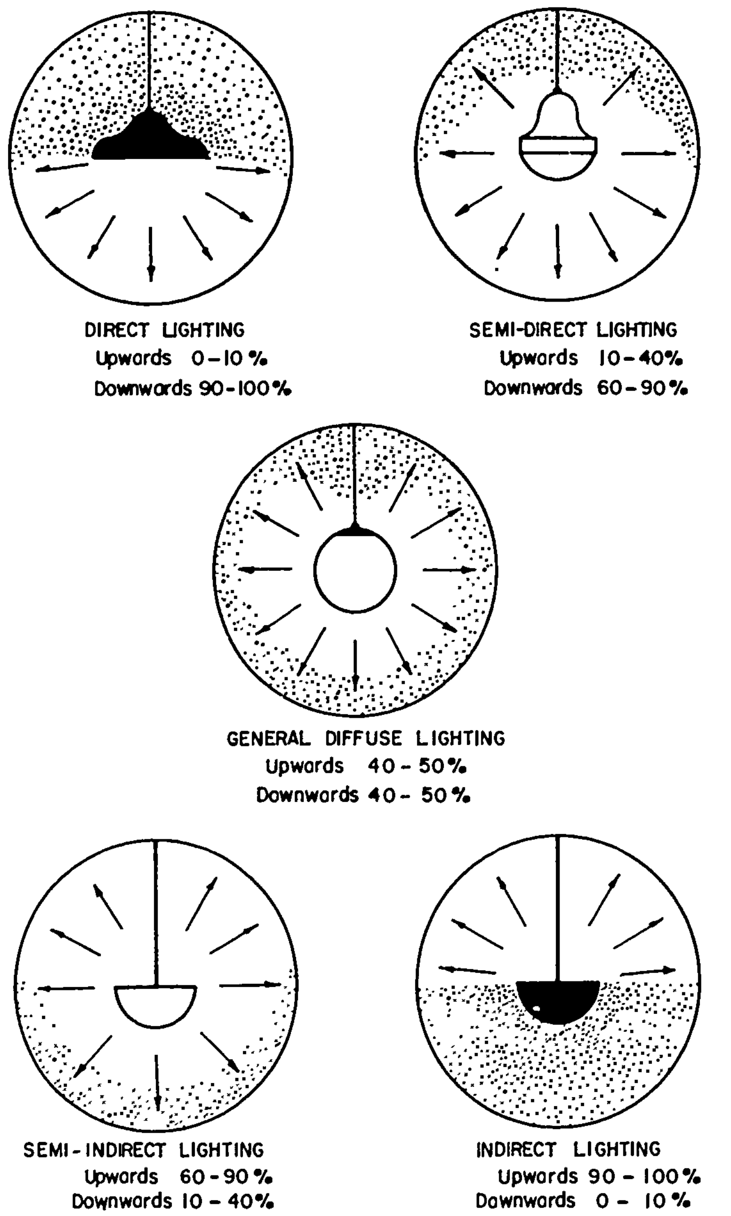


FIGURE 21

Schematic illustration of five different types of artificial lighting

TABLE 12

Approximate light distribution from different types of artificial lighting fittings

Type of fitting	Distribution (per cent)	
	Upwards	Downwards
Direct	0—10	90—100
Semi-direct	10—40	60—90
General diffuse	40—50	40—50
Semi-indirect	60—90	10—40
Indirect	90—100	0—10

(ii) *Semi-direct lighting*

The semi-direct type of fitting has a much larger downward than upward output, but the latter is generally sufficient to relieve the darkness of the ceiling and upper walls. Despite this, however, the shadows and luminance conditions characteristic of these fittings are of such a magnitude that they will cause glare unless the necessary precautions are taken to eliminate it. A well-designed fitting of this type, suitable for schools, is shown in Figure 22.

(iii) *General diffuse lighting*

The general diffuse type of lighting gives a more or

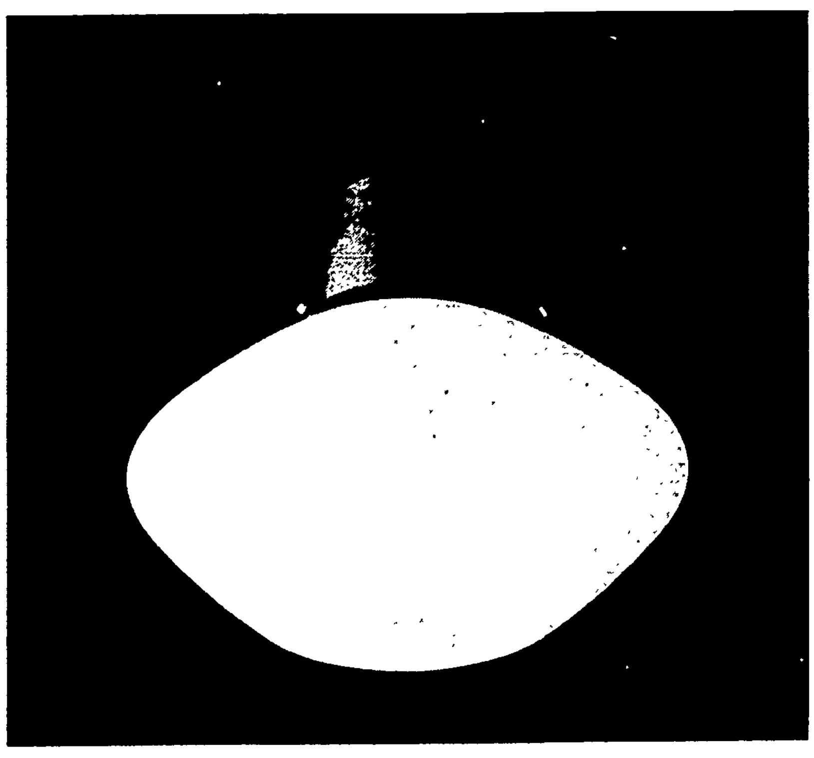


FIGURE 22

An example of a semi-direct fitting suitable for classroom lighting less even distribution upwards and downwards. Nevertheless, shadows will still be noticeable, though to a lesser degree than with the preceding two types. Some difficulty may be experienced with glare, as the source is generally fairly bright. This, however, may be overcome by the use of highly reflective surfaces for ceilings and walls and by large diffusing shades in the fittings. If properly designed, this type of lighting can be used in classrooms, offices, passages and the various rooms in hostels.

(iv) *Semi-indirect lighting*

In this type of lighting the upward component is usually between 60 and 90 per cent of the total output. Consequently, the ceiling acts as a secondary source of light and should, therefore, be painted a very light colour, preferably white. Although the downward component is small, there is still the danger of direct glare, particularly if filament lamps are used. Fittings falling into this category generally have translucent or opaque shades which tend to give low luminance contrasts with the ceiling. A very well-designed fitting of this type which has been developed overseas, and found suitable for school lighting, is shown in Figure 23.

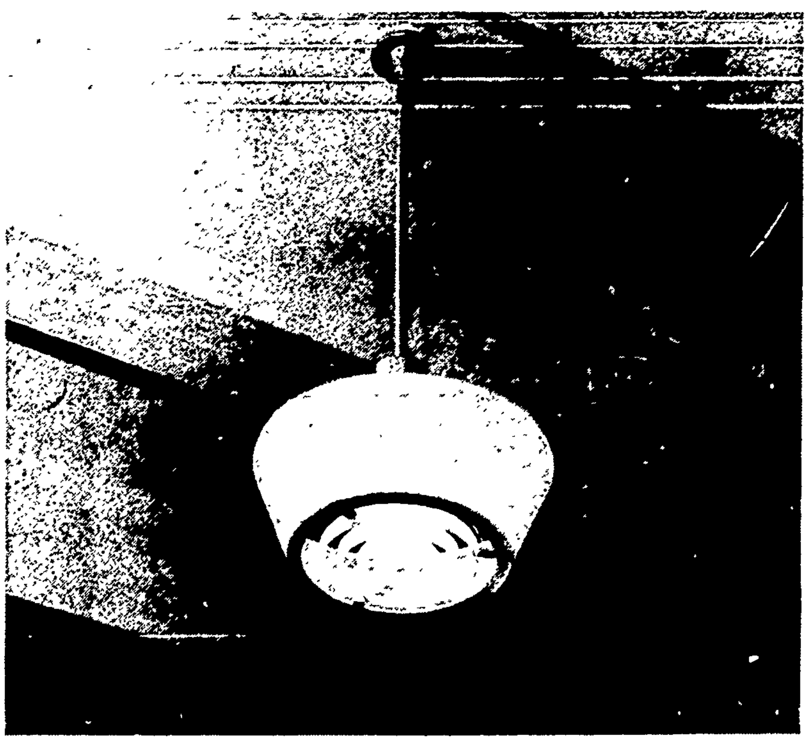


FIGURE 23
An example of a semi-indirect fitting suitable for classroom lighting

(v) *Indirect lighting*

In the totally indirect systems all the light is reflected towards the upper parts of the walls and ceiling, which then act as secondary sources of light. The colour of these surfaces must, therefore, be very light indeed, white being the most suitable colour for them. Similarly, the outside or underside of the fittings should be light-coloured to reduce the luminance contrast with the ceiling. The diffuse character of the light tends to minimize shadows as well as direct and reflected glare. Although, with this type, more powerful sources are required to deliver the same lighting intensity as the other types do, it gives better all-round illumination. Excessive luminance patches on the ceiling can be prevented by suspending the fitting not less than 1.25 ft from the ceiling. Incidentally, regular cleaning of this type of fitting is absolutely essential.

To calculate the spacing, mounting-height, number and wattage ratings of lamps, any of the standard methods described in the literature[21, 22, 30] can be used. To aid designers, however, information on designing artificial lighting systems is supplied in Appendix 1.

(b) **Chalk-board lighting**

Writing viewed from a distance is more difficult to read than that which is near the eyes. In a classroom some children are seated 8 ft from the board and others 25 ft away at the back of the room. The latter will, naturally, find it more difficult to read what is written on the board, especially if its surface has become grey from constant use, or if the teacher's writing is small.

As already pointed out, the illumination on the vertical chalk-board surface is usually lower than that on the horizontal working-plane. If, therefore, the latter lighting only just conforms to minimum requirements, the chalk-board will, in all probability, be inadequately illuminated. Under such circumstances local supplementary illumination of the chalk-board becomes very important. Increasing the illumination levels on the chalk-board will have the further advantage of minimizing any veiling glare from windows or light-sources.

Supplementary lighting on the chalk-board can be obtained from a variety of light-fittings and mountings. Whatever arrangement is used the fittings should be so positions that no glare will be experienced either by the pupil or by the teacher. Careful attention should also be given to the heat radiated from the light-sources because intense heat radiation will be uncomfortable for the teacher. The possible positioning of the chalk-board fitting is, therefore, limited, and it should be given careful consideration.

(i) *Fluorescent fittings*. In view of its length, high efficiency and relatively low luminance, the fluorescent tube lends itself favourably to the supplementary lighting of chalk-boards.

A type of wall mounting[1], which has been found suitable in overseas countries, is shown in Figure 24. The unit consists of a tube fitted in a parabolic aluminium reflector, which is aimed at a point 6 inches above the bottom of the board. The illumination intensities to be expected from a fitting of this type are also indicated in the Figure.

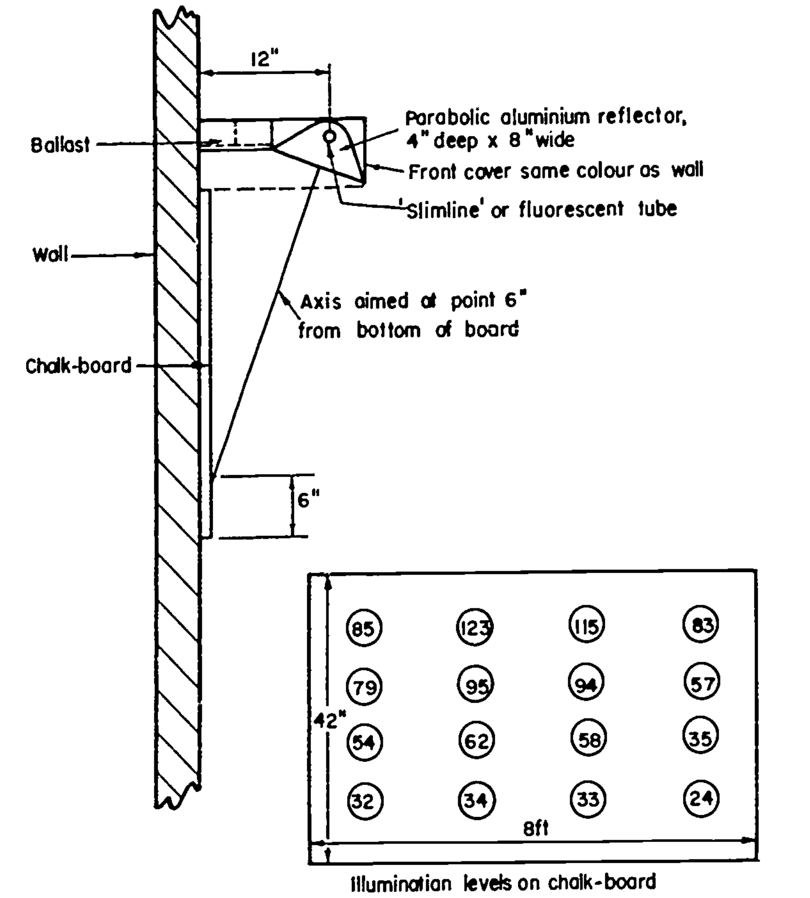


FIGURE 24

A shallow reflector type of wall mounting suitable for supplementary lighting of chalk-boards

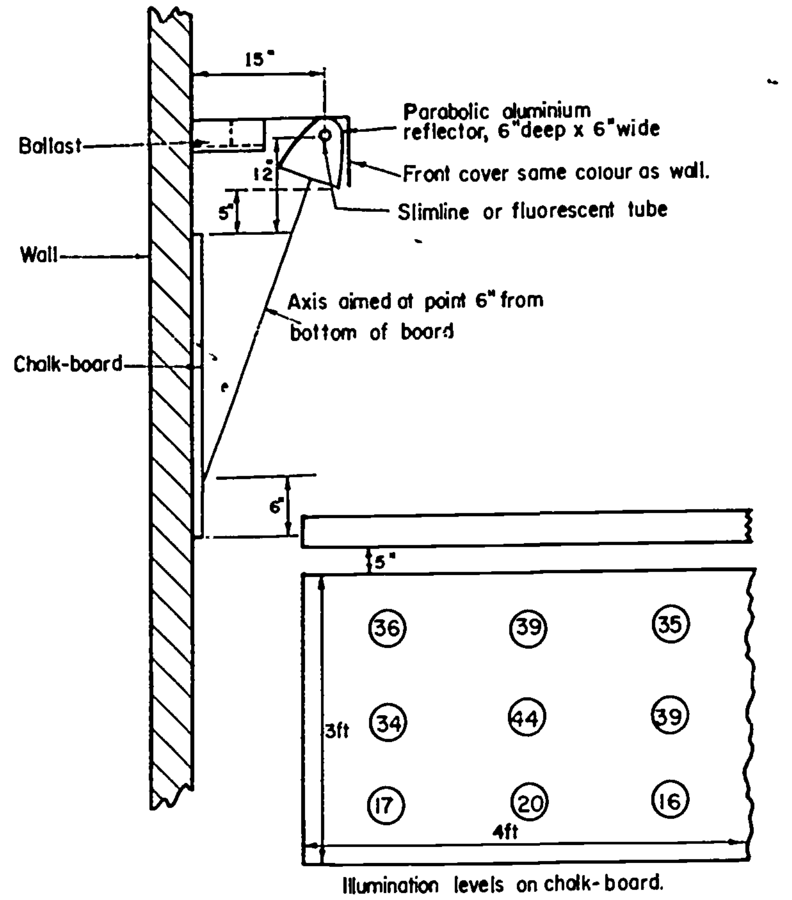


FIGURE 25

A deep reflector type of wall mounting suitable for supplementary lighting of chalk-boards

Another type of fitting suitable for wall mounting, consists of a parabolic aluminium reflector, 6 inches in both width and depth, mounted above the board. It was also tested, and the illumination values and details of this particular design are given in Figure 25.

With both these types of fittings, careful consideration should be given to the cut-off angle, in order to prevent any pupil from seeing the shiny reflector. The outside covering strip of the fitting should also be painted the same colour as the chalk-board wall, to minimize any distracting luminance or colour contrasts.

The fittings described so far are suitable for mounting on the chalk-board wall. Similar and other types of fittings are also available for mounting on the ceiling. One such fitting is illustrated in Figure 26.

(ii) *Incandescent lamps.* Incandescent lamps can also be used to provide lighting on chalk-boards. Here, however,

FIGURE 26

An example of a ceiling-mounted fitting suitable for supplementary lighting of chalk-boards it is of utmost importance to shield the high-luminance incandescent lamps from the pupils' view.

The fittings can be mounted either on the wall or on the ceiling in the positions indicated in Figure 27. A suitable combination was found to be a 'bullet' or conically shaped shade fitted with a 100-watt spotlight lamp. As can be expected the possibility of having an irregular lighting pattern with this type of fitting is very great unless careful attention is given to the spacing and mounting of the units. The arrangement shown in Figure 27 has been found to be fairly effective. One drawback with these fittings, however, is that they are easily tampered with and broken.

An alternative scheme is to use specially designed prismatic lighting fittings[2], which can be attached to the ceiling.

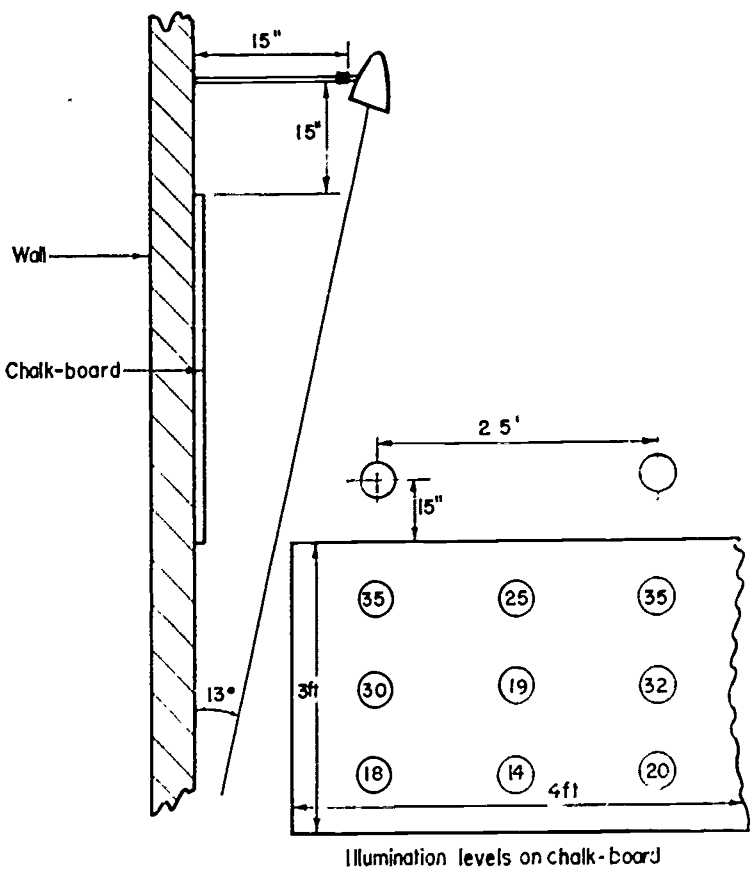


FIGURE 27

An example of an incandescent lamp arrangement suitable for chalk-board lighting

B. QUALITY OF LIGHT

It has already been emphasized that the provision of the desirable quantity of illumination is not the only design objective; the quality of the illumination is of equal importance. In this connection it has been shown that excessive luminances and luminance ratios should be avoided and that the task, being the most important object in the field of vision, should receive the greater part of the illumination. In order to aid designers, some of the more important design considerations for controlling the quality of lighting are elaborated below.

(a) Use of colour to control luminance ratios

Colour can contribute appreciably in achieving the desirable limiting luminance ratios listed in Table 4. In order not to exceed these limiting ratios, the reflection-factors of the more important surfaces in classrooms should fall within the ranges indicated in Table 13. Glossy surfaces should, of course, be avoided as far as possible to minimize reflected glare.

TABLE 13

Recommended reflection-factors for classrooms

Surface	Reflection-factor (per cent)	Suitable surfaces or colours
Desk-top	35—40	Light-coloured wood, e.g., pine or oak
Floor	15—30	Medium colours, e.g., brown, green, grey, etc.
Walls	50—60	Pastel shades, e.g., green, blue, etc.
Ceiling	80—85	Matt white
Window walls .. Reveals .. .. Window-bars .. Mullions	80—85	Matt white
Pinning-boards ..	50—60	Light colours
Chalk-board ..	15—20	Dark colours, e.g., green, blue, red or orange
Chalk-board wall..	50—60	Light colours, to harmonize with chalk-board colour

(b) Control of high outdoor luminances

Various methods may be employed for protecting children's eyes from high outdoor luminances. These include internal blinds, curtains, etc., but such devices should be used with discretion because they can have the disadvantage of interfering not only with the daylight intensity but also with the natural flow of air.

A practice frequently adopted in the United States[4, 6, 12, 5] is to place the desks in such a way that their fronts make an angle of about 50° with the forward reveal of the front window of the classroom.

Perhaps a more successful way of controlling sky luminance is to have external screen walls as shown in Figure 28, or by judiciously planting trees in rows at right angles to the window wall. By grading luminances from bright to relatively dark in this way[27], glare from a bright source is considerably reduced. The effectiveness of screen walls in the grading of luminances is illustrated

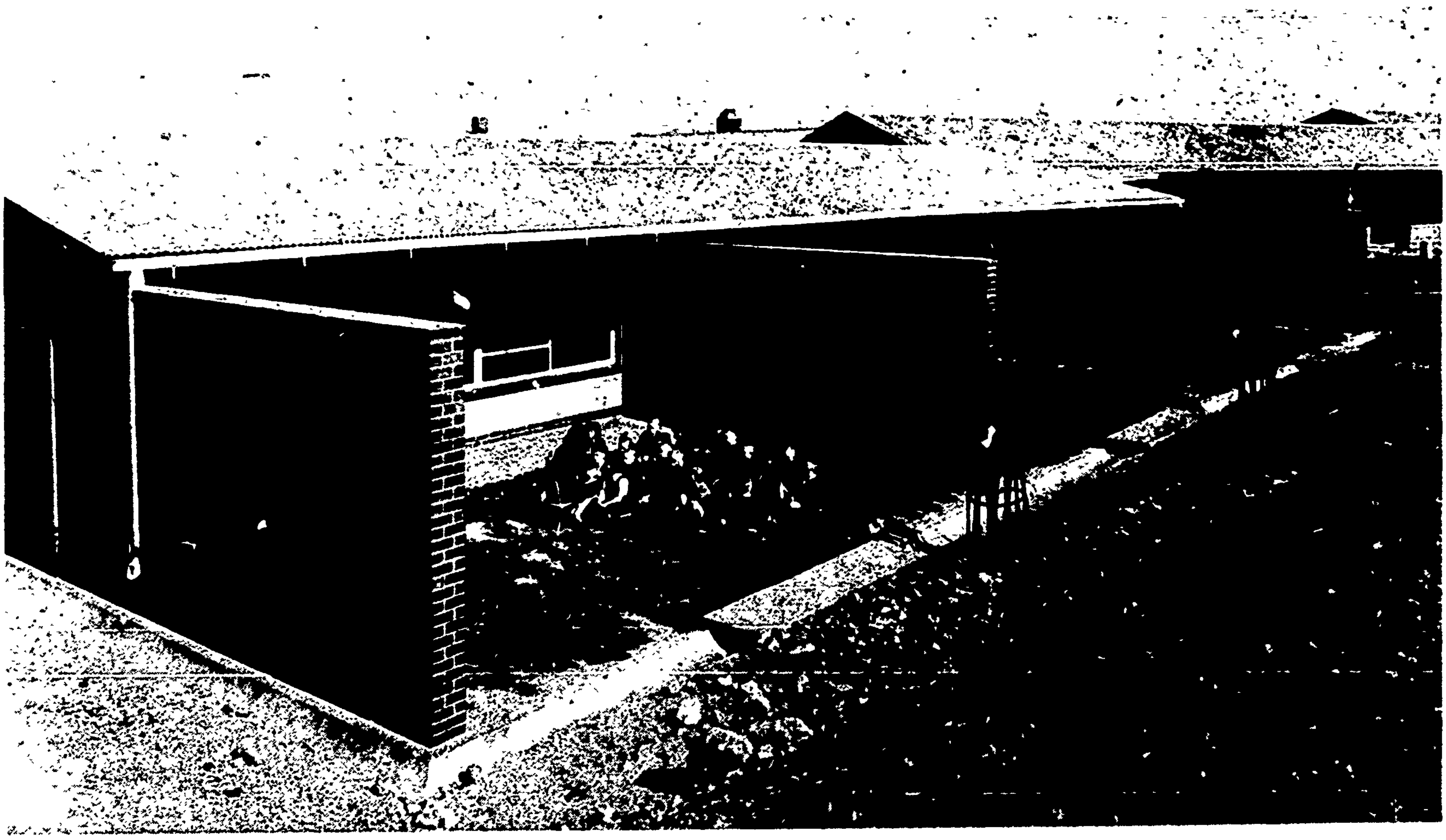


FIGURE 28

External screen walls to control sky luminance and sunlight

by the results obtained at the Waterkloof experimental school under fairly bright sky conditions. These results are listed in Table 14.

TABLE 14

Grading of luminances in the Waterkloof experimental school by means of external screen walls

Window	Surface	Luminance (footlamberts)
South-facing (no side walls, but trees 50 ft from wall)	Inside of window wall Trees .. .. .. Sky just above trees ..	61 540 1 500
North-facing with 7 ft 6 in overhang (with side walls and distant trees)	Inside window wall .. Side wall .. .. Trees .. .. .. Sky just above side wall and trees	27 110 100 1 400

(c) **Orientation of classrooms in relation to the sun**

Direct sunlight on the desk-tops or on the chalk-board can be a source of glare which could cause serious discomfort. A typical example of the effects of direct sunlight on a child's desk is illustrated in Figure 29. The degree of discomfort glare experienced in this particular case was calculated along the lines suggested by Petherbridge and Hopkinson[27] and it was found that it could be classified as 'intolerable'. Apart from the glare, the

FIGURE 29

An example of the effects of direct sunlight on pupil's desk diversity ratio, i.e., the ratio of maximum to minimum illumination, amounted to 166 : 1 which is considered too high for comfortable seeing.

Because of the foregoing it is felt that under no circumstances should direct sunlight be allowed to penetrate into classrooms during school hours. The only classrooms in which direct sunlight may be an advantage are kindergarten or grades rooms.

There are various methods of controlling sunlight, of which the most common is the introduction of internal or external louvres or blinds but unless these are properly designed, they have the serious disadvantage of interfering too much with natural lighting and ventilation and, because of this, they are not recommended for general use.

The most obvious solution is to position a building in such a way that penetration of sunlight is minimal. Normally, this can be achieved quite easily in school buildings by having the main windows facing either south or west, and by protecting windows in the opposite walls with suitable roof-overhangs, screen walls or louvres. Windows of kindergarten and grades rooms can, however, be arranged in such a way that the bigger ones face north in order to allow a certain amount of sun penetration. The length of roof-overhang and screen walls or, alternatively, the best arrangement of louvres necessary to give the required control over direct sunlight, can easily be determined by means of solar charts which have been plotted for South African conditions[32].

It must be borne in mind that all sun control devices will inevitably affect natural lighting to some extent and that allowance must be made for this in the choice of window sizes.

(d) **Luminances of light-sources and auxiliary equipment**

In the design of artificial lighting installations special attention should be given to the luminances of the light-sources and auxiliary equipment. The luminances of light-fittings should preferably not exceed the values listed in Table 15.

TABLE 15

Recommended maximum luminances of light-fittings for classrooms

Zone, if 0° is directly below the fitting	Luminance (footlamberts)	
	Preferred	Maximum acceptable
0—45°	2 500	No limit
45—60°	1 500	2 500
60—87°	500	1 500

The luminance of light-fittings can usually be controlled quite adequately by proper shields or covers. The sizes of the latter, given in Table 16, will serve as a guide in the selection of light-fittings for use in the lighting systems[20, 31] ordinarily found in schools.

TABLE 16

Bowl and shield sizes for general lighting fittings having filament lamps

Fitting	Lamp size (in watts)
6″-diam. sphere	40
8″-diam. sphere	60 or 75
10″-diam. sphere	100
12″-diam. sphere	150
14″-diam. sphere	200
16″-diam. sphere	300
14″-diam. semi-indirect fitting	200
16″-diam. semi-indirect fitting	300
18″-diam. semi-indirect fitting	500

Other points to bear in mind in the design of artificial lighting systems are:

1. The area of potential sources of glare should be as small as possible.
2. The surroundings, e.g. ceiling and walls, should be decorated to conform with the recommendations embodied in this report.
3. The fittings should have a cut-off angle of at least 30°.
4. The fittings should be mounted as high as possible and should be so spaced as to give an even distribution of light.
5. The colour of the light should be acceptable. Unless this is so, unacceptable colour conditions may be produced. The colour of a wall or ceiling may, for instance, be acceptable under one type of light-source at a given level of illumination, but not under another type or level. It is impossible to lay down definite rules in this connection and designers must use their own discretion.
6. Where artificial lighting is required to supplement daylight, it is desirable that the illuminant should blend with the natural light. Experience has shown that, where precise colour discrimination is unnecessary, light from incandescent filament lamps is generally suitable for moderate values of illumination, namely, between 2 and 25 lumens/sq ft. In regard to fluorescent lamps there is a preference in cold climates for those in warmer colours, whereas in warm climates lamps in colder colours or white are more popular.

Where accurate colour discrimination is required, fluorescent tubes with a colour temperature of 6 500°K would be a good choice but for general lighting, where precise colour discrimination is unimportant, tubes which have colour temperatures between 3 000 and 4 500°K will probably be more suitable.

GENERAL

However well a lighting system may have been designed, it will not function effectively for long periods unless it is properly maintained. Regular cleaning of windows and light-fittings is of the utmost importance. Defective lamps should be replaced, and group-replacing will probably prove worth while in installations where the lamps are burned for prolonged periods.

CONCLUSIONS AND RECOMMENDATIONS

Although this report covers chiefly the general lighting of classrooms, there are many other rooms in school buildings and hostels which require lighting. The same basic principles apply throughout and only require intelligent application. Useful additional information relevant to the lighting design of school buildings may be obtained from the literature listed in Appendix 2.

An index of the main conclusions and recommendations in respect of school lighting follows.

INDEX OF CONCLUSIONS AND RECOMMENDATIONS IN RESPECT OF SCHOOL LIGHTING

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APPENDIX 1

TABLES FOR DETERMINING THE NUMBER AND SIZES OF LAMPS REQUIRED TO DELIVER A PREDETERMINED ILLUMINATION LEVEL ON THE WORKING-PLANE

In order to simplify the calculation of the number of lamps required and the wattage ratings necessary for them to deliver a predetermined illumination level on the working-plane in rooms of different sizes, Tables 1 to 5 have been drawn up for the five main lighting systems referred to in this report, viz., direct, semi-direct, general diffuse, semi-indirect, and totally indirect systems, respectively.

The results listed in these Tables were calculated according to the well-known lumen method by assuming that:

(*a*) the illumination level is 20 lumens/sq ft;

(*b*) the reflection-factors of the ceilings will not be less than 70 per cent and those of the walls will not be less than 50 per cent, and

(*c*) the average lumen-output throughout the life of the particular lamps will be as indicated in Table 6. Tables 1 to 5 are attached at the back of this Appendix.

TABLE 6

Assumed lumen-output, average throughout life, of light-sources for the calculation of number and sizes of lamps

Light-source	Assumed light-output (in lumens)
75-watt incandescent lamp	785
100-watt ,, ,, ...	1 160
150-watt ,, ,, ...	1 970
200-watt ,, ,, ...	2 725
300-watt ,, ,, ...	4 430
4′ 40-watt fluorescent tube	2 000
5′ 80-watt ,, ,, ...	3 600
8′ slimline tube	4 800
8′ cold cathode tube	2 400

For average light-outputs or types of light-sources other than those covered in the foregoing Table, the number of lamps required can be determined by dividing the lumen values given in the second column by the respective average light-output.

It should also be stressed that, although the number of lamps and the wattage ratings given in Tables 1 to 5 are those required to give an illumination level of 20 lumens/sq ft on the horizontal working-plane, the number of lamps required for any other level of illumination can easily be determined by proportionately reducing or increasing the figures quoted. For instance, if an illumination level of only 10 lumens/sq ft is required, the number of light-sources required will be approximately half those given in the Tables.

The practical application of the Tables is best illustrated by means of an example. It is, for instance, desired to use a semi-indirect lighting system in a room decorated in light colours and measuring 15 ft×20 ft×9 ft high; what number of lamps would be required and what should their wattage ratings be in order to deliver 10 lumens/sq ft?

From Table 4 (a) it will be seen that, for a floor area of 300 sq ft and a ceiling height of 9 ft 6 in, a lighting level of 20 lumens/sq ft requires 22 800 lumens. Thus, for a lighting level of 20 lumens/sq ft any of the number of lamps listed in Table 7 may be used.

TABLE 7

Sizes and number of lamps required to give an illumination level of 10 lumens sq ft from a semi-indirect system in a room of 15 ft×20 ft×9 ft

Light-source	Number
75-watt incandescent lamp	15
100-watt ,, ,, ...	10
150-watt ,, ,, ...	5
200-watt ,, ,, ...	4
300-watt ,, ,, ...	2
4′ 40-watt fluorescent tube	6
5′ 80-watt ,, ,, ...	3
8′ slimline tube	2
8′ cold cathode tube	5

However, as far as the arrangement of the fittings is concerned some of the numbers of lamps suggested, particularly the uneven numbers, may not be a practical choice. Furthermore, it is essential to ensure a uniform distribution of light in order to avoid high contrasts from the darker to the better lit parts of the room, and this will depend entirely on the spacing, type, and mounting of the fittings. The spacings and mounting heights suggested in Table 8 have, however, been found to give a distribution within the required limits[25], and it is recommended that these be used as a guide in the design of artificial lighting installations in this country.

TABLE 8

Recommended spacing of fittings for different mounting and ceiling heights[25]

Height of		Maximum spacing between light-points	Maximum distance between points and side walls		Suspension distance of ceiling to light-centre for semi-indirect and indirect fittings
fitting above floor, for direct, semi-direct and general diffuse fittings (in ft)	ceiling above floor, for semi-indirect and direct fittings (in ft)	(in ft)	where aisles are next to wall (in ft)	where work-benches are next to the wall (in ft)	(in ft)
7	—	6	3	2	—
8	8	7½	3½	2½	1¼
9	9	9	4½	3	1½
10	10	10½	5	3½	1¾
11	11	12	6	4	2
12	12	13½	6½	4½	2¼
13	13	15	7½	5	2½
14	14	16½	8	5½	2¾
15	15	18	9	6	3
16	16	19½	9½	6½	3¼
17	17	21	10½	7	3½
18	18	22½	11	7½	3¾

TABLE 1 (a)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 7′—7.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	6 200	8	5	3	2	1	3	2	1	3
200	11 200	14	10	6	4	3	6	3	2	5
300	15 800	20	14	8	6	4	8	4	3	7
400	20 000	25	17	10	7	5	10	6	4	8
500	24 600	31	21	12	9	6	12	7	5	10
600	29 000	37	25	15	11	7	15	8	6	12
700	32 800	42	28	16	12	7	16	9	7	14
800	37 000	47	32	19	14	8	19	10	8	15
900	41 400	53	36	21	15	9	21	11	9	17
1 000	45 600	58	39	23	17	10	23	13	9	19
1 100	49 800	63	43	25	18	11	25	14	10	21
1 200	54 000	69	47	27	20	12	27	15	11	22
1 300	58 400	74	50	29	21	13	29	16	12	24
1 400	62 600	80	54	31	23	14	31	17	13	26
1 500	66 600	85	57	33	24	15	33	18	14	28

TABLE 1 (b)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 8′—8.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	7 000	9	6	4	3	2	4	2	1	3
200	12 000	15	10	6	4	3	6	3	2	5
300	17 000	21	15	9	6	4	9	5	4	7
400	21 600	28	19	11	8	5	11	6	4	9
500	26 000	33	22	13	10	6	13	7	5	10
600	30 200	38	26	15	11	7	15	8	6	13
700	34 200	44	29	17	13	8	17	9	7	14
800	38 400	49	33	19	14	9	19	11	8	16
900	42 600	54	37	21	16	10	21	12	9	18
1 000	46 800	60	40	23	17	11	23	13	10	19
1 100	51 000	65	44	26	19	12	26	14	11	21
1 200	55 200	70	48	28	20	12	28	15	11	23
1 300	59 600	76	51	30	22	13	30	17	12	25
1 400	64 000	82	55	32	23	14	32	18	13	27
1 500	68 000	87	59	34	25	15	34	19	14	28

TABLE 1 (c)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 9′—9.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 000	10	7	4	3	2	4	2	2	3
200	13 200	17	11	7	5	3	7	4	3	5
300	18 000	23	15	9	7	4	9	5	4	7
400	22 600	29	19	11	8	5	11	6	5	9
500	27 200	35	23	14	10	6	14	8	6	11
600	31 400	40	27	16	12	7	16	9	7	13
700	35 400	45	30	18	13	8	18	10	7	15
800	39 600	50	34	20	15	9	20	11	8	16
900	44 000	56	38	22	16	10	22	12	9	18
1 000	48 000	61	41	24	18	11	24	13	10	20
1 100	52 200	66	45	26	19	12	26	14	11	22
1 200	56 600	72	49	28	21	13	28	16	12	24
1 300	61 000	78	52	31	22	14	31	17	13	25
1 400	65 400	83	56	33	24	15	33	18	14	27
1 500	69 600	89	60	35	26	16	35	19	14	29

TABLE 1 (d)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 10′—11.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	9 200	11	8	5	3	2	5	3	2	4
200	14 600	19	13	7	5	3	7	4	3	6
300	19 600	25	17	10	7	4	10	5	4	8
400	24 400	31	21	12	9	6	12	7	5	10
500	29 000	37	25	15	11	7	15	8	6	12
600	33 200	44	29	17	12	7	17	9	7	14
700	37 400	48	32	19	14	8	19	10	8	16
800	41 600	52	36	21	15	9	21	12	9	17
900	45 800	58	39	23	17	10	23	13	10	19
1 000	50 000	64	43	25	18	11	25	14	10	21
1 100	54 200	69	47	27	20	12	27	15	11	23
1 200	58 600	75	50	29	22	13	29	16	12	24
1 300	63 000	80	54	32	23	14	32	17	13	26
1 400	67 400	86	58	34	25	15	34	19	14	28
1 500	71 600	91	61	36	26	16	36	20	15	30

TABLE 1 (e)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Direct
Ceiling height: —
Illumination level: 20 lumens/sq ft
Mounting height: 12′—13.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps: Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	10 800	13	9	5	4	2	5	3	2	4
200	17 200	21	15	9	6	4	9	5	4	7
300	22 400	29	19	11	8	5	11	6	5	9
400	27 800	35	24	14	10	6	14	8	6	11
500	32 200	41	28	16	12	7	16	9	7	13
600	36 400	46	31	18	13	8	18	10	8	15
700	40 800	52	35	20	15	9	20	11	8	17
800	45 400	58	39	23	17	10	23	13	9	19
900	49 800	63	43	25	18	11	25	14	10	21
1 000	54 200	69	47	27	20	12	27	15	11	23
1 100	58 600	75	50	29	22	13	29	16	12	24
1 200	63 200	81	54	32	23	14	32	18	13	26
1 300	67 600	86	58	34	25	15	34	19	14	28
1 400	72 000	92	62	36	26	16	36	20	15	30
1 500	76 600	98	66	38	28	17	38	21	16	32

TABLE 2 (a)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-direct
Ceiling height: —
Illumination level: 20 lumens/sq ft
Mounting height: 7′—7.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps: Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	7 400	9	6	4	3	2	4	2	2	3
200	12 600	16	11	6	5	3	6	4	3	5
300	17 800	23	15	9	7	4	9	5	4	7
400	22 600	29	19	11	8	5	11	6	5	9
500	26 800	34	23	13	10	6	13	7	6	11
600	31 400	40	27	16	12	7	16	9	7	13
700	35 800	46	31	18	13	8	18	10	7	15
800	40 000	51	34	20	15	9	20	11	8	17
900	44 200	56	38	22	16	10	22	12	9	18
1 000	48 800	62	42	24	18	11	24	14	10	20
1 100	53 000	68	46	27	19	12	27	15	11	22
1 200	57 400	73	49	29	21	13	29	16	12	24
1 300	61 800	79	53	31	23	14	31	17	13	26
1 400	66 000	84	57	33	24	15	33	18	14	28
1 500	70 000	89	60	35	26	16	35	19	15	29

TABLE 2 (b)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-direct — Ceiling height: —
Illumination level: 20 lumens/sq ft — Mounting height: 8′—8.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 000	10	7	4	3	2	4	2	2	3
200	13 800	17	12	7	5	3	7	4	3	6
300	19 200	24	17	10	7	4	10	5	4	8
400	24 000	31	21	12	9	5	12	7	5	10
500	29 000	37	25	15	11	7	15	8	6	12
600	33 400	42	29	17	12	8	17	9	7	14
700	37 600	48	32	19	14	8	19	10	8	16
800	42 000	54	36	21	15	9	21	12	9	17
900	46 200	59	40	23	17	10	23	13	10	19
1 000	50 600	64	44	25	19	11	25	14	11	21
1 100	55 200	70	48	28	20	12	28	15	11	23
1 200	59 400	76	51	30	22	13	30	16	12	25
1 300	64 000	82	55	32	23	14	32	18	13	27
1 400	68 000	87	59	34	25	15	34	19	14	28
1 500	72 200	92	62	36	26	16	36	20	15	30

TABLE 2 (c)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-direct — Ceiling height: —
Illumination level: 20 lumens/sq ft — Mounting height: 9′—9.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 800	11	8	4	3	2	4	2	2	4
200	14 400	18	12	7	5	3	7	4	3	6
300	20 000	25	17	10	7	5	10	6	4	8
400	25 200	32	22	13	9	6	13	7	5	10
500	30 000	38	26	15	11	7	15	8	6	12
600	34 400	44	30	17	13	8	17	10	7	14
700	39 000	50	34	20	14	9	20	11	8	16
800	43 600	56	38	22	16	10	22	12	9	18
900	48 000	61	41	24	18	11	24	13	10	20
1 000	52 400	67	45	26	19	12	26	15	11	22
1 100	57 000	73	49	29	21	13	29	16	12	24
1 200	61 600	78	53	31	23	14	31	17	13	26
1 300	66 000	84	57	33	24	15	33	18	14	27
1 400	70 200	90	61	35	26	16	35	19	15	29
1 500	74 600	95	64	37	27	17	37	21	16	31

TABLE 2 (d)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 10′—11.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	10 000	13	9	5	4	2	5	3	2	4
200	16 600	21	14	8	6	4	8	5	3	7
300	20 200	26	17	10	7	5	10	6	4	8
400	27 600	35	24	14	10	6	14	8	6	11
500	32 600	42	28	16	12	7	16	9	7	14
600	37 200	47	32	19	14	8	19	10	8	15
700	41 600	53	35	21	15	9	21	12	9	17
800	46 000	59	40	23	17	10	23	13	10	19
900	50 600	64	44	25	19	11	25	14	11	21
1 000	55 400	71	48	28	20	13	28	15	12	23
1 100	60 000	76	52	30	22	14	30	17	12	25
1 200	64 600	82	56	32	24	15	32	18	13	27
1 300	69 200	88	60	35	25	16	35	19	14	29
1 400	73 800	94	64	37	27	17	37	20	15	31
1 500	78 400	100	68	39	29	18	39	22	16	33

TABLE 2 (e)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-direct
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 12′—13.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	10 400	13	9	5	4	2	5	3	2	4
200	18 200	23	16	9	7	4	9	5	4	8
300	24 400	31	21	12	9	6	12	7	5	10
400	30 200	38	26	15	11	7	15	8	6	13
500	35 600	45	31	18	13	8	18	10	7	15
600	40 400	51	35	20	15	9	20	11	8	17
700	45 400	58	39	23	17	10	23	13	9	19
800	50 000	64	43	25	18	11	25	14	10	21
900	55 200	70	48	28	20	12	28	15	12	23
1 000	60 000	76	52	30	22	14	30	17	13	25
1 100	65 200	83	56	33	24	15	33	18	14	27
1 200	69 800	89	60	35	26	16	35	19	15	29
1 300	74 600	95	64	37	27	17	37	21	16	31
1 400	79 600	101	69	40	29	18	40	22	17	33
1 500	84 200	107	73	42	31	19	42	23	18	35

TABLE 3 (a)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: General diffuse
Illumination level: 20 lumens/sq ft

Ceiling height: —
Mounting height: 7′—7.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	7 200	9	6	4	3	2	4	2	1	3
200	13 000	17	11	7	5	3	7	4	3	5
300	18 200	23	16	9	7	4	9	5	4	8
400	22 600	29	19	11	8	5	11	6	5	9
500	27 600	35	24	14	10	6	14	8	6	11
600	31 800	41	27	16	12	7	16	9	7	13
700	36 000	46	31	18	13	8	18	10	8	15
800	40 400	51	35	20	15	9	20	11	8	17
900	45 000	57	39	23	17	10	23	12	9	19
1 000	49 400	63	43	25	18	11	25	14	10	21
1 100	53 600	68	46	27	20	12	27	15	11	22
1 200	57 800	74	50	29	21	13	29	16	12	24
1 300	62 200	79	54	31	23	14	31	17	13	26
1 400	66 400	85	57	33	24	15	33	18	14	28
1 500	70 800	90	61	35	26	16	35	20	15	29

TABLE 3 (b)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: General diffuse
Illumination level: 20 lumens/sq ft

Ceiling height: 9′—10′
Mounting height: 8′—8.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 000	10	7	4	3	2	4	2	2	3
200	14 000	18	12	7	5	3	7	4	3	6
300	20 000	25	17	10	7	5	10	6	4	8
400	24 400	31	21	12	9	6	12	7	5	10
500	29 600	38	26	15	11	7	15	8	6	12
600	34 000	43	29	17	12	8	17	9	7	14
700	38 200	49	33	19	14	9	19	11	8	16
800	42 400	54	37	21	16	10	21	12	9	18
900	47 000	60	41	24	17	11	24	13	10	20
1 000	51 400	65	44	26	19	12	26	14	11	21
1 100	56 000	71	48	28	21	13	28	16	12	23
1 200	60 000	76	52	30	22	14	30	17	13	25
1 300	64 400	82	56	32	24	15	32	18	13	27
1 400	68 600	87	59	34	25	15	34	19	14	29
1 500	73 400	94	63	37	27	17	37	20	15	31

TABLE 3 (c)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: General diffuse
Illumination level: 20 lumens/sq ft

Ceiling height: 10′—11′
Mounting height: 9′—9.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 800	11	8	4	3	2	4	2	2	4
200	15 400	20	13	8	6	4	8	4	3	6
300	21 000	27	18	10	8	5	10	6	4	9
400	26 000	33	22	13	!0	6	13	7	5	11
500	31 000	39	27	16	12	7	16	9	6	13
600	35 400	45	31	18	13	8	18	10	7	15
700	40 000	51	34	20	15	9	20	11	8	17
800	44 400	57	38	22	16	10	22	12	9	19
900	49 000	62	42	25	18	11	25	14	10	20
1 000	53 800	69	46	27	20	12	27	15	11	22
1 100	58 000	74	50	29	21	13	29	16	12	24
1 200	62 400	79	54	31	23	14	31	17	13	26
1 300	66 800	85	58	33	25	15	33	19	14	28
1 400	71 000	90	61	36	26	16	36	20	15	30
1 500	76 000	97	66	38	28	17	38	21	16	32

TABLE 3 (d)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: General diffuse
Illumination level: 20 lumens/sq ft

Ceiling height: 11′—12′
Mounting height: 10′—11.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	9 600	12	8	5	4	2	5	3	2	4
200	16 600	21	14	8	6	4	8	5	3	7
300	22 400	29	19	11	9	5	11	6	5	9
400	28 000	36	24	14	10	6	14	8	6	12
500	33 600	43	29	17	12	8	17	9	7	14
600	38 000	48	33	19	14	9	19	11	8	16
700	42 400	54	37	21	16	10	21	12	9	18
800	47 200	60	41	24	17	11	24	13	10	20
900	52 000	66	45	26	19	12	26	14	11	22
1 000	56 400	72	49	28	21	13	28	16	12	24
1 100	61 200	78	53	31	22	14	31	17	13	26
1 200	65 800	84	57	33	24	15	33	18	14	27
1 300	70 000	89	60	35	26	16	35	19	15	29
1 400	75 200	96	65	38	28	17	38	21	16	31
1 500	80 000	102	69	40	29	18	40	22	17	33

TABLE 3 (e)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: General diffuse — Ceiling height: 13′—14′
Illumination level: 20 lumens/sq ft — Mounting height: 12′—13.5′

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	11 000	14	9	6	4	2	6	3	2	5
200	18 000	23	16	9	7	4	9	5	4	8
300	24 800	32	21	12	9	6	12	7	5	10
400	30 200	38	26	15	11	7	15	8	6	13
500	36 000	46	31	18	13	8	18	10	8	15
600	41 000	52	35	21	15	9	21	11	9	17
700	43 600	56	38	22	16	10	22	12	9	18
800	50 800	65	44	25	19	11	25	14	11	21
900	56 000	71	48	28	21	13	28	16	12	23
1 000	61 200	78	53	31	22	14	31	17	13	26
1 100	66 000	84	57	33	24	15	33	18	14	28
1 200	70 800	90	61	35	26	16	35	20	15	30
1 300	76 000	97	66	38	28	17	38	21	16	32
1 400	81 000	103	70	41	30	18	41	23	17	34
1 500	86 000	110	74	43	32	19	43	24	18	36

TABLE 4 (a)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-indirect — Ceiling height: 9′—9.5′
Illumination level: 20 lumens/sq ft — Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	8 400	11	7	4	3	2	4	2	2	4
200	15 800	20	14	8	6	4	8	4	3	7
300	22 800	29	20	11	8	5	11	6	5	10
400	28 600	36	25	14	10	6	14	8	6	12
500	34 200	44	29	17	13	8	17	10	7	14
600	40 000	51	34	20	15	9	20	11	8	17
700	45 200	58	39	23	17	10	23	13	9	19
800	50 200	64	43	25	18	11	25	14	10	21
900	55 600	71	48	28	20	13	28	15	12	23
1 000	61 000	78	53	31	22	14	31	17	13	25
1 100	68 000	87	59	34	25	15	34	19	14	28
1 200	72 000	92	62	36	26	16	36	20	15	30
1 300	76 800	98	66	38	28	17	38	21	16	32
1 400	82 400	105	71	41	30	19	41	23	17	34
1 500	87 600	112	76	44	32	20	44	24	18	37

TABLE 4 (b)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-indirect — Ceiling height: 10′—11.5′
Illumination level: 20 lumens/sq ft — Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	10 000	13	9	5	4	2	5	3	2	4
200	16 800	21	14	8	6	4	8	5	4	7
300	25 400	32	22	13	9	6	13	7	5	11
400	31 800	41	27	16	12	7	16	9	7	13
500	37 600	48	32	19	14	8	19	10	8	16
600	43 400	55	37	22	16	10	22	12	9	18
700	48 800	62	42	24	18	11	24	14	10	20
800	54 200	69	47	27	20	12	27	15	11	23
900	59 600	76	51	30	22	13	30	17	12	25
1 000	65 000	83	56	33	24	15	33	18	14	27
1 100	70 200	89	61	35	26	16	35	20	15	29
1 200	76 000	97	66	38	28	17	38	21	16	32
1 300	81 200	103	70	41	30	18	41	23	17	34
1 400	86 400	110	74	43	32	20	43	24	18	36
1 500	92 000	117	79	46	34	21	46	26	19	38

TABLE 4 (c)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Semi-indirect — Ceiling height: 12′—13.5′
Illumination level: 20 lumens/sq ft — Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	11 600	15	10	6	4	3	6	3	2	5
200	19 800	25	17	10	7	4	10	6	4	8
300	27 400	35	24	14	10	6	14	8	6	11
400	34 000	43	29	17	12	8	17	9	7	14
500	39 800	51	34	20	15	9	20	11	8	17
600	45 600	58	39	23	17	10	23	13	10	19
700	51 000	65	44	26	19	12	26	14	11	21
800	56 600	72	49	28	21	13	28	16	12	24
900	62 000	79	53	31	23	14	31	17	13	26
1 000	68 000	87	59	34	25	15	34	19	14	28
1 100	73 600	94	63	37	27	17	37	20	15	31
1 200	79 400	101	68	40	29	18	40	22	17	33
1 300	84 400	108	73	42	31	19	42	23	18	35
1 400	90 400	115	78	45	33	20	45	25	19	38
1 500	96 000	122	83	48	35	22	48	27	20	40

TABLE 5 (a)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Totally indirect
Illumination level: 20 lumens/sq ft

Ceiling height: 9′—9.5′
Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	11 600	—	10	6	4	3	6	3	2	5
200	20 000	—	17	10	7	5	10	6	4	8
300	27 600	—	24	14	10	6	14	8	6	11
400	34 000	—	29	17	12	8	17	9	7	14
500	40 000	—	34	20	15	9	20	11	8	17
600	46 200	—	40	23	17	10	23	13	10	19
700	52 000	—	45	26	19	12	26	14	11	22
800	58 000	—	50	29	21	13	29	16	12	24
900	64 000	—	55	32	23	14	32	18	13	27
1 000	70 000	—	60	35	26	16	35	19	15	29
1 100	76 000	—	66	38	28	17	38	21	16	32
1 200	82 000	—	71	41	30	19	41	23	17	34
1 300	88 000	—	76	44	32	20	44	24	18	37
1 400	94 000	—	81	47	34	21	47	26	20	39
1 500	99 600	—	86	50	37	22	50	28	21	41

TABLE 5 (b)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Totally indirect
Illumination level: 20 lumens/sq ft

Ceiling height: 10′—11.5′
Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	13 200	—	11	7	5	3	7	4	3	5
200	22 000	—	19	11	8	5	11	6	5	9
300	30 000	—	26	15	11	7	15	8	6	12
400	39 000	—	34	20	14	9	20	11	8	16
500	44 000	—	38	22	16	10	22	12	9	18
600	50 000	—	43	25	18	11	25	14	10	21
700	55 600	—	48	28	20	13	28	15	12	23
800	62 000	—	53	31	23	14	31	17	13	26
900	68 000	—	59	34	25	15	34	19	14	28
1 000	74 000	—	64	37	27	17	37	21	15	31
1 100	80 000	—	69	40	29	18	40	22	17	33
1 200	86 000	—	74	43	32	19	43	24	18	36
1 300	92 000	—	79	46	34	21	46	26	19	38
1 400	98 000	—	84	49	36	22	49	27	20	41
1 500	103 600	—	89	52	38	23	52	29	22	43

TABLE 5 (c)

Number and wattage ratings of lamps required to deliver a predetermined illumination level in rooms of different sizes

Type of lighting: Totally indirect
Illumination level: 20 lumens/sq ft

Ceiling height: 12′—13.5′
Mounting height: —

Floor area (sq ft)	Lumens required	Incandescent Lamps					Fluorescent Lamps			
							Hot Cathode		Slimline	Cold Cathode
		75W	100W	150W	200W	300W	4′—40W	5′—80W	8′—74W	8′—52W
100	15 600	—	13	8	6	4	8	4	3	6
200	24 000	—	21	12	9	5	12	7	5	10
300	32 600	—	28	16	12	7	16	9	7	14
400	39 600	—	34	20	15	9	20	11	8	16
500	46 400	—	40	23	17	10	23	13	10	19
600	52 600	—	45	26	19	12	26	15	11	22
700	58 800	—	51	29	22	13	29	16	12	24
800	64 800	—	56	32	24	15	32	18	13	27
900	70 800	—	61	35	26	16	35	20	15	29
1 000	77 600	—	67	39	28	18	39	22	16	32
1 100	83 600	—	72	42	31	19	42	23	17	35
1 200	90 000	—	78	45	33	20	45	25	19	37
1 300	95 800	—	83	48	35	22	48	27	20	40
1 400	102 000	—	88	51	37	23	51	28	21	42
1 500	107 600	—	93	54	39	24	54	30	22	45

APPENDIX 2

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