Building Bulletin 33

Department of Education and Science

LIGHTING IN SCHOOLS

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July, 1966.

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Introduction

The importance of good lighting

1. Good lighting is an essential ingredient of a successful school building. This factor was recognised in the first statutory building regulations made under Section 10 of the Education Act 1944 which incorporated improved standards of both day and artificial lighting. This positive influence of legislation on lighting standards in a building type was unique at the time.

2. Good lighting is desirable in any building, but a careful and informed approach to lighting design is particularly important in schools for they contain a very wide range of activities embracing a complex array of different visual tasks, many of which may have to be carried out in the same room. It is desirable to provide good lighting conditions for children and young people during their school life, not only so that they shall not be handicapped in the business of learning – already sufficiently complex – but also so that they may develop the habit of using their eyes intelligently and may carry into later life an awareness of the value of good lighting conditions.

3. The efficiency with which a school building provides a satisfactory environment for education depends to an important degree upon the design of its lighting. Lighting that is insufficient or of low quality leads to poor work, slower reading, more mistakes in writing, and a larger number of breakages and accidents. Pupils – and staff – find concentration more difficult and tire more easily. Children whose vision is less than average are placed under a severe handicap. Badly lit buildings are less interesting to their occupants and provide a lacklustre environment. In short, a school which is not well lit wastes money and human effort.

4. The adaptability of the human eye can lead us to be uncritical of short-comings of which we should be aware. Thus we will often work in our own light, strain to see the face of a speaker silhouetted against a bright window, or continue to work without artificial light long after daylight has faded. While the remedy at times may lie with the users of the school, more often it must come from a fresh approach to the lighting design as a whole.

5. For all these reasons the provision of good lighting of sufficient quantity and high quality should be one of the school architect's main pre-occupations. The most successful designs have been those in which fluent planning to meet the educational requirements of the school is integrated with a skilful solution to the problems of providing for the physical needs of the occupants. This is possible only with a detailed knowledge of the visual implications of the various activities in the school, an understanding of the main physiological aspects of vision, and a grasp of the appropriate technology of lighting. To the architect this may seem a formidable programme but fortunately the principles of good lighting are now more widely understood than they were twenty years ago, owing largely to the work of the Building Research Station, and to the efforts of professional bodies such as the Illuminating Engineering Society. A number of the most useful publications in which the general principles of lighting are set out is given in the short bibliography (see Appendix 7). The purpose of the present Building Bulletin is to discuss the application of these general principles to school design.

6. Part 1 is concerned with the general principles of light and vision as they affect lighting in schools. Parts 2 and 3 deal with the application of these principles to daylighting and artificial lighting respectively. It is convenient to deal with these two aspects separately, for although they are based upon the same principles each affects the design of the building in a different way. Part 4 discusses the circumstances in which the daylighting and the artificial installation can be designed to be used together, so that each complements the other. Part 5 and Appendices 1 and 2 consider in more detail some of the problems which arise in the lighting of particular spaces in the school, in the lighting of schools for the partially-sighted and in remodelling old schools.

7. The Bulletin is intended primarily for architects who have schools to design, although much of what is said should also be relevant to buildings for further education. It may at the same time prove to be useful to lighting engineers by describing the general process of design to which their skills contribute. It is hoped it will also be of interest to the local authority officers and school managers or governors who brief the architect and maintain the schools, as well as to the teachers who use the buildings, so that all may have a fuller understanding of the considerations that go into lighting design. Some notes for the user are given at Part 6 of the Bulletin.

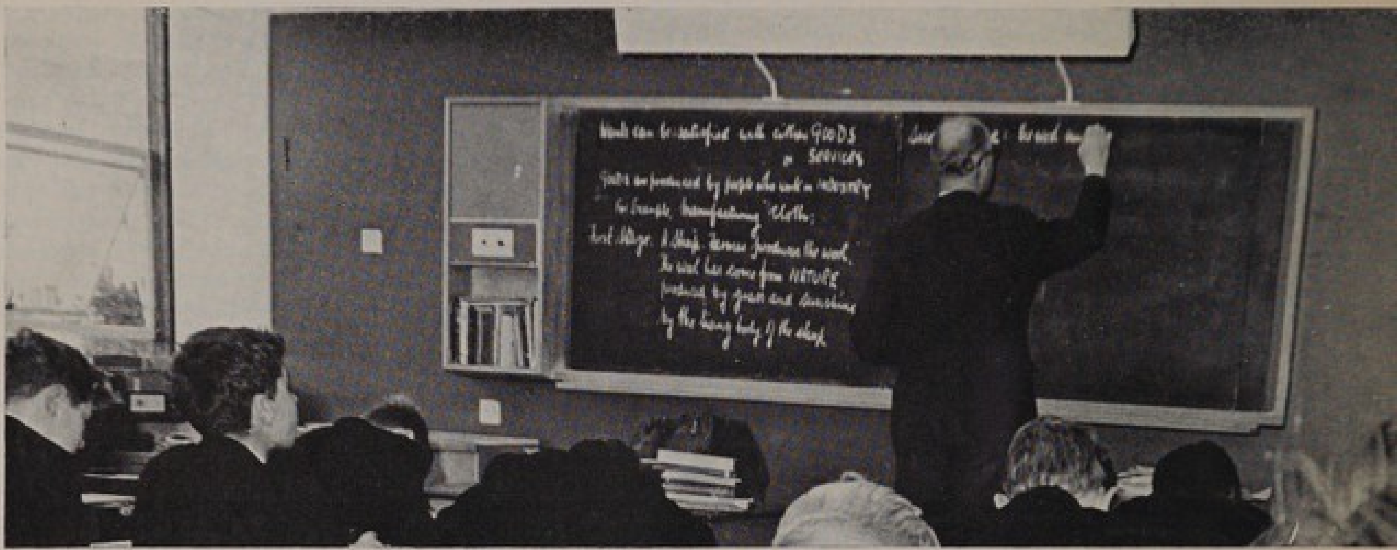
8. Some aspects of lighting in schools have been discussed in earlier Building Bulletins and references to these will be found in the text. In particular, Building Bulletin Number 9, 'Colour in School Buildings' (Third Edition), deals with an important aspect of lighting design in more detail than is possible in the present Bulletin.

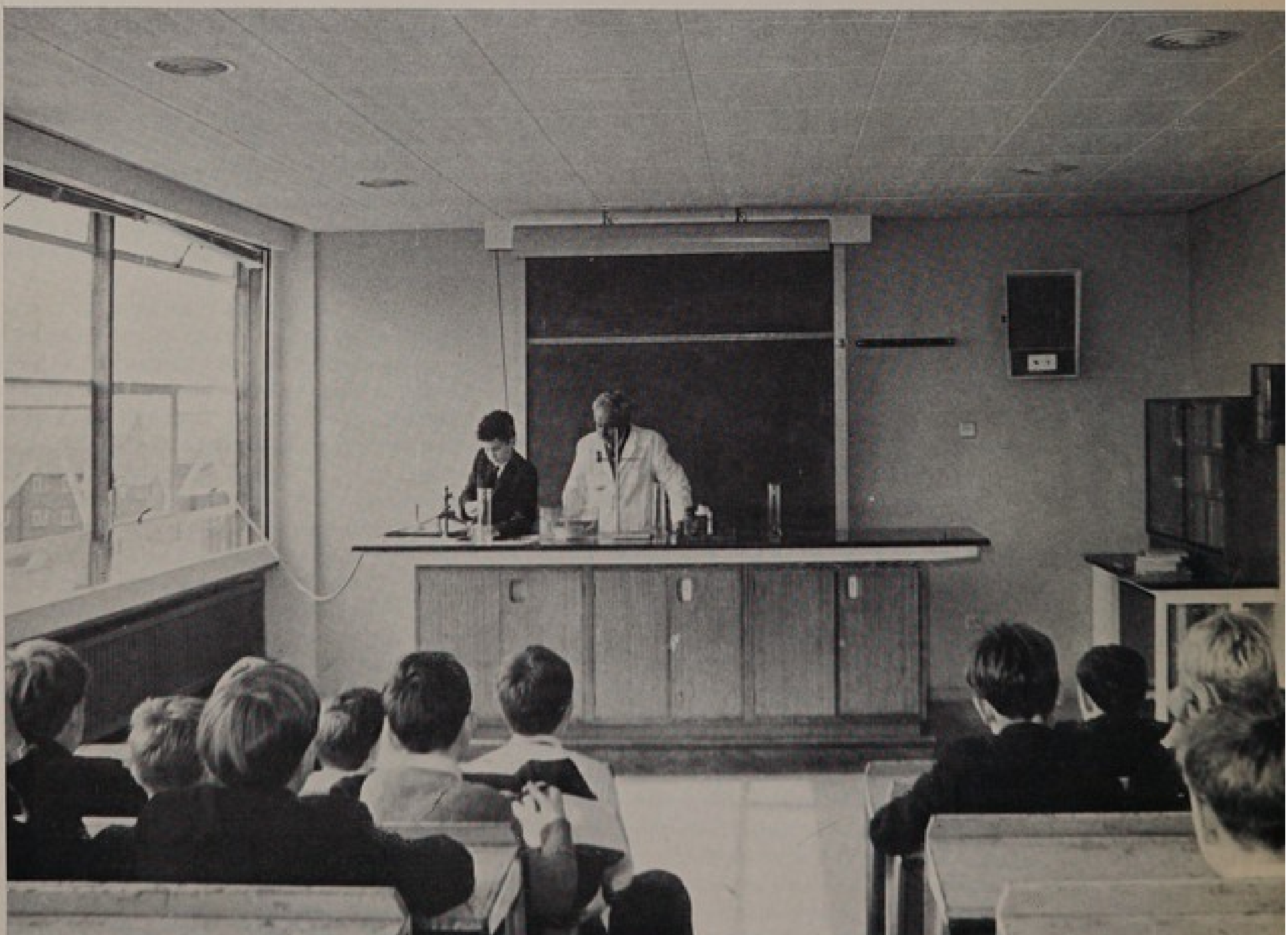
9. Recently, demand has been growing for a more detailed comprehensive study of the application of good lighting principles to both natural and artificial lighting in schools. Public interest in the subject has increased, and at the same time there has been some misunderstanding of the objectives of school lighting design. In some school buildings some relevant factors may have been insufficiently considered so that criticism has been justified. For example, recent experience has emphasised the need for efficient sun control. There have been rapid developments of new and more efficient artificial fittings and techniques. It was perhaps inevitable that twenty years ago the simpler task of providing mere quantity of illumination should have been the main pre-occupation; now it is realised that the emphasis on this aspect was too strong and that there is an urgent need to redress the balance with more attention to the qualitative side.

10. The authors would like to take this opportunity of acknowledging their debt to colleagues who work in the field of lighting, both in public service and elsewhere, and in particular to the lighting research team at the Building Research Station on whose work many of the recent advances in school lighting have been based.

1 Taking notes from chalkboard
Making notes from writing on a chalkboard is one of the most exacting of the common visual tasks in schools. The writing on the board should be large and clear. The illumination of the board should be at least as much as that on the pupils' tables, and a chalkboard fitting is necessary. The colour of the chalkboard should be considered carefully in relation to that of the surrounding wall (paragraphs 195-196).

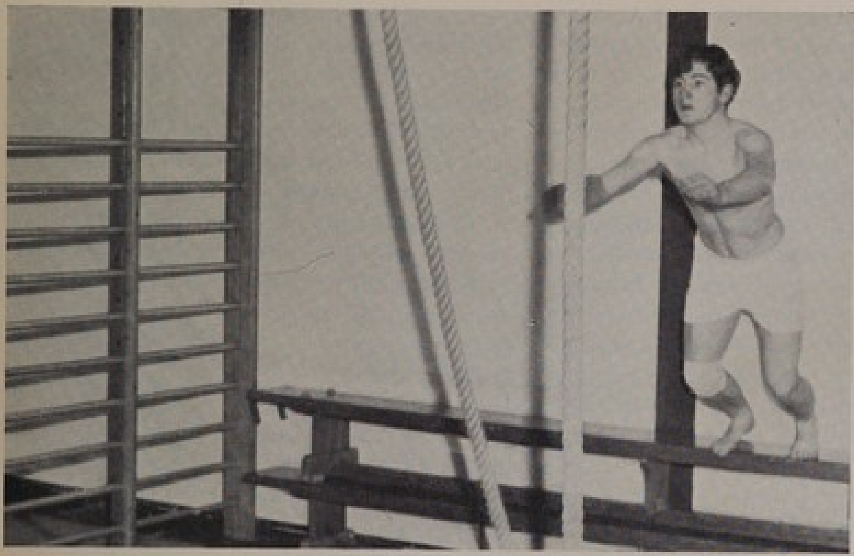
2 Demonstration in science lecture room
Following scientific demonstrations can be difficult. Good sight lines and a high level of illumination on the demonstration bench are required. The photograph shows the importance of arranging an unconfused background to the demonstration (paragraphs 197-199).

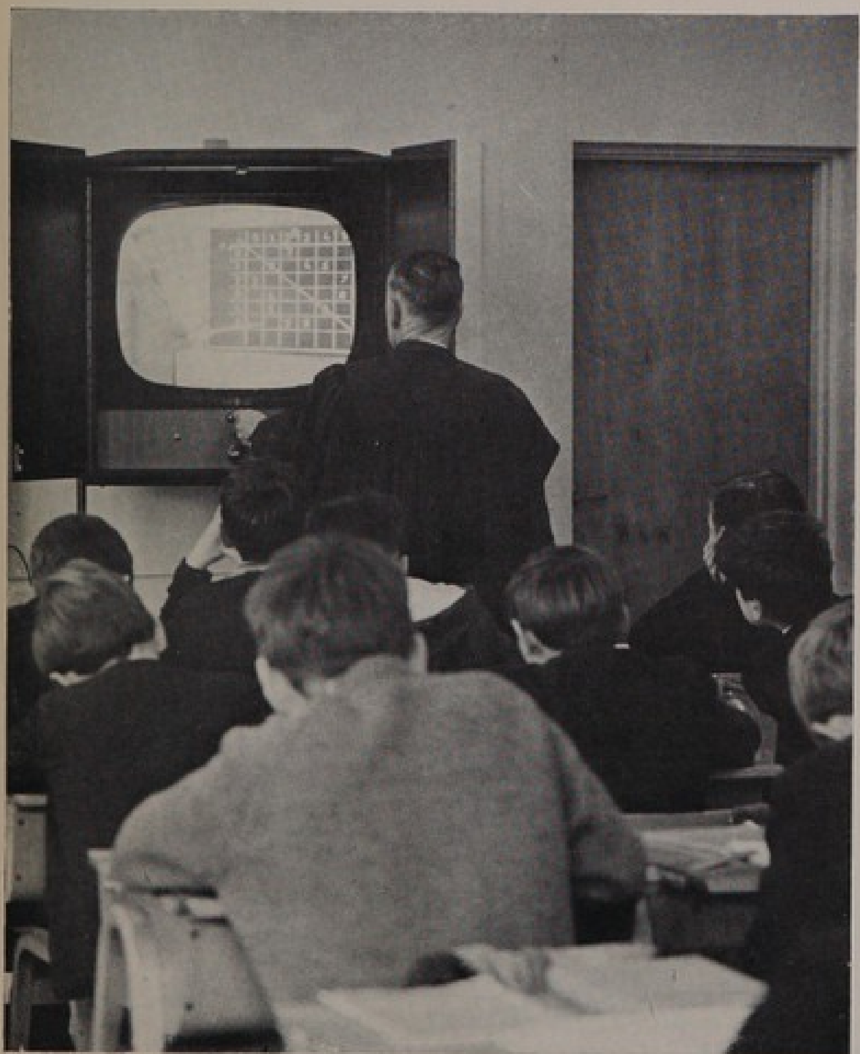




3 Jumping for a swinging rope
Many activities in a gymnasium call for clear vision of fast-moving objects and split-second timing. A good level of glare-free lighting is required (paragraphs 221-230).

4 Group watching television
Many of the visual aids now used in schools need the right lighting conditions if they are to be effective. Television can now be viewed under normal lighting levels, but the set should not be placed against a bright window and care should be taken to avoid reflections of windows or light fittings on the screen (paragraphs 194-207).





Lighting design – some general principles

The aims of good lighting

11. The chief aim of the lighting designer is, in brief, to help the users of the school to see well. To be able to say that this aim has been realised, the staff and pupils must be able to see clearly and comfortably in any of the many and various educational tasks which they may undertake. These will range from copying an equation from a chalkboard, to sewing a fine seam; from following an intricate demonstration in a science lecture room, to painting a picture; from judging the swing of a rope in a gym, to watching television; or just gazing – thoughtfully – out of a window (photographs **1** to **4**).

12. Whether or not people can see well to do these things will depend on the quality of the design of the whole visual environment, and not just on the quantity of light which has been provided. This will in turn depend upon how much the designer knows of the nature of the visual task itself, and of how our eyes react to it. Our understanding of this important aspect of lighting design has been extended in recent years by research work which has developed subjective techniques for assessing the quantity and quality of lighting in terms of how it appears to the observer. This research has shown that, for instance, the advantages of a high level of illumination can be lost if it is accompanied by glare and, conversely, that moderate levels are sufficient for much everyday school work, provided that there is the right distribution of brightness through the room.

13. In order to establish the principles on which good lighting in schools should be based, this part of the Bulletin deals first with some aspects of the nature and behaviour of light itself, and with the scope and limitations of human eyesight. The range of visual tasks in schools is then examined and from this the characteristics of the lighting which should be provided are deduced. Lastly, the broader aspects of lighting as one of the architectural elements in the design of the school are considered, and this is followed by a summary of the main aims in design.

Light

14. Our eyes cannot see without the stimulus of light, which is one form of energy in the shape of electromagnetic radiation. It is the visible section of the spectrum which also contains X-rays and radio waves differing from them only in wavelength and frequency.

15. The only differences in the nature of the light given out by the sun, a clouded sky, a tungsten lamp or a fluorescent tube, are in the various combinations of colours of different wavelengths and intensities of which it is made up, but in design terms these are important differences. Although each of these sources

is commonly considered to produce 'white' light, there is in fact a wide variation in colour composition. This affects not only the appearance of colours used in buildings, but also the visual efficiency of different light sources. The reason for this is that the eye is stimulated to a greater or less degree by light radiations which differ in colour but have equal energy. For example, the eye is more responsive to green-yellow light than to blue or red (diagram 1). Therefore the lighting designer needs to be able to measure light in terms of its effect on the eye and on what is seen. The rate of flow (or flux) of light which illuminates what we see is therefore measured in *lumens*, in units which are corrected for their subjective visual stimulus.

16. The level of illumination on a surface is measured in *lumens per square foot* (lm/ft²), a unit which is identical to the older term *foot-candle* (see Appendix 6). However, this unit only measures the amount of light falling on a surface; and the effect as seen by the eye has to be expressed in terms of its brightness. The physical measure of brightness is called *luminance*, and the luminance of a surface depends upon the illumination falling on it, and upon its reflectivity. The unit in which luminance is normally measured is the foot-lambert (ft-L), one foot-lambert being the luminance of a fully-diffusing, matt surface of 100 per cent reflection factor which receives one lumen per square foot. Thus Reflection Factor (%) × Illumination (lm/ft²) = Luminance (ft-L) (diagram 2).

17. For example, a surface with a reflection factor of 40 per cent (approximately equivalent to Munsell Value 7) on which 10 lm/ft² is falling will have the same luminance as a surface whose reflection factor is 20 per cent (approximately equivalent to Munsell Value 5) on which 20 lm/ft² is falling. Each surface will have a luminance of 4 ft-L.

$$\frac{40}{100} \times 10 = 4$$

and

$$\frac{20}{100} \times 20 = 4$$

18. The light given out by any source, whether natural or artificial, will reach the object which it illuminates in two ways: *directly* from sun, sky, or light fitting; and *indirectly* after inter-reflection from other surfaces inside and sometimes also outside the room. Under artificial illumination, the proportion of the direct component to the indirect component will vary according to whether the fittings direct most of their light upwards or downwards, and according

Diagram 1:
The eye's response to different wavelengths
This shows the eye's response to light of equal energy at different wavelengths. The eye is more sensitive to green-yellow light than to other colours (paragraph 15).

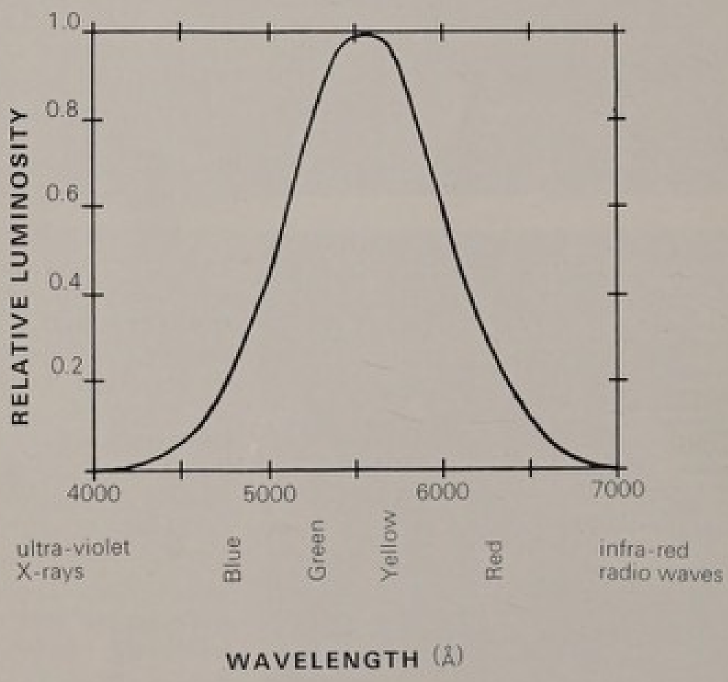
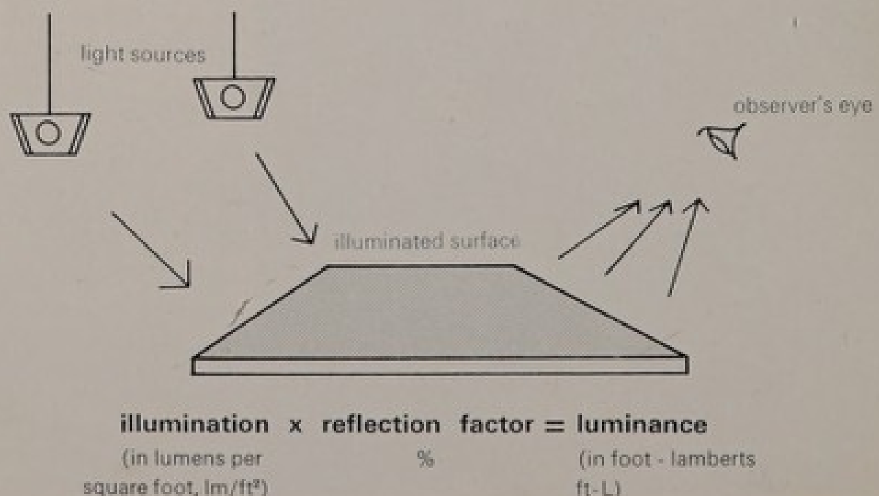


Diagram 2:
Relationship of illumination, reflection factor and luminance
The luminance of a surface will depend both on its reflection factor and upon the illumination falling on it. The surface's apparent brightness to the observer will also be affected by the adaptation level of his eye (paragraphs 16, 17 and 40).



to the reflectivity of the surfaces in the room. In daylight, the proportion will depend upon the size and position of the windows and upon the reflectivity of surfaces in the room, particularly the floor. For example, in a classroom daylit from one side only, and with light interior surfaces, as much as half of the illumination on the desks at the back of the room can be from inter-reflected light. The reflection factor and colouring of surfaces immediately outside the room – green grass, red paving, white concrete – can also have a marked effect upon lighting within the building. Differing proportions of direct to indirect light will influence the appearance of interiors, both in terms of the distribution of illumination and of the character of the space. It can range from the strong modelling with high lights and deep shadow produced by sunlight or directional light fittings, to the soft, diffused effect of wholly indirect lighting.

19. Light striking any surface is either *reflected* or *transmitted* or *absorbed*.

Reflection

20. Rays of light falling on a smooth polished surface will be reflected in a specular fashion, the angle of incidence equalling the angle of reflection. Light-fitting designers make use of this when it is necessary to direct light in a narrow beam. An example of this is the fitting shown in (photograph **27**), which was designed to boost the illumination on chalkboards. It has a polished aluminium reflector with a parabolic profile which throws light out in a parallel beam, in the same way as a car headlight. The use of polished metallic reflectors for such fittings also has the advantage that, when viewed from angles out of the main beam of light, the surface will appear dark and thus will not be a distraction.

21. Smooth, opaque surfaces other than polished metal and glass will give a more diffuse reflection which will include a brighter specular component in one direction. Gloss paint, and a high polish on wood linoleum or plastics reflect light in this way. For this reason, these materials should not be used on desk and table tops, as a distracting dazzle can be caused by the reflected images of light fittings, or bright windows. This effect will be most noticeable on polished surfaces which are dark, as the contrasts will be greater. The reflection of light fittings in uncurtained windows at night can also be irritating.

22. A matt surface will give a diffused reflection which is equally bright in every direction. This is generally to be preferred for the main visible surfaces of a teaching room – walls, floor, ceiling – in order to avoid disturbing reflections. For the same reason, the surfaces of chalkboards should be maintained in a matt condition. Where visual tasks will not be hindered, sparkle can be provided when required by the polished edges of fittings, equipment and architectural trim, which can give controlled reflections on a small scale.

Transmission

23. Rays of light passing through clear glass will be displaced by refraction, which occurs when light passes from a dense to a less dense medium, or vice versa. Use is made of this property in prismatic window glass or light fittings to re-direct light, or to make its surface appear less bright from critical viewing angles.

24. Most artificial light sources are too bright to be viewed directly in comfort, and diffusing materials can be used to reduce the brightness of the source to within the limits required by the building regulations.[1] With a partial diffuser such as frosted glass the source will still be seen, although less brightly, and will appear as a 'hot spot'. Using a more complete diffuser such as a dense opal acrylic plastic, the surface will be evenly illuminated but will probably transmit less light. So a compromise will have to be made in which satisfactory appearance is combined with the output of light required from the fitting as a whole. The bright lamp need only be shielded from normal viewing angles.

25. Similar considerations apply to the choice of suitable materials for window blinds, for the blind must check the direct rays of the sun, but must at the same time allow sufficient light to pass for general illumination. The design problem which this creates is discussed further in paragraphs 86-95.

Absorption

26. Radiation which is neither reflected nor transmitted will be absorbed by the surface on which it falls. Thus a metal, glass or plastic shade will heat up when the light is switched on, and allowance must be made for this in its design. Where higher levels of illumination are provided for, the total heat emitted by the lamps may prove to be an embarrassment. Thus tungsten filament fittings giving 30 lm/ft² in a room of about 1,000 sq ft will emit about 6 kilowatts, with a consequent heating effect both of direct radiation on the occupants, and by raising the internal temperature.

27. To understand and thus to be able to control the ways in which light spreads through a room is clearly most important to the lighting designer as it will help him to create whatever lighting conditions he thinks to be appropriate. To understand the lighting conditions that will achieve the aim of helping the users of the school to see well, it is now necessary to look more closely at the ways in which lighting conditions affect our eyesight.

Eyesight

Scope and limitations

28. The human eye has an impressive performance, with the capacity to adapt itself to a wide range of lighting conditions. 'It will achieve enough vision to enable one to get about in starlight, and it will function, although in discomfort, in full sunlight on snow-covered ground. The sunlit snow is more than a *million million* times as bright as the starlit scene.'[2] However, the eye takes some while to adapt itself from one extreme to another – as we know when walking out of a cinema into broad daylight. It cannot cope easily with abrupt changes in brightness, such as looking up from a notebook on a sunlit desk to try to make out writing on a chalkboard in a shaded part of the room. Therefore one should not abuse the adaptability of the eye by forcing it to work near to the limits of its capabilities, but should aim to bring about those lighting conditions in which it can function most satisfactorily. There is little evidence that the extent of bad lighting to be found in schools can have any permanent harmful effect on children's

[1] The term 'building regulations' is used in this Bulletin to denote the *Standards for School Premises Regulations*: the current version was published in 1959 as *Statutory Instrument*, 1959, No. 890.

[2] *Some General Principles of the Lighting of Buildings*. B.R.S. Digest No. 70 (1st Series), October, 1954.

eyes. The danger is that bad lighting can retard the process of learning by making concentration more difficult and by hastening the onset of tiredness during the day, through the physical and mental strain of trying to see under unfavourable conditions.

29. For these reasons it is most important for the architect to understand the limitations as well as the range of human vision, and from this to be able to create the conditions under which the eye can perform best, with as little effort as possible.

The visual task

30. The essentials of the task that a school child's eyes have to do lie in making out the key features of the scene which is being observed by distinguishing differences in shape, position in space, texture, colour and brightness. The eyes have to supply the brain with sufficient information for it either to be able to recognise objects already familiar from previous experience or, if the objects cannot be identified precisely, then to provide enough clues for an intelligent guess at their nature to be made.

31. The visual difficulty of the work will vary widely. It may be relatively straightforward, as in reading a clearly printed book. It may be very much more difficult as, for example, when trying to trace accurately over a faded engineering print (photograph **5**), or to differentiate between two colours which are very close, or to align precisely the markings on a vernier scale (photograph **6**). The visual task may be one that has to be done very quickly and without the chance of retracing one's steps, such as when sight-reading music (photograph **7**). The object, observed may be stationary or it may be moving fast as when trying to follow the rapid movements of a P.E. instructor demonstrating a handspring (photograph **8**). The task may be only intermittent or it may be one requiring sustained visual concentration. Clearly the nature of the visual task which is being undertaken will determine both the quantity and the quality of light that should be provided if the work is to be done easily.

Quantity of light

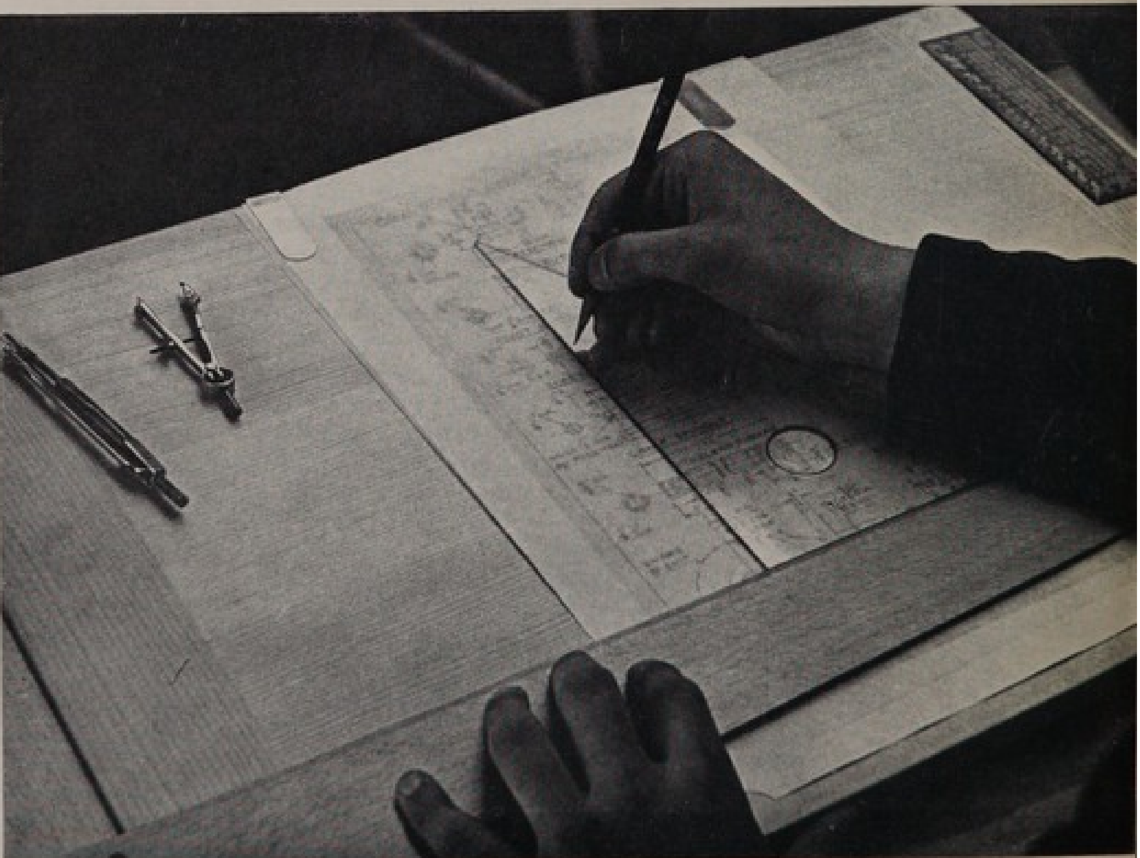
General note

32. The general rule is that the more difficult the visual task, the greater is the amount of light that should be provided to allow the job to be done efficiently. If work has intricate and small-scale detail, lacks contrasts of light and dark or of colour, has to be done very quickly or requires sustained attention, then it will be carried out more easily under a high level of illumination, always providing the lighting is of commensurate quality. Thus pupils in a needlework room or in a technical drawing office will benefit from a higher level of lighting on their work than they would require in a general-purpose classroom.

Recommended levels of illumination

33. Regulation 52(2) of the building regulations requires that 'In all teaching accommodation and kitchens the level of maintained illumination and the daylight factor, on the appropriate plane in the area of normal use, shall be not less than ten lumens per square foot and 2 per cent respectively'. This is the *minimum* permitted: to ensure that none of the working areas in the room falls beneath this, it is necessary to design for a higher *average* level of illumination. The reason why this level was chosen as the minimum was that research work had shown that at least four-fifths of school children achieved a good standard of vision at 10 lm/ft^2 and could see well enough to do normal school work such as reading ¾ inch high writing on a chalkboard at a distance of 30 feet. Below this level of illumination visual acuity fell away rapidly. Above 10 lm/ft^2 it was found that visual performance did not improve proportionately with increases in the level of illumination.

34. At the same time it is worth bearing in mind that a visual task will be made easier by an improvement in any of its aspects, for instance, by an increase in the contrast or size of the details. Moreover, such improvements will increase the ability to see more



5 Technical drawing
Technical drawing, and particularly tracing, is best performed under a high level of illumination with the minimum direct or reflected glare. Normally general overhead lighting will be sufficient, but for advanced work an adjustable light at the board may be preferred (paragraph 181).

6 Precision work in engineering
Precise measurements such as the reading of vernier scales have often to be made in science and workshop crafts (paragraph 186).

7 Sight-reading music
Sight-reading music is an unusually exacting visual task. In the photograph the music stand is well lit, but glare from the windows could be distracting when trying to follow the conductor. Intelligent use of a room can anticipate some of these difficulties (paragraph 31).

8 Agility work in physical education
Demonstrations of swift moving agility work in P.E. need to be seen under good lighting conditions. A background of bright windows or a very highly polished floor is not helpful (paragraphs 221-230).

effectively than higher levels of illumination will. Thus for the teacher to write on the chalkboard with letters 1½ inches high instead of 1 inch high would be as effective in improving visibility as would raising the level of illumination by *ten times*. Unfortunately, it is usually the case that increases in the size and contrast of detail, desirable as they may be, are beyond the architect's control: he cannot dictate the size of writing on the chalkboard, the size of print used in text books, or the contrastiness or positioning of wall maps. These matters are in the hands of the education authorities and the teachers. For these reasons weak-sighted children should have special consideration and should be encouraged to sit closer to the chalkboard. This will be the most effective means of helping them for, as has been mentioned, increases in the apparent size of what one is looking at can have a marked effect on visual performance – for a child to move four feet closer to the chalkboard will have visual advantages for him which can only be matched by raising the level of illumination by thirty times. This emphasizes the importance of planning rooms which have a chalkboard so that children do not have to sit too far from it. Thirty feet should be considered a maximum, and less than this would be preferable in rooms for subjects such as mathematics and science where intricate formulae and symbols are used.

35. In some subjects both reading and practical work will be much more exacting visually than in normal classrooms, and higher levels of illumination will be needed to allow the work to be done easily. Regulation 52(1) of the building regulations deals with this point in general terms: 'In every school and in all boarding accommodation, the lighting, both natural and artificial, of each room or other space shall be appropriate to the normal use for which the room or other space is designed.' The architect and lighting engineer will have to use their judgement to decide what this level should be and whether this is to be provided over the whole of the room or only in limited areas. The lighting of particular spaces is discussed in more detail in Part 5. The Code of the Illuminating Engineering Society makes recommendations for maintained illumination levels in schools and colleges, and these are given in Table 1. However, these are not the Department's official recommendations and the actual quantity of lighting provided will have to be decided after consideration of the likely capital cost of the electrical installation (and of the charges for current), bearing in mind the principle that it is desirable that the money available for a school should be distributed in a balanced fashion over the various elements in the building. It may well be necessary to choose a level of lighting which falls between the I.E.S. Code figures and the Regulation minimum of 10 lm/ft^2. For example, in a secondary school designed in 1957 by the Department's Development Group it was found to be practicable within normal cost limits to provide an average level of overall lighting of 15 lm/ft^2 in general classrooms, including the chalkboards, 20 lm/ft^2 in science laboratories, and 30 lm/ft^2 in technical drawing and needlework rooms, with additional local lighting where this was necessary.

Table 1 Values of illumination in schools and colleges

Note: The following illumination values are taken with permission from the *1961 Code of the Illuminating Engineering Society*.(a) They do not represent the official recommendations of the Department, but will help to indicate relative values in different parts of the building. The significance of the limiting Glare Index is explained in paragraph 122 (Part 3 of the Bulletin).

	Recommended Illumination lm/ft^2	Limiting Glare Index
Assembly halls:		
general	15	16
when used for examinations	30	16
platforms	30	16
Class and lecture rooms:		
desks	30	16
chalkboards (b)	20 to 30	
Embroidery and sewing rooms	70	10
Art rooms (c)	45	16
Laboratories	30	16
Libraries:		
shelves, stacks (b)	5 to 10	—
reading tables	30	16
Manual training (varies according to trade, see full IES Code)		
Offices	30	19
Staffrooms, common rooms	15	16
Corridors	7	—
Stairs	10	—

Notes: (a) see pages 41, 42 and 54 of the Code
(b) on vertical surface
(c) special attention should be given to the direction and colour quality of the light

36. The levels of lighting given in Table 1 will allow high standards of visual performance, provided that there is freedom from glare and that there is no visual discomfort from other causes. This is an essential proviso: the advantages of a high – and costly – level of illumination can be lost if great care is not taken to design a lighting installation of good quality in an environment which is free from visual discomfort.

Quality in lighting

General note

37. The eye's ability to adapt itself to changing conditions of light has already been mentioned. The structure of the eye makes this a two-stage process. First, the 'aperture' of the iris contracts or expands quite rapidly to regulate the amount of light entering the eye. Secondly, the retina adjusts its sensitivity to changes in the levels of brightness of the light falling upon its surface. There is in fact a third stage as the eyelid can close and act as an emergency shutter to shield the eye from sudden overloads of bright light.

38. This is a familiar process: when first entering a room blacked-out for a film show you grope your way to your seat, but after a little while your eyes get used to the dim interior and you can see quite easily. It is worth remembering that adaptation from light to dark takes place more slowly than from dark to light. Unexpected changes of brightness in a dimly lit entrance hall can be dangerous if you come upon them soon after you have left the bright outdoor scene. The illumination outside on a sunny day will be as much as 500 times higher than that inside. For this reason it is probably wise to lead people gradually and by easy visual stages into the much lower levels of illumination within a building.

39. The slowness of this process of adaptation also suggests that, if a person's activities within a room

involve him in looking repeatedly from one part to another, as a pupil will when looking up from the notebook on his desk to the chalkboard and then down again, the general brightnesses of each zone should be as nearly as possible the same to prevent unnecessary muscular effort caused by repeated adaptation of the eyes. This does not mean that there should not be contrasts of light and shade and colour in the detail within each zone, for this will be necessary to focus attention and allow detail to be seen easily. This crucial design problem of providing comfort without a soporific flatness, and stimulus without discomfort is discussed further below.

40. Another important aspect of this process of adaptation is that the eye adjusts itself to the *average* level of brightness of the scene in front of it, in much the same way as a photographic light meter. This scene may well include areas which are much lighter or darker than the average – a splash of sunlight by the window on the one hand, and deep shadows behind furniture at the back of the room on the other. The occupant's judgement of the brightness of the part of the room in which he is sitting will depend upon the *average* level to which he is adapted. If he is sitting on a summer's day at the back of a classroom from which he can see a brilliant sunlit area by the window and bright clouds through it, his eyes will tend to adapt to the bright areas by the window. By contrast, the illumination on his desk at the back of the room will seem inadequate. If a window blind is lowered enough to cut out the direct sun and the view of the bright sky beyond, then the pupil sitting at the back of the room will adapt after a while to a lower level. The illumination on his desk will then subjectively seem to be higher even though it may, with the blinds down, be a little less as measured by a light meter. The control of the pattern of *apparent* brightness in the field of view, as well as the actual levels of illumination, is one of the main ways in which the architect can create conditions for good vision.

Avoiding glare

41. While the eye is very adaptable, there are limits beyond which it cannot cope with extreme contrasts in brightness which occur side by side in the field of view. If these occur, glare is caused and visibility suffers particularly in the darker parts. This can be demonstrated by looking at a window from which there is a view of a bright patch of sky, or at a bright light fitting, and then trying to look into the shadowed area around it. If you then cover the bright source with your hand, you will see much more detail in the shadow. This glare is caused partly by the veiling due to the scattering of bright light in the eye, and partly because the eye tends to adapt itself to the highest average levels in its field of view. There is also the irritation caused by the constant effort to force one's attention away from the bright areas.

42. Some forms of glare are self-evident, such as the feeling of discomfort bordering on pain that one experiences when looking directly at a bare lamp in a gloomy room. Other forms of glare are not so obvious and may only cause irritation and discomfort after some while. Indeed, children may attribute their headaches and tired eyes to some other cause. This more insidious type of glare commonly occurs in rooms where a high level of illumination has been provided without giving sufficient attention to the quality of the lighting, and where there are a large number of bright light fittings or a range of large windows within the normal field of view.

43. The most common causes of glare are unscreened lamps or fluorescent tubes; bright light fittings seen against a dark background; bright areas of sky seen through large unshaded windows; and the presence of dark surfaces of columns, transoms, mullions or window bars silhouetted against the sky (photographs **9** and **10**).

44. The glare caused by the specular reflection of bright light sources in glossy paper or shiny instruments, on gloss painted walls or chalkboards which have lost their matt surface, or on polished desk tops can also be troublesome. While it is sometimes possible to move one's head to avoid these reflections, this becomes increasingly difficult with higher illumination levels and the consequent close spacing of light fittings.

45. Ways in which the risk of glare can be reduced are discussed in the two following parts. But before this is dealt with in more detail, it is necessary to consider briefly some other ways in which the quality of lighting can be improved.

Aiding concentration

46. The eye is attracted involuntarily to that part of the field of view which is the brighest or has the greatest contrast of light and dark, or of colour. This phenomenon is called phototropism and with appropriate lighting it can be used to direct the pupils' attention where it is required: for example, to the book on the library table or to the chalkboard in the lecture room. This can be done by increasing the amount of local lighting on the job in hand, such as with a pendant light over a library table, and this may be reinforced by making sure that the immediate object of attention – book, lathe, ball, instrument dial – is light-coloured and contrasty compared with other objects around it. Harsh contrasts are not necessary to achieve this effect; what is required is a gradual stepping-down of brightness from the work into the immediate and then the general surroundings. Black print on a white page is clearly a good focal point; this is best seen against a light coloured desk top and beyond that a medium coloured floor of about Munsell Value 6. Vivid contrasts in the surroundings should be avoided in such circumstances, as one's eye would then be drawn to them by the same phototropic effect; a black-and-white chequer pattern on the floor would be most distracting when seen alongside one's desk, and glaring windows or light fittings would cause the same trouble. It is of course possible to override this counter-attraction and keep one's attention on one's work, but this requires a conscious effort which becomes tiring and irritating after a time.

47. The exploitation of phototropism need not be confined to teaching rooms. It can also be used to draw attention to a change of level in a corridor or perhaps to a lively mural painting at the end of it.

The role of modelling

48. Artists from Rembrandt onwards have used shadows to fix the position and confirm the identity of objects or of textured surfaces. In the same way directional lighting can help to place objects and clarify their shape and details. For the general run of school work it is usually sufficient for there to be an overall distribution of light, with modelling emphasised by a punch of light from one direction, for example, from the main run of windows or from the nearest light fitting. But for more difficult visual tasks, such as operating a sewing machine, dissecting

9 Glare from the sky
During daytime, glare can be caused by the view of an excessively bright sky through a window, particularly if it is very close to places at which pupils have to look. In the photograph the teacher should have avoided sitting with his back to the window. Window blinds should be used to control glare (paragraphs 41-45 and 83-95).

10 Glare from light fittings
After dark, glare can be caused by bare lamps or large excessively bright light fittings seen against backgrounds which are relatively dark. The brightness of fittings should be reduced and that of the general environment should be raised. In the photograph the uncurtained windows and dark floor also cause the room to look gloomy (paragraphs 41-45 and 116-123).

a dogfish, or doing an intricate piece of work on a lathe, it will be necessary to provide additional local lighting which can be adjusted to reveal the details of the task as well as giving a high level of illumination on the work in hand (photographs **20**, **21** and **26**). While it may at times be possible to gain this additional lighting by taking the work to the window, more usually the pupil will have to stay at his work place with the local lighting being brought to him by a portable light fitting. Care must be taken to see that such local lighting does not cause dazzle or glare to the user or to other occupants of the room.

49. In these ways local and directional lighting can be used to model the visual task in a manner that makes work easier. The architect will also use directional lighting, and the play of light and shade it can give, to model the building itself: to articulate spaces and solid forms. This extends the discussion of good quality in the lighting of specific visual tasks to the more general question of designing the visual environment as a whole, both being an inseparable part of good lighting in schools.

Lighting and architecture

General note

50. When designing the lighting – or any other part – of a school, the architect's primary aim will be to satisfy the main educational requirements and to provide comfortable physical surroundings. In the course of achieving this aim he will have to make many decisions on points of design which will inevitably affect the general visual environment in important ways. In some cases the decision will depend upon factors which do not arise from the requirements of lighting and yet may have a considerable effect upon it. For example, the choice of one particular method of construction can limit the size and position of windows or, again, the need for durable and acid-resistant bench tops in laboratories may restrict the choice of material to dark-coloured woods. In most cases, however, while decisions on details of design will depend mainly on considerations other than lighting, there will remain some freedom of choice to allow the most appropriate lighting condition to be selected. Thus the size and position of an architrave may already be fixed by structural considerations, but its finish and colour can be chosen to suit the visual objectives of the lighting scheme.

51. Light is the primary medium through which we appreciate our architectural surroundings. The play of light and shade models solid forms, gives a surface its texture, and makes space intelligible. In the early stages of design, architects are rightly conscious of the formal aspects of their buildings, visualising them as solids and voids, as three-dimensional enclosures of space. However, the full realisation of these forms also needs sympathetic consideration of how they will appear when coloured and lit, both by day and after dark.

Visual character

52. The general appearance of most work spaces in a school will be moulded by functional requirements, including of course the visual tasks which the occupants have to undertake. But within the range of possible solutions to the functional requirements the architect will have some room to manoeuvre in giving the interior the right visual character. The creation of an appropriate visual character for the various spaces in a school is one of the most elusive and yet one of the most important facets of an architect's work. We do not yet know very much about the psychological reasons for the ways in which the appearance of our physical environment helps to form our emotions. Most people, however, are ready to describe a room as being on the one hand 'gay', 'stimulating' (or perhaps 'restless', 'jazzy'), or on the other hand 'restful', 'calm' (or perhaps 'dull', 'lifeless'). Where the line is drawn between surroundings which are 'stimulating' and those which are 'restless', and between a 'restful' room and a 'dull' one will often depend on the mood of the observer. But at the extremes it seems probable that the stimulating room will be one that contains lively contrasts in light and shade, and in colour, while in the restful room contrasts will be more subdued. To judge, first, what visual character a room should have, and then to create surroundings which take on this character is one of the most difficult aspects of design. It demands the careful consideration of the interaction of lighting with space, form, and colouring from the earliest stages of the design through to every detail.

53. For example, most teachers would say that the school library should have a special character of its own. But what should this character be, and how can lighting contribute to this? Should it have that sombre, dignified air with dark oak panelling, the honours boards and the bust of the founder, the leather-topped tables, the high sills ('to prevent distractions'), the standard bindings with a little discreet gilt, the green-shaded lights – a virtual mausoleum to the printed word? Or should it not rather be light and inviting, with restful views within the room as well as a pleasant prospect through the windows to encourage reflection (for poems as well as essays are written in libraries) and as a visual release from the close work of reading and writing; also with full facilities for the stimulating display of the books themselves, their jackets, their illustrations, and their relevance to the other activities of the school. Lighting and colour are indispensable in helping to create the right character.

Lighting and colour[1]

54. In the creation of good lighting conditions in a school the lighting itself, either natural or artificial, and the colouring of the interior surfaces of the building should be considered together, as they are often complementary. This concerns both the strength (Munsell *chroma*) of the colour, and its lightness (Munsell *value*) which is directly related to its reflection factor.[2] Thus in a room lit from one side only, the use on the rear wall of a colour of high reflection factor (Munsell value 9, or even white) will both increase the amount of inter-reflected light at the back of the room and also give a sensation of brightness which will help to compensate those sitting at a distance from the window. A wall seen at the end of a corridor may well be a good position for a strong, light colour for it will provide an effective visual stop and prevent an indeterminate tunnel effect. If the wall is not well lit, one can use the group of colours which combine high value and high chroma – the yellow-reds, yellows, and green-yellows.

[1] See Building Bulletin Number 9, *Colour in School Buildings* (Third Edition, 1962), for a full discussion of this subject.

[2] Reflection factor = V (V-1) per cent, where V = Munsell value.

55. The role of light and colour in an interior can be seen clearly if one imagines a room in which every surface is decorated with the same colour, and which is illuminated by wholly diffused lighting. The total absence of contrast will make it very difficult to see at all, and the lack of visual stimulus will have a soporific effect. If the lighting is made directional, one's visual appreciation of the room will then depend upon the play of light and shade across plain and textured surfaces, on projecting mouldings, and around the furniture and other contents of the room. Such monochrome interiors are sometimes created deliberately, but there is a danger, particularly under our typically soft daylight conditions, that such a design will be flat and dull. Therefore colour contrasts in hue, value and chroma are used not only to improve lighting conditions in a room but also to bring liveliness and clarity to the interior, demarcating one element from another.

56. In Building Bulletin No. 9 a useful distinction is made between elements '. . . which are *extensive in area*, such as walls, doors, floors and ceilings, and those which are *linear*, such as beams, pilasters and pipes'. (Page 11.) It goes on to suggest that the main colour emphasis would be placed most appropriately upon the former, allowing the linear elements – columns, pilasters, skirtings, cornices, architraves and mouldings generally – to be left in neutral colours, framing and delimiting the areas of stronger colour. However, strong colours should generally be avoided on walls or pin-up boards which are likely to be used for the display of school work and similar material.

57. This approach also makes sense when considering lighting, as the linear elements, being for the most part architectural 'trim', will normally project from the main surfaces and thus be modelled by highlight and shadow.

The importance of visual contrasts

58. Visual contrasts play a leading role in this aspect of design – contrasts of light and dark, highlight and shadow; contrasts between different textures such as between a matt and a gloss paint; contrasts between colours which differ in hue, value or chroma. Such contrasts should be made a part of the overall design by considering the interaction of form, colour, and lighting from the earliest stages. The use of white, a neutral grey, or even black will form a reference point against which other colours may be read. Small areas of a dark, rich colour can act as a bass note, as it were, to set off an otherwise high-key colour scheme. These contrasts are valuable not only because they introduce interest and variety, and help to articulate the appearance of the building visually, but also because they can be used to make some visual tasks easier. Excessive contrasts may, if badly handled, have the opposite effect, and result in a confusing and disjointed interior which hinders visual performance. Thus the contrasts on a chalkboard wall should be low, allowing the eye to rest on the chalkboard without distractions (see Building Bulletin Number 9, pages 28-30).

Illusion and reality

59. In addition to using lighting and colour to meet functional requirements and to create an appropriate visual character, the architect will also use lighting and colour to clarify the layout of the plan and the structural logic of the building. The illusionistic tricks of the architect's trade, by which ceilings can be made to appear to float or walls to dissolve, the use of colour to make surfaces advance or retreat, the warping of scale to make things seem bigger or smaller than they really are, the falsifying of perspective to make spaces seem longer or shorter, the extension of space with mirrors – all these may have some place in the repertoire of an architect designing a school, for it need not always be a prosaic building. But for most of the time the pupil should see the world unambiguously, and the architect should use his knowledge of lighting to further this. It will not help the pupil if his half-finished painting changes colour violently when the lights are switched on, or if the rope in the gym appears to swing faster as it comes under a light.

60. So for teaching areas where straightforward vision is required the aim should be to use lighting and colour to create an unconfused visual environment in which the various parts of the building each take their place logically in a unified design.

Summary of design aims

61. The five main considerations which should be borne in mind in the course of lighting design may be summarised as follows:

(i) *Consider the type of work* which is to be carried out in the room. Is it of a simple nature, or does it involve detailed, sustained, or unusually difficult visual tasks? Has the room to be used flexibly, or are the work places fixed? Are there special visual focal points such as chalkboards or demonstration benches?

(ii) *Provide a sufficient amount of light* distributed as necessary through the room by both general and local lighting. Good *quality* in lighting will be more valuable in helping people to see well than the highest levels of illumination.

(iii) *Avoid visual discomfort* by eliminating excessive contrasts of brightness in the field of view which would cause glare or which would tire the eyes by the need for repeated adaptation from one level to another. Is it possible to work with equal comfort facing in any direction in the room?

(iv) *Focus attention* on the key parts of the work by building up a comfortable pattern of brightness through the room.

(v) *Create an interesting environment* with an appropriate visual character by designing from the earliest stages for sufficient contrasts in light and colour.

62. The remaining Parts of this Bulletin deal with the application of these principles to natural, artificial and combined lighting in the various parts of school buildings.

2 Daylighting

Daylighting re-appraised

63. Until recently daylighting has been unchallenged as the most suitable and economic technique for providing working illumination in school buildings. It would probably be true to say that no single influence – other than education itself – has been so powerful in shaping schools as the need to secure good daylight. Almost every layout, plan form, section, window and top light disposition has been influenced by this. However, in recent years technical developments have reduced the cost of artificial lighting to the point when it has been necessary to re-examine daylighting methods to see whether their use has been solely because they are cheap, or whether daylight has in fact some special properties which makes it desirable on other grounds as well.

64. Some other factors have also prompted this re-appraisal of daylighting. Large windows, it is said, can lead to overheating on sunny days in summer: conversely, they cause excessive heat losses on cold days in the winter. Windows tend to be more expensive than solid walls. It is pointed out that daylight is not in fact free but has to be paid for in the cost of lengthy perimeters and elaborate sectional devices which are necessary to secure its entry to the building. Moreover, window blinds have often to be added, and window cleaning is an expensive form of maintenance. It is suggested that as the artificial installation has to be provided in any case for use after dark, why not use it during the day and leave out the windows? Some schools in the U.S.A. are windowless with a constant artificial indoor climate – so why not here? It is also argued that high levels of illumination are now necessary and that daylighting could not provide these satisfactorily.

65. These arguments are forceful ones and need to be considered seriously, especially as they are often based upon justifiable user complaints about particular buildings with unsatisfactory daylighting. Nevertheless, it remains true that for most day schools on normal sites in this country, daylight when properly designed is still the most satisfactory and economic method of providing working illumination, and it makes a contribution to the educational and visual environment of a school which can not be made in any other way. This part of the Bulletin explains how this conclusion has been reached.

66. Under some exceptional circumstances the use of daylight and artificial lighting in combination might be the best answer, but daylight is still an essential part of this technique, which is discussed more fully in Part 4. On closer examination it was found that many of the complaints about daylighting originated in buildings in which daylighting techniques had been improperly applied rather than anything inherent in daylighting itself.

67. In our temperate climate, with its high proportion of clouded skies and sunless days, the common desire for daylight and for buildings into which the infrequent sun may penetrate is an understandable one, especially as it is associated with the natural human desire to keep in touch with the world outside and with the constant shift in our weather and the variety of the seasons. A pleasing view through the window is of course a prerequisite, and this should be considered as carefully as the interior of the building, perhaps with moving foliage combined with man-made elements to make a varied and interesting scene.

68. In more extreme climates, where the winters are much colder and the sun in summer is much hotter, the discomforts which an external window may bring in terms of excessive heat loss or gain will have to be offset against the advantages mentioned above. In such countries these climatic conditions will justify more costly solutions, such as double glazing to conserve heat and elaborate screening devices to shield the windows from the direct rays of the sun. These measures are naturally expensive and architects have been tempted to bypass these problems and to resort to windowless schools with permanent artificial lighting, and thus to deny people the qualities of daylight. The arguments for and against such a solution are discussed in Chapter IX of Building Bulletin Number 18, *Schools in the U.S.A.*

69. In Britain, however, the sun is not so hot nor the winters so cold as to call for a windowless building. Moreover the activities conducted in a school will very rarely require the clinical control of environment possible in a closed, air-conditioned room. Nevertheless, even in our country, rooms with extensive areas of unprotected glass facing south can experience a distressing build-up of heat on a sunny summer's day, and efficient methods of sun control must be incorporated. A method which enables designers to estimate solar heat gains is now available.[1] In winter thermal losses through the windows are offset to a considerable extent by heat gained by radiation from the sky and sun. But for comfort and economy to go hand in hand, the heating controls in the various parts of the school must be flexible enough to maintain comfortable conditions on exceptionally cold and windy days, as well as to allow for the intermittent gains from sunlight during milder weather. Only on the most exposed sites might the need for exceptional measures to ensure physical comfort justify the additional expense of double glazing. It will be seen below that very large windows are not in fact necessary to give good standards of lighting, and that there are ways in which the difficulties mentioned above can be overcome so that the fresh and vital atmosphere that daylighting can give to a school can be enjoyed without reservations.

Quantity of daylighting

Lighting from the sky

70. Since we cannot rely upon direct sunlight as a steady source of illumination, daylight design must be based upon the clouded sky and any attempt to

[1] Building Research Station Current Papers, Research Series:
No. 37 *Investigation of Summer Overheating at the B.R.S., England* by A. G. Loudon and E. Danter.
No. 39 *Sunpath Diagrams and Overlays for Solar Heat Gain Calculations* by P. Petherbridge.

establish a method of calculation has to start from an examination of the overcast sky as a source of light. Measurements taken through the year show that there is, as one would expect, a wide range of illumination from 200 lm/ft² on a dull February afternoon to 3,000 lm/ft² on a bright summer morning with the sun shining on light, hazy cloud. The various levels of illumination to be expected through the year are given in Table 2.

71. Any method of lighting design using daylight as the main source of illumination must make sure that there is sufficient light in the building on all but the dullest days, and must take into account the hours during which schools are occupied. While illumination from the sky varies through the year, it has been accepted that in our latitude a sky providing 500 lm/ft² should be taken as the lowest level that a designer would be expected to cope with. This figure

Table 2[1] Percentages of total working time of the number of hours during the year for which the illumination exceeds certain recommended levels at given daylight factors

Daylight Factor (per cent)	Illumination (lm/ft²) 10	15	20	30	45	70	100
0·5	35	5	—	—	—	—	—
1·0	67	52	35	5	—	—	—
2·0	85	75	67	52	24	—	—
3·0	90	85	79	67	52	22	—
5·0	93	91	88	81	71	54	35
10·0	95	94	93	91	86	78	67

(Calculations based upon 9.0-5.30 p.m. five-day working week giving a yearly total of 2,186 hours.)

is inevitably a compromise, as skies providing less light than this will occur occasionally in mid-winter, or in the early morning or late afternoon in spring or autumn. On such days it was thought reasonable to assume that artificial lighting at the back of the room would be used to supplement daylight. This is likely to be necessary for about 200 hours per annum over the part of a school room designed to a 2 per cent minimum daylight factor. The electrical wiring should be arranged so that the light fittings in areas furthest from the windows are switched together. One local authority has experimented with a technique for the automatic switching of such supplementary lighting.

The 2 per cent daylight factor standard

72. For reasons explained in Part 1 the building regulations on lighting are aimed at ensuring that the level of illumination on the working surface shall be at least 10 lm/ft². To translate this into terms that the architect could use for daylight design, the regulations state that the lowest level of natural illumination in all teaching accommodation shall be a 2 per cent daylight factor. This means that on working surfaces within the building the least level of illumination provided by the light received both directly from the sky and indirectly after reflection from surfaces inside and outside the room, shall be 2 per cent of the illumination received simultaneously on a horizontal surface outside from an unobstructed sky which, for the purpose of these regulations, is assumed to have a C.I.E. distribution. It will be seen that a sky which gives an illumination of 500 lm/ft² outside will provide an illumination of $\frac{2}{100} \times 500 =$ 10 lm/ft² in a room satisfying the 2 per cent minimum daylight factor. At the same time it will be seen from Table 2 that a room with a 2 per cent minimum D.F. will often have an illumination much higher than 10 lm/ft². For two-thirds of the year, when the average outside illumination is over 1,000 lm/ft², the minimum illumination within the room will be over 20 lm/ft². In school rooms of normal size large areas of glass are not necessary to achieve a 2 per cent minimum D.F.; with careful design and light coloured decorations this may be done with an area of glass which is about 15 to 20 per cent of the floor area, depending on the placing of the windows. In rooms in which difficult visual tasks may be undertaken in all parts of the room, the architect may decide that the minimum D.F. should be higher than 2 per cent. But in such cases care should be taken to see that sky glare, and excessive solar heat gain and loss do not outweigh the advantages of higher levels of illumination. It will probably be found that some form of top lighting will be necessary.

73. The 2 per cent minimum D.F. standard has been found in practice to have the following main advantages:

(a) It provides sufficient working illumination on all but the dullest of days.

(b) It is an acceptable compromise that meets (a) and yet avoids the large areas of glazing and severe glare that would arise from much higher levels of daylighting.

(c) It is not restrictive to the architect, and permits a wide range of design solutions.

Methods of calculating daylight factors

74. It is clearly important for the architect to be able to calculate at an early stage in design the amount of daylight reaching a given point in a room. This makes it possible to compare alternative methods of fenestration and other variations in the geometry of the building, and to see which combination is most likely to produce the other qualities of good lighting that have been discussed in Part 1. The total daylight at any point in a room (diagram 3) consists of a direct component, A, coming direct from the sky and an indirect component, made up of light reflected from objects outside the window, B1, and light inter-reflected within the room, B2. At one time, before the role of reflected light was fully appreciated, it was customary to design classrooms to meet a 2 per cent *sky* factor, thus ignoring reflected light. This produced rooms with much larger windows which could give a true minimum daylight factor of about 4 per cent.

75. There are several methods of calculating daylight factors at sketch plan stage which are available to the architect. A tabular method has been developed at the Building Research Station.[2] A graphical method of computing the direct daylight component which is suitable particularly when there are complex obstructions is that based on the Waldram Diagrams.[3] The best known method of calculating the direct daylight component is probably that employing the B.R.S. Daylight Factor Protractors, with the indirect reflected component being estimated with the use of a table or nomograms. Once the simple technique for

[1] Reproduced with permission from Technical Report No. 4, *Availability of Daylight*, Illuminating Engineering Society, London.

manipulating these protractors is mastered, results of sufficient accuracy may be obtained quickly. This method is explained fully in Appendix 3 where a worked example is given.[4]

76. Calculating daylight factors is of course only the starting point in the design of daylighting. But it is a useful first step, as the process of calculation helps to draw attention to the factors affecting the distribution of daylight throughout a room. Experienced designers will use calculation mainly to check their own commonsense approach but at times it will show that intuition is not in itself enough. For example, it is obvious that the closer one comes to the window the greater will be the direct component from the sky and the higher will be the level of illumination, but it may not be so easy to see that at the back of a room decorated in light colours the reflected light may be greater than the light direct from the sky. Some examples of classrooms of average size lit by a variety of means are given in diagrams 4-7 and photographs **11–14**. These show that it is easier to obtain a good distribution of light through the room when there are windows on more than one side, but that it is possible to get a reasonable spread of light in rooms, even those over 20 feet deep, with unilateral lighting as long as care is taken to provide light reflection factors, particularly on the floor and rear walls. The rational use of a colour scheme to further this aim is described in Building Bulletin Number 9 (Third Edition), pages 24 to 26. The examples also illustrate another advantage of being able to place windows in more than one wall: that it is possible to achieve the same minimum level of illumination (and a better distribution) in rooms of a given size with lower (and therefore more economic) ceiling heights.

[2] *Simplified Daylight Tables*, National Building Studies No. 26, H.M.S.O.
[3] Chapter V, *The Science of Daylight*, by J. W. T. Walsh, (MacDonald).
[4] See also Appendix A of B.S. Code of Practice, C.P. 3: Chapter I: Part 1: 1964, *Daylighting;* and in B.R.S. Digests (second series) numbers 41 and 42.

Quality in daylighting

General note

77. Good design in daylighting not only provides a sufficient quantity of illumination; it must also help to give the interior a character appropriate to its use, and at the same time allow the occupants to see clearly in all positions in the room. This needs an imaginative design solution to three main requirements which flow from the behaviour of the eye discussed in Part I:

(a) a satisfactory balance of brightness through the room;
(b) the right proportions of direct and indirect light;
(c) the absence of glare from the sky or sun.

A balance of brightness

78. Having established that the *quantity* of light in the room is sufficient, the first step in ensuring a good *quality* of lighting is to try and produce a satisfactory balance of brightnesses on the main visible surfaces and objects in the room. If there is too great a contrast between the high brightness on the walls close to the window and the lower brightness on the walls at the back of the room, children sitting at a distance from the windows will feel at a disadvantage, even though there may be the right meter reading on their desks, as their eyes will adapt to the areas of higher brightness by the window. It will be remembered that brightness is a function of illumination and reflection factor. Thus it is possible to compensate for lower levels of illumination away from the windows by using higher reflection factors, particularly on the walls as the flow of light from the windows is largely horizontal. This will help to maintain a balance of brightness – and thus of adaptation levels – in the room. This does not mean that brightness in the room should be uniform; the room would be very dull if it was. To avoid this the design should include

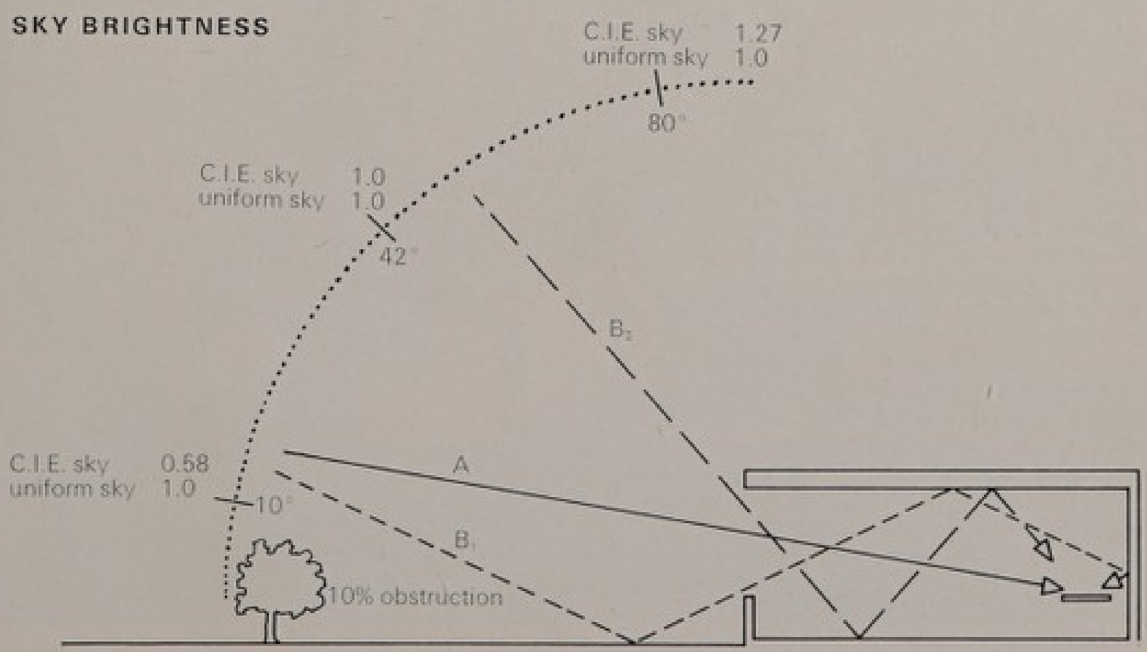


Diagram 3:
Direct and indirect daylighting
The total daylight factor at any point in a room is made up of a direct component, A, and indirect components, B_1 and B_2. At the back of a room with light decorations the indirect component will amount to about half of the total D.F. (paragraph 74).

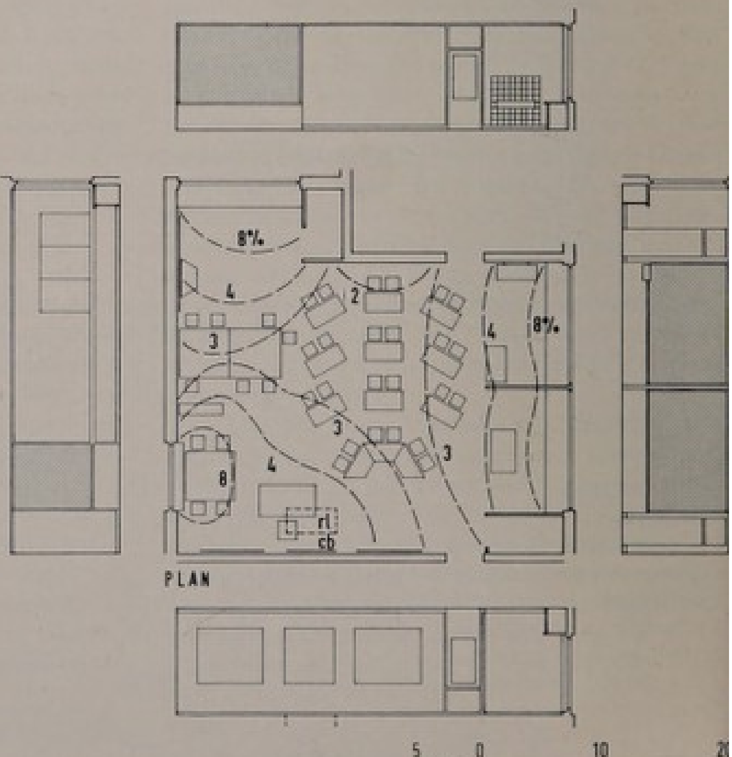


Diagram 4 and Photographs
11(a), (b) and (c)
Woodside Junior School, Amersham

Windows placed on three sides of this room, with a roof light placed over the main chalkboard/display wall give even, well-rounded lighting, allowing the children to work easily in any part of the room. Although the glazing area is about 24% of the floor, there is no sky glare as the main window looks on to a shaded court and timber screens are placed to restrict a direct view of the sky. Roller blinds in a light grey woven plastic are provided on the windows to allow control of very bright skies or strong sun. White, splayed reveals to the windows help to grade light into the room. The colour scheme in the room both helps the distribution of brightness in the room and provides a sympathetic background for colourful displays of the children's own work. The average reflection factor of the floor is 35%, the walls 40% and the ceiling 65%.


Thursday

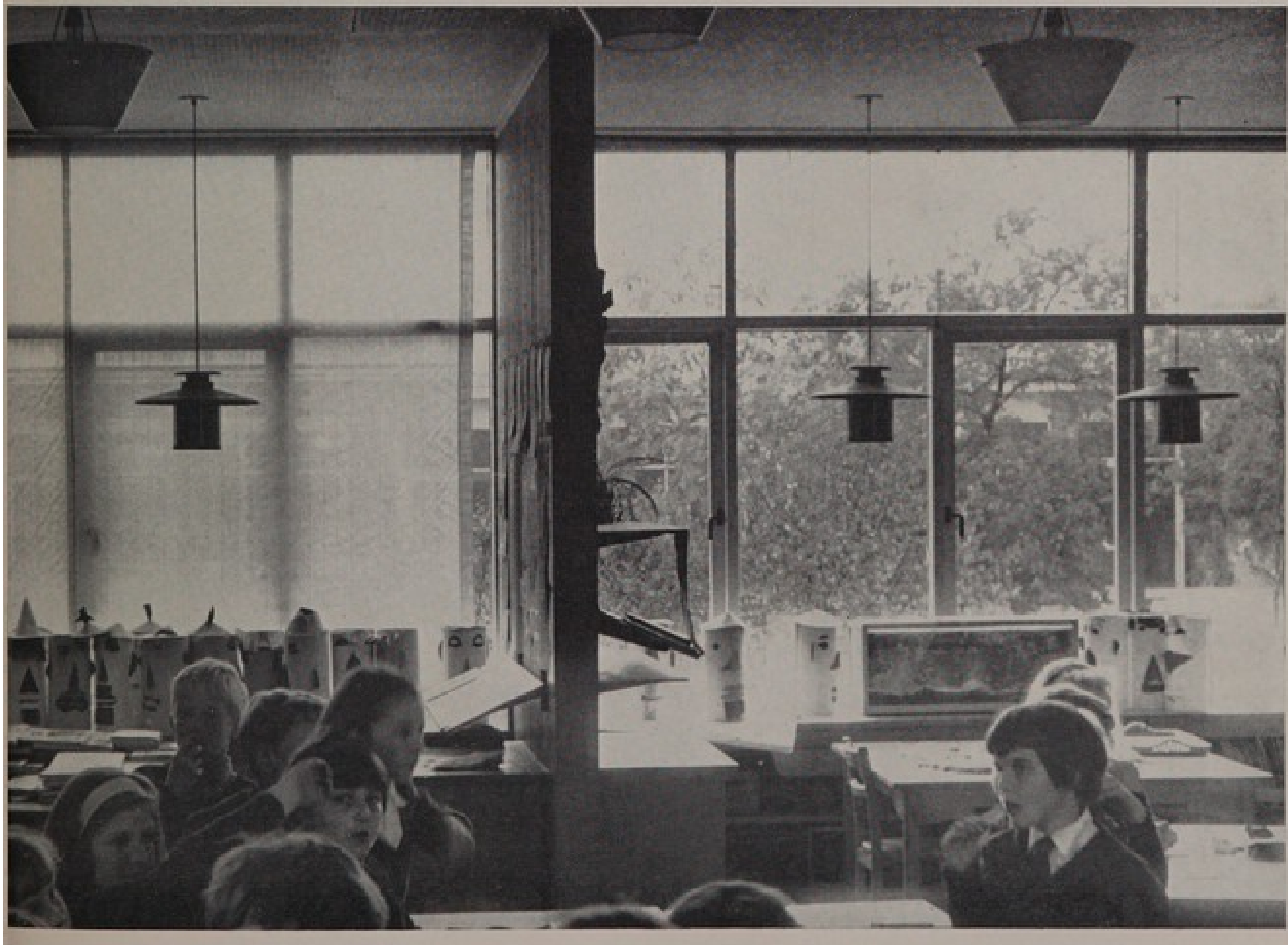
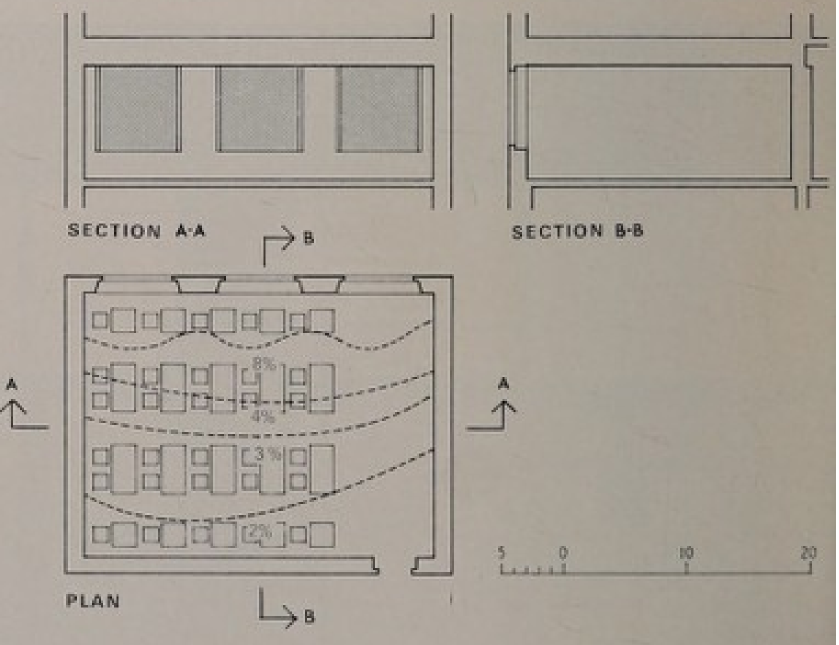
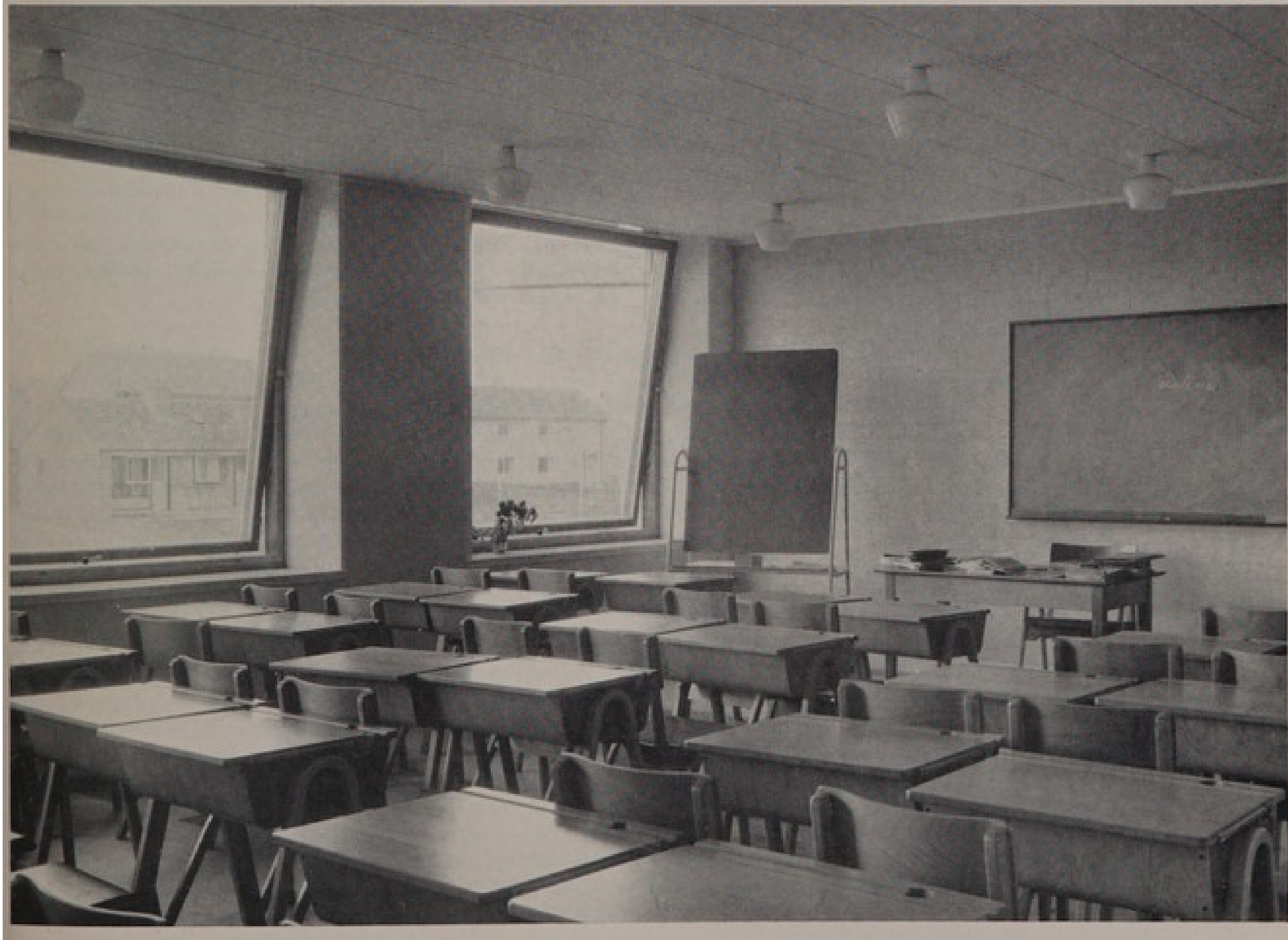


Diagram 5 and Photographs
12(a) and (b)
High School, Thurso

This example shows that daylighting of good quality can be achieved without excessively large areas of glass. This school was on an exposed site in the north of Scotland, and the architect designed the daylighting with windows that were as small as possible to give a 2% minimum daylight factor. The room is about 600 sq ft in area with a 9 ft high ceiling, and is lit by three double-glazed windows, each 6 ft by 6 ft, which in this instance could be placed in one wall only. The average reflection factors are high: ceiling 80%, walls 60%, floor 45%. A 2% minimum daylight factor is achieved except in the area near the door which would not be a working area. This has been done with a glazed area equal to about 18% of the floor area. The area of glass could have been reduced further if single glazed windows had been used, for these have a higher transmission factor. There is a low gradient of illumination and of brightness across the room and this means that the back of the room does not appear gloomy compared with brighter areas by the window. The deep splayed reveals allow good penetration of daylight and help to grade brightness when viewed from the inside. The architect for the High School, Thurso, was Sir Basil Spence and Partners with advice on daylighting from the Building Research Station.





small areas of stronger contrasts of shadow and highlight, with perhaps the crisp accents of white gloss paint on architectural trim and the glint of metal fittings.

Direct and indirect light

79. Varying the proportions of direct and indirect light in an interior has a marked effect upon its character. With a high proportion of light direct from the sky, the room will have a harsh, dramatic character with strong contrasts of light and shade, and consequently a risk of glare. It will be difficult to see detail in the heavy shadows as the eye will adapt to the brightest areas in the room. These characteristics will be exaggerated if there are windows on one side only.

80. A room with a high proportion of indirect light will have softer contrasts as much light will be reflected into the shadows. There will be little risk of glare, and comfortable vision will be possible in most parts of the room. There is a danger that the interior may appear washed out and anaemic if sufficient contrast and stimulus is not built-in to the detailed design and colouring of the room.

81. In each case the decision on the appropriate balance between direct and indirect light, and on the best means of achieving it, will in the end depend upon an imaginative interpretation by the designer of the character required in the room. As we have seen, the character grows out of the activities and physical needs of the occupants.

General and local daylighting

82. The extent to which one level of illumination is required generally through the room will depend upon its use. There is an increasing tendency for activities in many rooms to be diversified, and allocated to particular areas. This gives the designer the opportunity to provide an interesting variety of lighting solutions, made-to-measure for each activity. Thus a Biology laboratory may have a general work space with overall lighting, and at one side a more brightly-lit demonstration area; opening off this, bays for intricate practical work with high levels of daylighting; and another corner for books and display with its own local lighting, perhaps from a roof light.

Absence of glare

83. The main cause of glare is the presence of excessive contrasts in brightness in the field of view. In the field of daylighting the most common situations causing glare are where a window through which a bright sky can be seen is behind or immediately adjacent to places in the room at which the pupil has to look, such as a chalkboard, demonstration bench, or fume cupboard. One should also bear in mind that a teacher has to spend much of his time looking across the room at his pupils, and it will be tiresome if they are seen silhouetted against a window. Even in rooms in which there are no windows near to objects of attention, considerable discomfort can be caused by glare from large, bright windows which are in or on the edge of the general field of view. These conditions are accentuated if the brightness of the room as a whole is low, or if the surrounds to the window are dark in colour. Irritating glare is not confined to places at which one has to look. The effect of phototropism (see paragraph 46) draws the eye to wherever glare is, and then the damage is done. The only safeguard is to reduce glare as far as possible throughout the building.

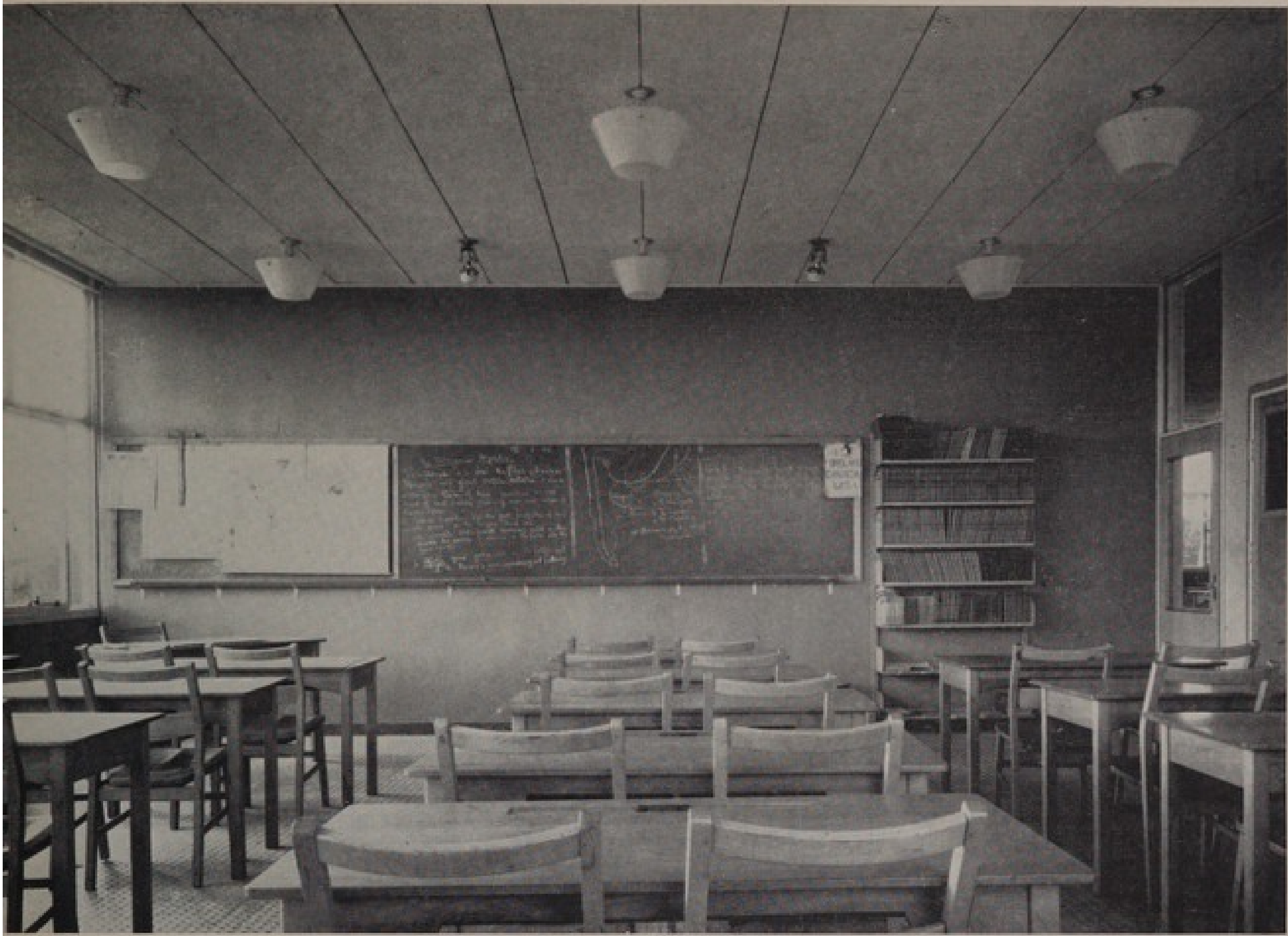
84. To minimise glare it is important, first, to avoid putting windows near to visual focal points. For example, windows should not occur in walls on which a chalkboard is mounted, or above a speaker's rostrum. The second method of reducing glare is to raise the general brightness of the room and to lighten the immediate surrounds to the windows, detailing the frame and reveals so that there is a gentle gradation from internal to external brightness. The deep reveals that resulted from traditional load-bearing construction were used both to grade light in this way, and to reduce the amount of bright sky visible from oblique views. Many modern buildings have comparatively thin external walls but even so it is sometimes possible to use structural fins or internal partitions to achieve a similar grading effect (diagram 4, photographs **11** (a), (b) and (c)). Transoms, mullions and glazing bars should be tapered towards the inside of the room and wide, flat bands across the window should be avoided. It is a safe rule to paint window frames and glazing bars white, and to use colours of a high reflection factor on the surrounding walls and on ceilings interrupted by roof lights. It may help if the reveals to a roof light, which may appear very bright as they often receive direct sunlight, are painted a rather darker colour than the ceiling itself. Cross lighting from secondary windows will help by lightening the inner faces of the other window walls, and thus reducing contrasts. In this way the trouble caused by silhouetting can be minimised.

85. The third method of reducing sky glare is by the use of devices such as screens, blinds, and louvred shutters which reduce the brightness of the sky as seen from within the room. Inevitably most of these will also reduce the amount of daylight entering the room. However, some will at the same time alter the distribution of light within the room so that there is less close to the window and proportionately more at the back of the room. The majority of these devices also help to shield the occupants from the direct rays of the sun. Indeed, they are often installed primarily with this aim in view, and their design will be biased in this direction. But it must be emphasised that bright, cloudy skies are as serious a cause of glare as direct sunlight – and they occur more frequently.

Sunlight control

86. In our climate most people would say that they like to be able to have sun in the rooms in which they spend their day. The warmth, radiance and sense of well-being which it gives are welcome particularly during the winter. On the other hand, a common complaint in schools during the summer is of the glare and exhaustion caused by the direct rays of the hot sun, and some protection from this is highly desirable. The architect has to try and reconcile these two conflicting requirements, and any protective device used on the windows should therefore admit light without also admitting excessive heat or glare.

87. The main benefit of sunlight is as an amenity, and the orientation of rooms in which children will spend a substantial part of their day should be carefully considered. It is generally thought that sun in the morning is preferable to later in the day, as it makes a cheerful start to the day and avoids the hotter periods at midday and in the afternoon. If the room is lit from one side only then an orientation towards the south-east is highly desirable on these counts. This also avoids the inconvenience of glare from the low



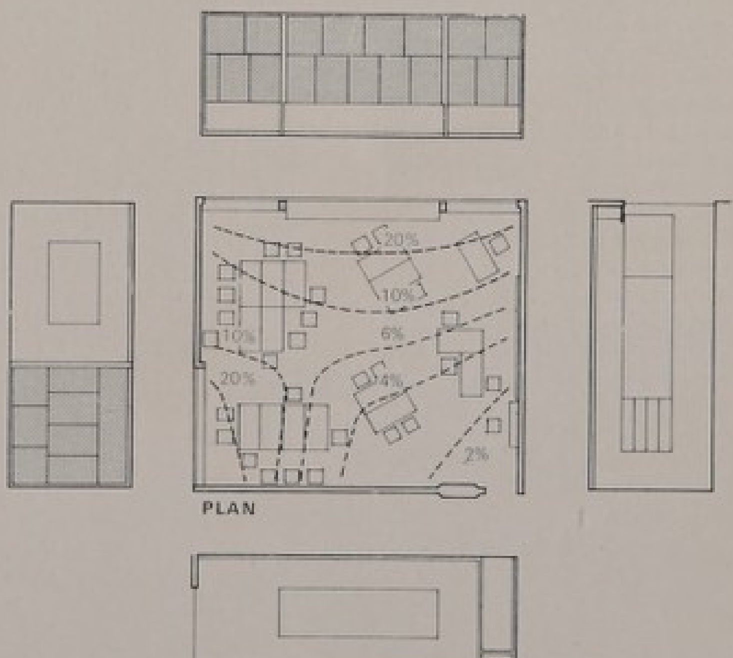


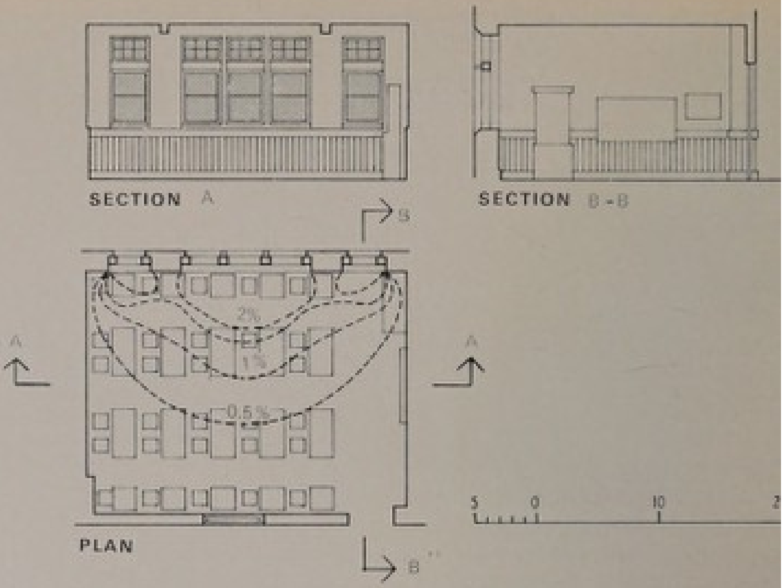
Diagram 6 and Photograph 13

St. Crispin's Secondary School, Wokingham

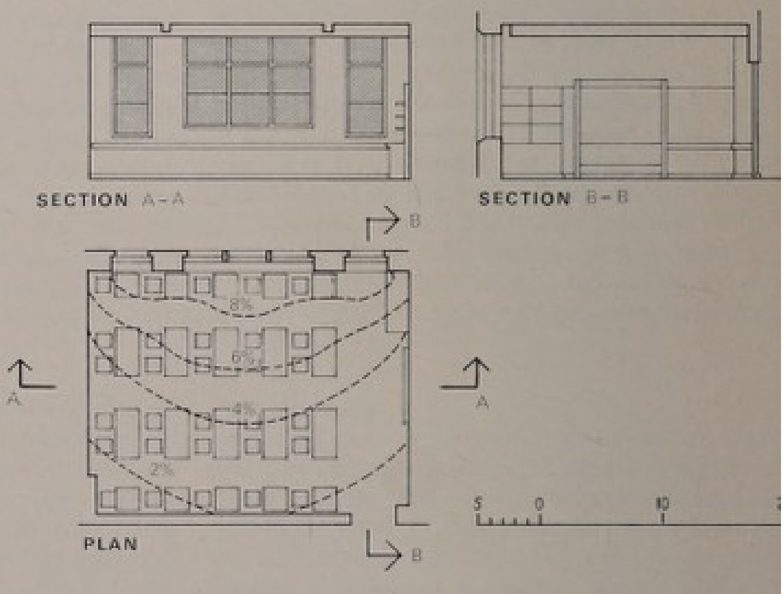
In this room the daylight from the main window is supplemented by a second window in an adjacent wall (behind the position from which the photograph was taken). This rounds out the lighting and allows the pupils to work in many different positions in the room without shadowing their own work. With a glazed area equal to about one third of the floor area and a 10 ft high ceiling, there is a high level of illumination, only falling to 2% D.F. by the door. White venetian blinds are fitted on all windows. The average reflection factor of the walls is 35%, of the floor 15% and the ceiling 70%. Two chalkboard fittings give added illumination on the chalkboard when required.

Diagrams 7(a) and (b), and Photographs **14 (a) and (b)**
Greenhead High School, Huddersfield

When old schools are being remodelled to modern standards, it will often be found that lighting in particular needs attention. In this case – a grammar school 50 years old – the minimum daylight factor in many classrooms was well under 2%, due to the small, obstructed windows and dark interior surfaces. The walls had an average reflection factor of about 20% and the floor of about 10%.



Remedial steps included improving the reflection factor of the walls to 60% and of the floor to 40%. This had the effect of doubling the minimum daylight factor from 0·5% to 1% The old windows with their heavy frames, transoms and glazing bars were replaced by new lighter sashes, and the sills of two windows were lowered from 4 ft to 3 ft high. This doubled the area of glass to about 20% of the floor area, and the minimum daylight factor then rose to 2%. The combined effect of these alterations was also to improve the quality of lighting in the room – reducing sky glare and allowing a view out across the gardens outside. Steps were also taken to improve the artificial lighting (see Appendix 2).



altitude westerly sun setting in the later afternoon in winter. If there are secondary windows in a classroom, there will be greater freedom in the orientation and placing of windows and other considerations such as the view from the room can carry more weight.

88. Another benefit of sunlight is that it can be a useful additional source of heat. In excess, of course, this becomes a disadvantage and even in winter the sun can cause over-heating if the heating installation is not flexible enough to allow for the additional input of solar heat.

89. The commonest complaints about excessive sun in schools are usually given in the following order:

first, the feeling of exhaustion caused by the direct rays of the sun striking the body;

second, the discomfort from over-heating due to the 'greenhouse' effect;

third, the glare caused either by the disc of the sun being visible through a window, or by the excessive contrasts of sunlight and shadow on desk or chalkboard (the level of the illumination in the sunlit areas can approach 100 times as much as the rest of the room).

90. This last form of glare can be dangerous if it causes temporary blindness in the gymnasium or a workshop. Glare which is as severe, though of a different order, can also be caused by a view of a bright, overcast sky. Any sunshade or window blind should also be used to deal with sky glare, which in our country is a more frequent cause of discomfort than the sun.

Sun protection devices

91. Sunlight can be controlled to give comfortable working conditions in a number of different ways. It is possible to design fixed overhangs, canopies or louvres to shield the window from, say, the midday sun in May to July. Permanent sun breaks are common in the tropics but in our climate, where sunny days are the exception rather than the rule, fixed shading devices have the major disadvantage that they will also cut down the amount of light from the sky entering the room in the winter. Furthermore, external appendages or breaks in the external wall are usually expensive and will be difficult to justify unless they arise from some other function in the building as well.

92. For the variable conditions of our climate, adjustable screening devices are more appropriate. Of these, the simple draw curtain, the spring-roller blind, and the venetian blind can meet most of the requirements as long as they are correctly specified and used. They can be adjusted to shield the body from the direct rays of the sun, even at low angles, and can cut out glare from sun or bright skies. However, blinds or curtains mounted inside the glass are not very effective in keeping out the heat from the sun, although the lighter the colour of the surface facing the glass the better. In very sunny positions or for rooms which need special protection from high temperatures, the most effective shading device is a blind mounted outside the window so that it keeps the sun off the glass. This may be either of the shop blind type – a projecting canvas awning under which it is possible to see – or a simple roller blind in a durable natural or artificial fabric (photographs **15** (a) and (c)). Either needs to be secured against the wind.

93. When selecting the material for the blind or curtain, care should be taken to see that it is neither so light when the sun shines on it that it becomes a distraction or a source of glare in itself, nor so dark that it makes a glaring contrast with the bright scene outside and reduces unduly the light within the room. Suitable materials would be those with a transmission factor of about 40 per cent and with an internal surface brightness, when lit from outside by the sun, of about 1,000 foot-lamberts. Neutral or near-neutral colours should be chosen for the blind materials, or the room will be liable to become suffused with colour.

94. For internal use venetian blinds can meet the lighting requirements satisfactorily, but difficulties in operation and mechanical troubles, particularly in the rise-and-fall mechanism, have meant that they have often been ineffectual and untidy in appearance. Some of the best types now available have a resilient toughened aluminium slat, heat-set Terylene tapes with anti-flutter strands above and below the slats, and a single control (rod or cord) for tilt and rise/fall.

95. Other matters that should be considered when choosing window blinds are: *Blackout*. This may either be a 'dim-out', which is all that is required for certain visual aids, or 100 per cent 'blackout', which is necessary for optical work in Physics laboratories.[1] Dim-out may be provided by an opaque curtain or roller blind, or by a venetian blind with the slats turned flat, as long as light does not leak around the margins. It is possible to use these blinds for glare control also but complete blackout will have to be provided separately from the sun blinds. Venetian blinds painted wholly in dark colours should be avoided as they are likely to cause glare between the slats when used for sun control. The cheapest method is a simple draw curtain battened down at the edges, with a good overlap at the sill and with a deep pelmet box. A disadvantage of such curtains is that when drawn open and hanging at the sides of the window, they will cause a glaring contrast with the bright scene out of doors, unless they can be lined with a light material. A more satisfactory method is a light-proof roller blind running in deep channels at side and bottom, and withdrawing completely when not in use into a blind box, all being designed as a part of the frame of the window.

Ventilation. There should be sufficient ventilation when the blinds are drawn on a hot day, particularly if they are on the only window in the room. When blackout blinds are likely to be used for long periods it is normal to provide mechanical extract ventilation. Care should be taken to see that the windows can be opened when the blinds are drawn, and that the blinds do not swing and gape in the breeze when the window is open.

[1] Increasing use is being made of visual aids such as television and overhead projectors which can be seen in full daylight. The problems of designing for visual aids are discussed further in paragraphs 194-207.

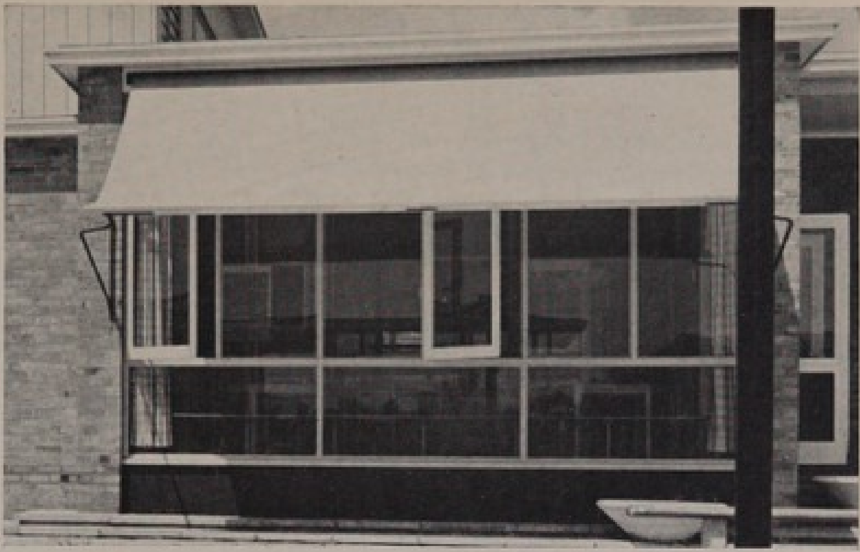
15 Window blinds

The photographs show types of blinds installed on windows facing south-east and south-west to shield occupants when necessary from the direct rays of the sun.

The most effective method of preventing unwanted solar heat gain through windows is a blind mounted outside the glass (paragraphs 91-93).

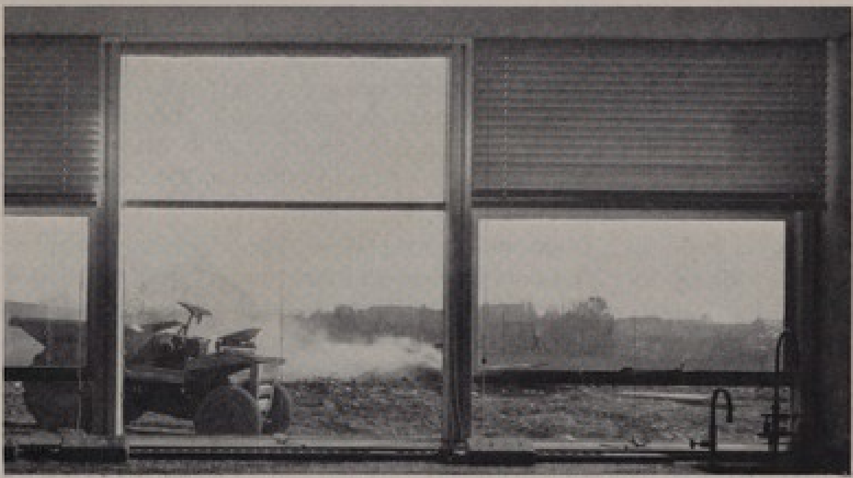
This may be either

(a) *Projecting awning* of the shop blind type under which it is possible to see, or, alternatively, a roller blind in a durable material. Either needs to be secured against the wind.

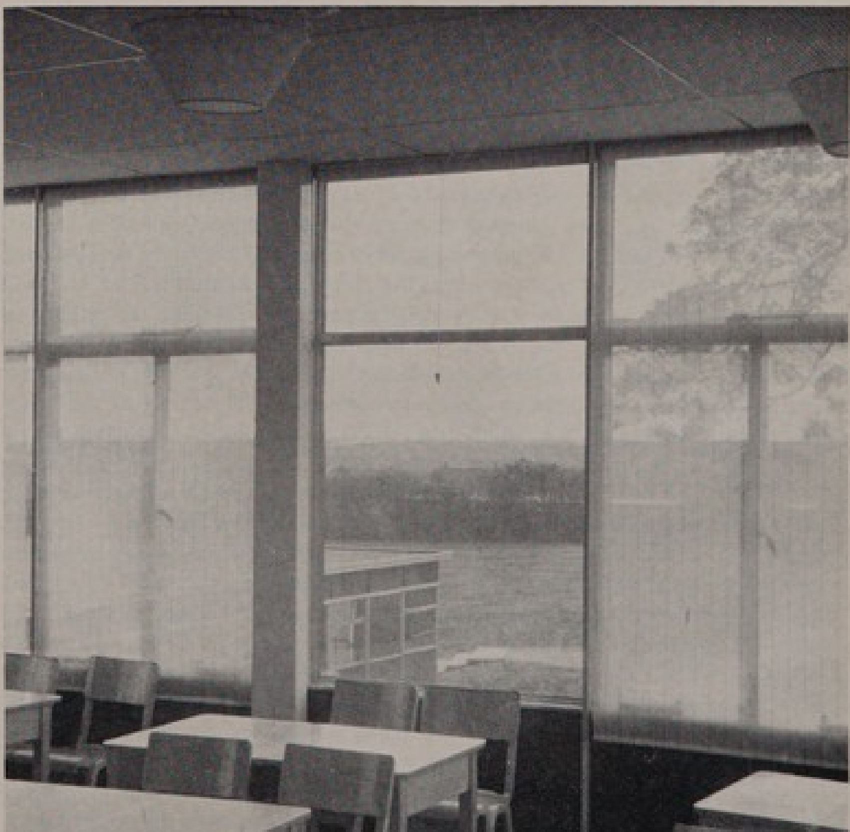


Internal window blinds are also used to counteract sky glare (paragraph 85).

(b) *Venetian blinds.* When properly adjusted, venetian blinds can reduce sky glare and check the direct rays of the sun, while at the same time redirecting some light to the ceiling and allowing free ventilation. The method of operation should be simple and foolproof (paragraph 94).



(c) *Roller blinds.* The materials used in roller blinds may be either the traditional holland, or, as in the photograph, a woven plastic giving the correct transmission factor (paragraph 93).



3 Artificial lighting

General functional requirements

96. Artificial lighting is required in day schools for three main purposes:

(a) to provide at any time in the day additional local lighting for visual tasks of particular difficulty (for example, dissecting, sewing-machine work, etc);

(b) to supplement failing daylight from skies which provide an illumination outside of less than 500 lm/ft² (see paragraphs 70-71);

(c) to provide full illumination for interiors after darkness has fallen.

97. Each of these requirements should be taken into account when designing the artificial installation. Lighting after dark is of particular importance even though it will not in a day school be used for long periods, for it is required when the energies of both staff and pupils are at a low ebb and when the stimulus and variety of daylighting is absent. The place of permanent supplementary artificial lighting of interiors (P.S.A.L.I.), where natural and artificial lighting are combined, is discussed in Part 4.

98. The general user requirements which affect the design of artificial lighting in schools have already been discussed in Part 1 and are summarised in paragraph 61.

99. In many teaching spaces in a school the work is generalised and the rooms will be used for a wide range of different activities. These may range from a full class at their desks with their attention directed to the chalkboard, to numerous small groups and individuals, whether they be nursery children or sixth formers, each busy with their own work in various parts of the room with the loose furniture grouped in many different ways. In such a case, it should be possible to work with equal comfort and convenience facing in any direction. The architect will plan the room and its furniture and fittings to allow for this flexibility in use. The artificial lighting scheme should in the first place provide an adequate level of illumination over the whole of the room including the walls, which may be important teaching and display areas. This does not mean that the lighting should be uniform and featureless. There is scope within a well-designed scheme for plenty of interest and variety in the choice of surface brightness and colour, and in the sparkle from metal fittings and gloss painted trim. There may also be some local lighting giving emphasis to, say, display areas. But if substantial areas of the room are much less bright than the general level – say, less than half the general level – these parts will appear gloomy and children who have to work in them will feel deprived. Having to work alongside a dark-coloured wall or an uncurtained window at night can have the same effect.

100. In other rooms in the school work will be more differentiated, and the various activities within each room will be localised. This is the result of new educational methods which are on the increase, and the implications for lighting design are considerable. This has been discussed in terms of daylighting (paragraph 82), and the artificial lighting scheme should also help to develop local emphasis and a varied character appropriate to the activities in the room. In the school library, for example, the work places will probably be fixed, and local lighting can be used to give the pupil a sense of seclusion and concentration. Elsewhere in the room illumination will be needed on the backs of the books on their shelves, and perhaps on some display areas. This may be all that is needed as sufficient general illumination can result from the spill from the local lighting.

101. Local lighting will make it easier to carry out the more difficult tasks, as the level of illumination on them will be increased and the details made more vivid and contrasty. The additional lighting should not be too brilliant or the rest of the room will seem unpleasantly gloomy to those working under the local lights. As a general guide the level of the local lighting should not exceed three times that of the general lighting.

102. The preferential lighting of a chalkboard is one of the commonest instances of additional local lighting, but it can also be appropriate in, for example, alcoves off the main space in a room, on display areas, in individual study bays, or over wall benches away from the main windows (photographs **18–21**). This local artificial lighting will often be used to supplement the daylight. A chalkboard light fitting, for example, will be on at any time during the day or after dark when the chalkboard is in use unless, of course, a roof light has also been provided to boost the lighting on the chalkboard. Further examples of this use of local lighting are given in Part 5 when discussing the requirements of individual rooms.

103. Apart from achieving the right distribution of illumination through the room, the requirements for a good quality of artificial lighting are similar to those specified under daylighting (paragraph 77):

(a) the distribution of brightness through the room should allow comfortable adaptation and should assist attention being focused on the key parts of the work;

(b) there should be the right balance between direct and indirect light;

(c) the excessive contrasts which cause visual discomfort and glare should be avoided.

To achieve these aims will need careful co-ordination of the design of the lighting installation with the colouring and detail of the interior.

104. While the prime aim of a scheme for artificial lighting will be to provide an adequate level of illumination of good quality, this should be done with maximum economy both in the capital cost of the installation and in running costs. There are of course times when it is difficult to combine high quality with low costs. To take an extreme example, the most 'economic' scheme would be one in which a few high-powered, unscreened clear lamps were placed in a white room. The proportion of the light leaving the lamps which reached the working plane would be very high. However, the glare caused by the unscreened lamps and the monotony induced by the all-white interior would together make the room unusable. Thus the design of general purpose light fittings for schools starts at this point: with the need

to provide comfortable conditions for seeing by a simple method of screening the bare lamps, while at the same time maintaining the highest possible output of light from them.

Choice of light fitting[1]

General note

105. In order to choose the type of light fittings most apt for his purpose, the designer will base his selection upon the following considerations: efficiency, light distribution, ease of maintenance, cost, and appearance.

Efficiency

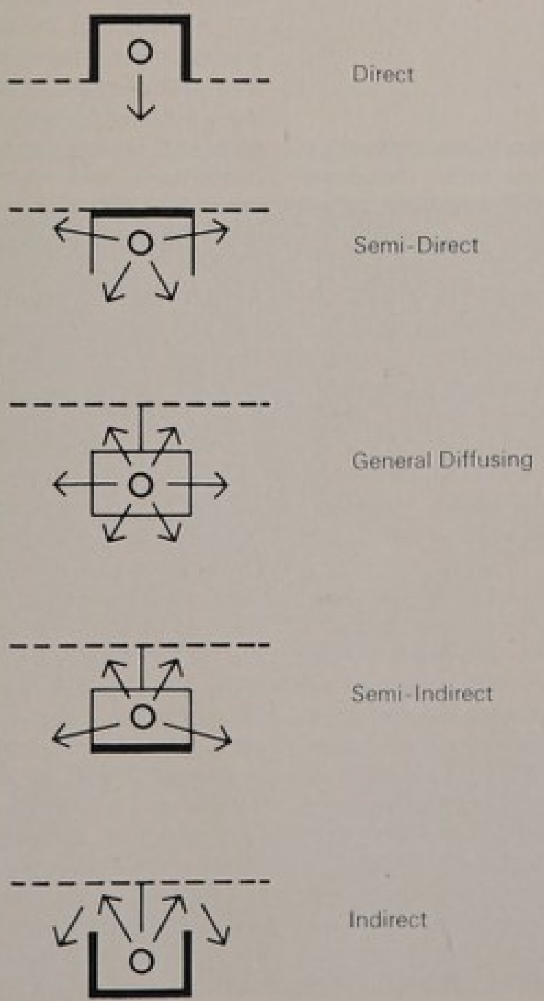
106. This is usually measured in terms of the fitting's light output ratio, that is, the percentage of light produced by the lamp which is finally emitted after inter-reflection and absorption within the fitting. The light output ratio of any commercial fitting should be provided by its manufacturer, and one would normally use the most efficient fitting which at the same time meets the requirements under the four other headings.

Light distribution

107. Fittings may be classified for the purposes of lighting design under five headings (see diagram 8):

Direct: all light goes downwards.
Semi-Direct: 90 per cent to 60 per cent goes downwards, but some upwards as well.
General Diffusing: light is distributed in more or less equal proportions in all directions.
Semi-Indirect: over 60 per cent upwards.
Indirect: all light upwards.

Diagram 8:
Types of light fitting
Light fittings classified according to the direction in which they distribute light. The designer will also need to know their light output ratios, and glare characteristics (paragraphs 105-107 and 116-123).



108. As is the case in the design of daylighting, varying the proportions of direct and indirect artificial light has a marked effect upon the character of an interior.
109. The use of fittings giving mainly direct light downwards can produce a rather harsh quality with heavy, hard-edged, overlapping shadows. As there is relatively little light on the ceiling it will tend to be dark, and the fittings glaring unless special precautions are taken. This harsh quality will be counteracted if the main surfaces in the room – ceiling, walls, floor, furniture – are in light colours, thus increasing the proportion of indirect light.
110. The use of general diffusing fittings and light-coloured decorations – say, an average reflection factor of about 40 per cent – will give softer contrasts and lighter shadows, as a high proportion (nearly half) of the light at any point in the room will have been reflected. In these 'high key' interiors, the use of colour and of small-scale local contrasts can help to avoid a washed-out appearance.
111. Thus, while most fittings used in schools will be those which give a general distribution of light, some used for particular purposes and in local lighting may need to be highly directional.

Maintenance

112. The fitting should preferably have a simple shape on which dust does not lodge and which is easy to clean. It should be possible, at least for tungsten filament fittings, to re-lamp without having to take the fitting apart. It should be proof against accidental knocks. The design should of course be electrically safe, and the wiring should terminate in a flame-proof enclosure to satisfy the I.E.E. Regulations. Fluorescent tubes do not flicker as noticeably as they once did, but some people can still be bothered by this. Fluorescent control gear should be carefully adjusted, and the ends of the tubes concealed from a direct view.

Cost

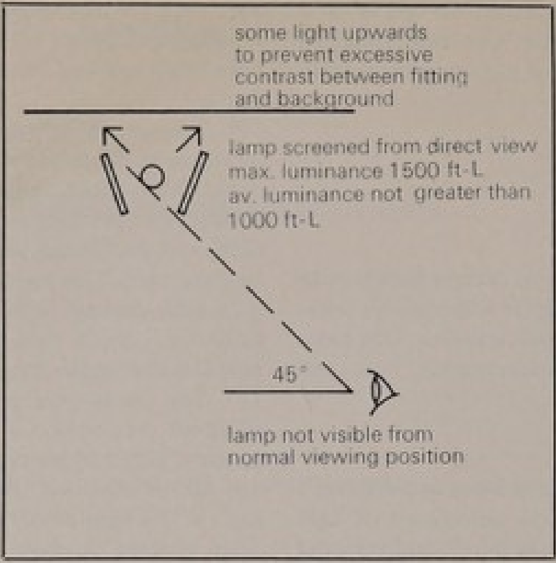
113. When comparing the costs of various fittings, it is necessary to take into account its cost-in-use, that is, the capital cost of the fitting and of the wiring to it, the cost of re-lamping, and the cost of current consumed. An approach which considered cost alone would suggest that small numbers of high-powered fittings are the best buy but this must be considered against the need for an installation of good quality and suitable character. Thus four 300 watt tungsten fittings in a 500 sq ft room will give approximately the same average illumination as eight 150 watt fittings but the distribution of light will be very uneven, with peaks and valleys, and the appearance is likely to be most unsatisfactory. Costs are considered further in paragraphs 130-133 and in Appendix 4.

Appearance

114. The designer will want to consider the appearance of the fittings, both when lit and not lit. Some fittings may be required to make a definite contribution to the character of an interior – perhaps pendant fittings used for local lighting or in a special place such as an entrance hall. However, most fittings in a school are likely to be chosen for an unobtrusive character which merges into the architectural

[1] This term is used for convenience to cover not only the individual fitting suspended from, or mounted on, ceiling or wall, but also the light source which is built into the fabric of the building.

Diagram 9:
Reduction of glare from fittings
Diagram illustrating principles required by Regulations to give comfortable lighting with reduced glare (paragraphs 116-118).



background. This seems to suggest a louvred fitting recessed into the ceiling, and this may in fact be the right solution in certain circumstances, such as when designing a scheme for P.S.A.L.I. (see Part 4). But for general purposes the recessed fitting has two main drawbacks. First, its geometry means that it will have a relatively low light output ratio, probably less than 50 per cent. Second, it can be a source of glare, for the recessed fitting can appear excessively bright against the ceiling, which is relatively dark as the only light reaching it is that reflected from the floor.

115. Therefore it can be seen that the appearance and character of an artificial installation, as well as its efficiency, will depend on the design of the fitting, the position in which it is mounted, and the brightness of the surrounding surfaces. The correct relationship between these elements will help to achieve an installation which is glare-free.

Glare

116. The main cause of glare is the presence of excessive contrasts in brightness within the normal field of view. The severity of the glare one experiences depends upon the size and brightness of the glare sources, their position in one's general field of view, and the degree of contrast between them and the background against which they are seen. The main cause of glare in artificial lighting installations occurs when large bright fittings, or fittings with exposed lamps, have to be viewed against a background that is relatively dark (photograph **10**). To counter this, light fittings should be reduced in brightness and the background against which they are normally seen – ceiling and upper walls – should be raised in brightness.

117. The maximum brightness of a 150 watt pearl lamp is over 11,000 foot-lamberts, and that of a fluorescent tube is about 3,000 foot-lamberts. Objects of this order of brightness will cause excessive contrast and glare, even if seen against a well-illuminated ceiling. Accordingly in schools all lamps, tungsten or fluorescent, should be screened from sight at normal angles of vision. The building regulations state (regulations 52 (3) and 52 (4)):

'In all teaching accommodation and kitchens no luminous part of any lighting unit, or mirrored image thereof, having a maximum brightness greater than 1,500 foot-lamberts or an average brightness greater than 1,000 foot-lamberts, shall be visible to any occupant in a normal position within an angle at the eye of 135 degrees from the perpendicular from the eye to the floor.

'A sufficient part of the light emitted from the lighting fittings shall illuminate the ceiling and upper parts of the walls so as to prevent excessive contrast between the fittings and their background.'

118. Diagram 9 illustrates the principles involved, with the minimum screening of the lamp to achieve the required results. Diagrams 10 and 11, and photographs **16** and **17** (a) and (b), show two fittings designed to meet these principles, one with a tungsten filament lamp, the other with a fluorescent tube. Such fittings have the maximum efficiency compatible with good quality, and have a light output of 85 per cent to 90 per cent, distributed upwards and downwards in roughly equal proportions. Before fittings are selected for use in teaching spaces, their manufacturers should be asked to state whether or not they meet the requirements of these regulations.

119. It has been found that the most comfortable conditions for viewing such fittings are created when the brightness of the shade is at its highest in the centre part, and falls off towards the edges, rather than being evenly bright over the whole of the shade. This helps to grade the brightness of the fitting into its surroundings, thus avoiding abrupt contrasts.

120. This process of contrast grading is also helped if the background against which the fittings are seen is itself brightly illuminated, hence the importance mentioned in the regulations of the fittings throwing some light upwards. This upward light will be spread more evenly if it is possible to mount the fittings some distance beneath the ceiling. There are very few situations in workrooms in which the ceiling should not be painted white or at least a colour of Munsell Value 9. A light coloured floor finish will also help to reflect light back on to the ceiling.

121. Fittings may be designed in different ways to give an appearance of low brightness when viewed from normal angles, while at the same time maintaining a reasonable light output ratio. Examples are those with louvres which are either opaque or of low transmission, with silvered reflectors which do not direct light above normal viewing angles, or with prismatic diffusers which direct light preferentially downward. However, such fittings tend to be less efficient with a light output ratio of 50 per cent to 60 per cent as compared with 70 per cent to 90 per cent for the more open fittings. For this reason, more of them are needed to achieve a given level of illumination.

122. The Illuminating Engineering Society has established a method of assessing the direct glare which may be experienced in any lighting installation, and has at the same time put out a list of recommended glare indices for various room uses (see Table 1). Teaching rooms are given the fairly stringent glare index of 16 since the nature of the work, with pupils and staff looking across the room as well as down at their desks, means that occupants will be very conscious of any glare there may be. This method of assessing glare is described in the I.E.S. Code, 1961. In general, it may be expected that the conditions for schools given in this Code will be satisfied if light fittings which comply with the Department's building regulations are used, provided that the average level of illumination in the room does not exceed 20 lm/ft², and the fittings are relatively small in size (not more than about 100 sq in visible from normal angles of view). If levels higher than this are

Diagram 10 and Photograph **16**
Tungsten filament light fitting
One of a range of inexpensive fittings designed round a tungsten filament lamp. It meets the Regulations' requirements for a limited brightness and some upward light, and at the same time has a high light output ratio of 85-90%.

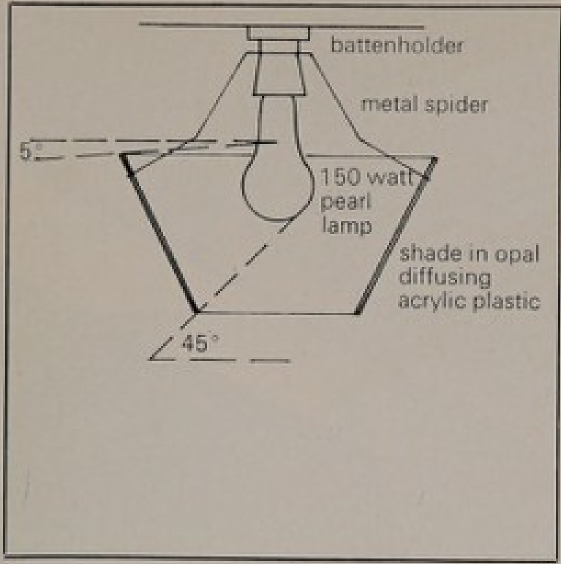
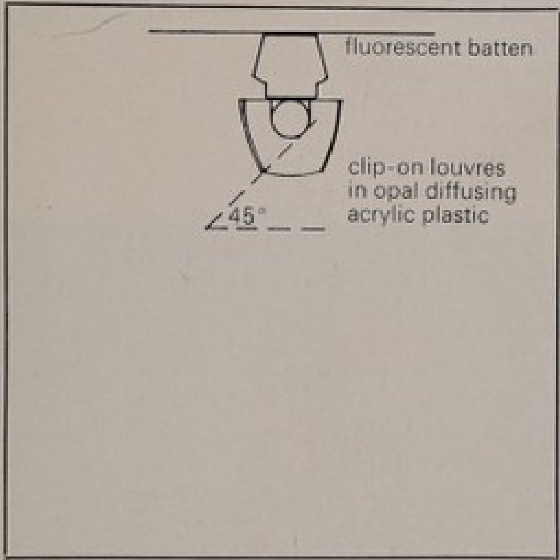
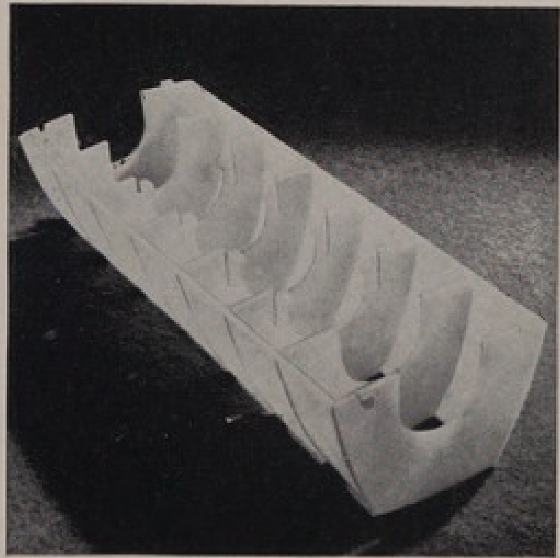
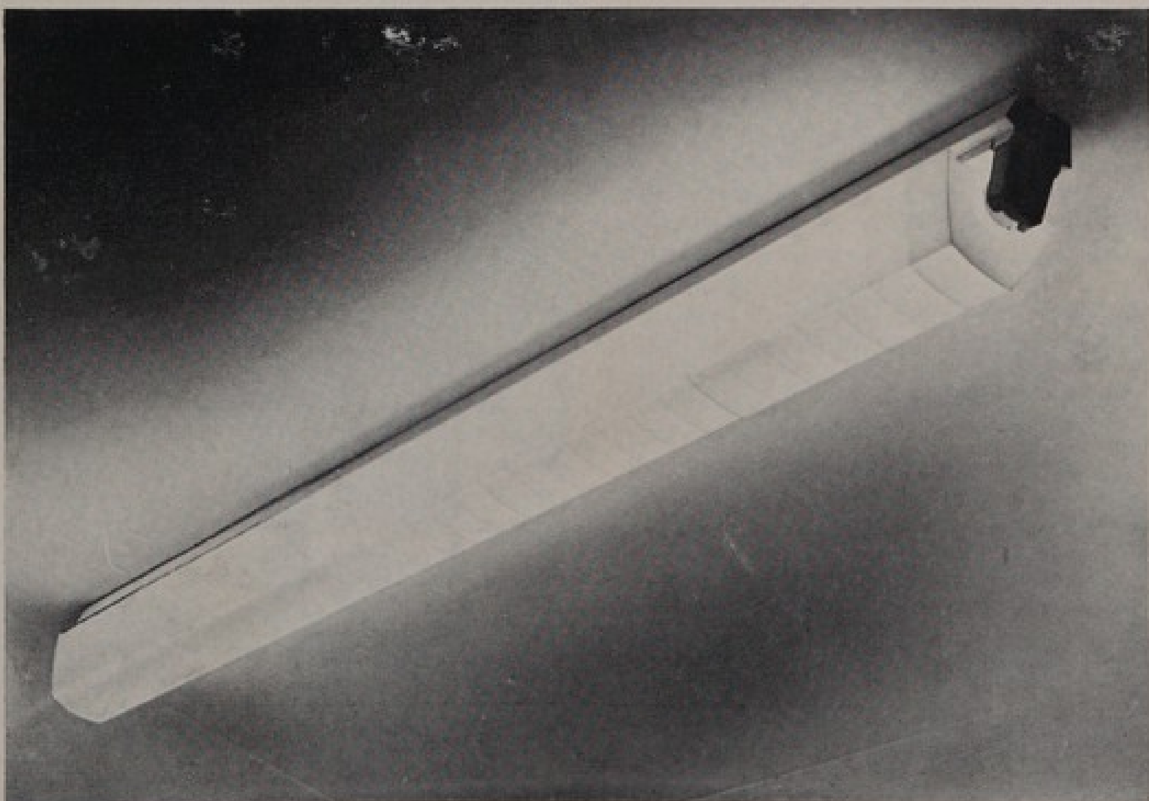
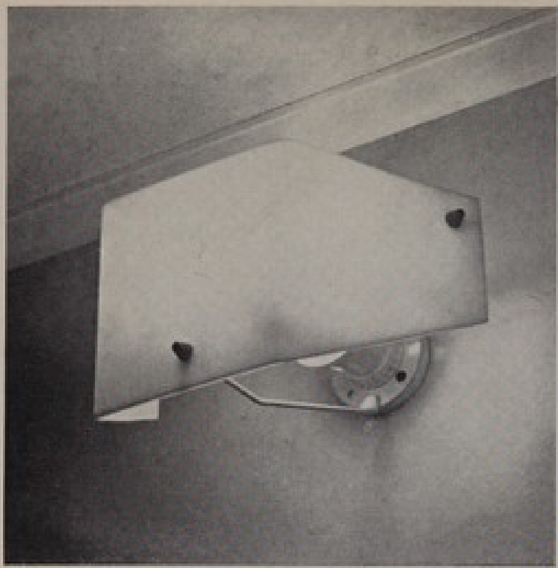


Diagram 11 and Photographs **17(a) and (b)**
Fluorescent light fitting
A simple clip-on diffuser for fluorescent fittings designed to meet the Regulations, and made in sections to suit 4 ft, 5 ft, or 8 ft tubes.

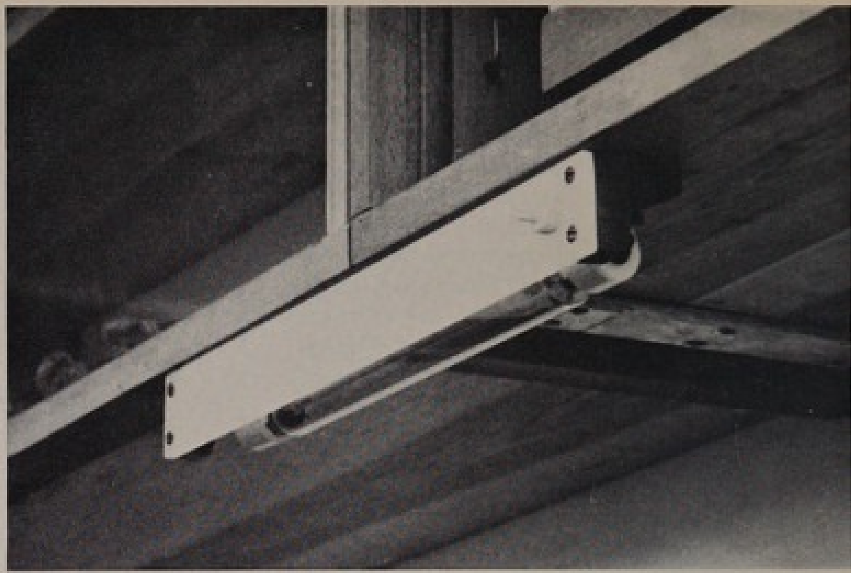






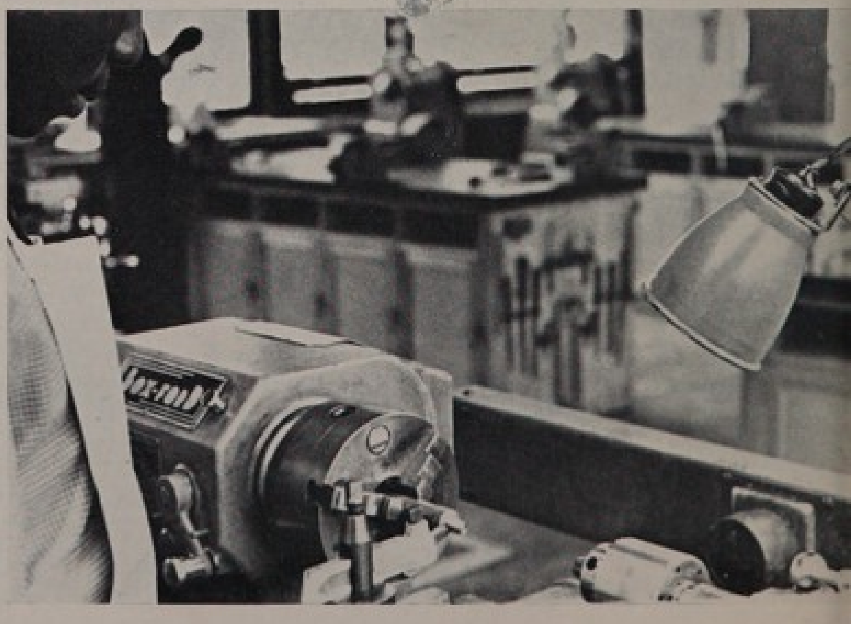


18 Wall lighting
A simple fitting moulded from acrylic plastic sheet, and designed within the Regulations concerning cut-off and brightness for use with a 60 watt tungsten lamp on walls where pupils may at times have to work with their backs to the main windows.



19 Lighting under cupboards
Another fitting for situations where close work has to be done under wall cupboards or shelves. Designed for a tungsten filament strip light, but a miniature fluorescent lamp could also be used (paragraphs 101-102).

20 Light on sewing machine



21 Light on lathe
Work which presents particularly difficult visual tasks can be done more easily with additional local lighting which can be adjusted to reveal the details of the work, as well as giving a high level of illumination on the work in hand. Such local light fittings are often attached to the piece of equipment which is being used, and should be adjusted so that they do not cause glare to the user or to other occupants of the room (paragraph 48).

used then it would be as well to ensure that a check on glare using the I.E.S. method is carried out.

123. In addition to direct glare, discomfort and even inability to see may be caused by the reflection in shiny surfaces – desk tops, worn chalkboards, etc. – of bright light fittings, particularly those of the open-bottomed type. The risk of this can be reduced by making sure that surfaces such as writing tops, floors and walls are not given a gloss finish, and are at the same time light in colour. Chalkboards should not be allowed to get shiny, and chalkboard light fittings should be placed to avoid direct reflections (diagram 14).

Choice of light source

General note

124. The character and quality of an artificial lighting scheme will depend not only on the way in which light is distributed through the room from the lighting fittings but also upon the colour and size of the source of illumination itself. These factors will also affect the cost of the installation, both in terms of its capital cost and its running cost. The choice of the most suitable type of light source will be made on two main counts: colour and efficiency.[1]

Colour

125. A distinction has to be made between the colour of the source itself, and the way in which it renders the colours of other objects which it illuminates. Good colour rendering and high efficiency are often incompatible. Of the many types of sources at present available commercially, the need for at least a reasonably truthful colour rendering (as compared with daylight) limits the sources suitable for use in schools to (a) *incandescent tungsten filament lamps*, and (b) *certain types of fluorescent lamps*.

126. *Tungsten Filament Lamps*. The filament is heated to incandescence and emits a light which is predominantly red in colour and rather deficient in blue. Such bias as it has is in a direction which flatters complexions and makes food look palatable, and through its widespread use one has come to accept it as a standard. However, when it is being used in conjunction with daylight its red bias can be seen more easily and it can create a 'torrid' atmosphere.

127. *Fluorescent Lamps*. The colour-rendering properties of fluorescent lamps range widely from a red-biased tube (often called 'de luxe warm white') which is similar to the colour of a tungsten filament lamp, to a tube whose colour is very close to that of daylight (often called 'colour-matching'). There seems to be little standardisation in either the colour-rendering properties or the names of the various tubes, and the designer is advised to check that the tube does in fact have the colour-rendering properties that he considers most appropriate for his purpose.

128. Situations in a school in which it may be thought particularly desirable to have accurate colour rendering and a good match with daylight include the art and craft rooms, where colour work started under daylight may have to continue under artificial light. This is discussed further in paragraphs 176–179. Some scientific work, such as chemical titration experiments, may also require good judgement of colour. It is important to bear in mind that the combination in one building of two light sources with quite different colour-rendering properties tends to exaggerate their differences, and a design of such a combined installation needs to be handled very carefully. For example, if the general lighting is by fluorescent diffusing fittings with some local lighting in tungsten, it is better if the tungsten fittings are of a type that conceals the colour of the tungsten lamp entirely.

[1]A fuller description of the characteristics of the various sources is given in B.R.S. Digest No. 81 (First Series).

129. Apart from their colour-rendering properties, the lamps themselves have a colour which needs to be considered. The warm hue of tungsten lamps is a familiar one and normally is quite acceptable. The cool blue appearance of 'colour matching' tubes and the greenish-yellow cast of 'warm white' tubes may not always be so acceptable, especially when used in combination with other sources. In such cases it may be necessary to choose light fittings in which the colour of the tube itself is not apparent.

Efficiency and cost

130. The efficiency of a light source may be rated by the quantity of light emitted (in lumens) for each unit of power put in (in watts). A broad comparison between the various sources is given in Table 3.

Table 3 Efficiency of light sources

Lamp	*Rated Life (hours)*	*Average Efficiency (lumens per watt)*[1]
Tungsten Filament		
100 watt (single coil)	1,000	12
150 watt	1,000	13·5
200 watt	1,000	14
300 watt	1,000	15
Hot-Cathode Fluorescent		
De Luxe colours	5,000	25–33
Cool colours (daylight, north light, colour matching)	5,000	28–47
White, warm white	5,000	43–65
Cold-Cathode Fluorescent	15,000	20–28

[1] Average efficiency of fluorescent fittings allows for 25% extra consumption of current by control gear.

131. It will be seen that the fluorescent tubes are between 2 and 3½ times more efficient than the tungsten lamps, and last 5 times as long. However, the cost of both the fluorescent tubes and of the control gear and fittings designed for them is much higher than that of the cost of tungsten lamps and of their fittings. Assuming that there are no over-riding considerations of the kind discussed above (colour rendering, etc.) leading to a choice of one or other type of source, it will be necessary to make at some stage in the design of the artificial lighting installation a comparison between the relative capital and running costs:

(a) **Capital cost**
This will be determined largely by the efficiency of the various sources, which will indicate the number of fittings required for a given room. When one knows the cost of each fitting and of the circuit wiring and switch gear to each point, then the relative capital costs can be compared.

(b) **Running cost**
Factors which will need to be considered are the length of life and replacement cost of the lamps, the cost of cleaning the fittings, the hours of use of the installation, and the cost of current per unit.

132. If figures are known for these capital and running costs then it is possible to make a comparison

between lighting installations with different sources, and such a calculation is set out in Appendix 4. As one would expect, the higher capital cost of a fluorescent installation, which can be expressed in terms of its amortization charges each year, is offset to a greater or lesser degree by its lower running cost. The longer the artificial lighting is used in a year, or the higher the unit charge for electricity, then the sooner will the economy in use of a fluorescent installation show itself.

133. In general, with current at about 2d. per unit, a tungsten installation seems to be the more economic choice if the artificial lighting is not likely to be used for more than about 200 hours per annum, as is probable for instance in a day school with little evening use. If on the other hand it is expected that the installation will be used for over 250 hours per annum, then it seems possible to make a good case for a fluorescent installation as the savings in current charges will rapidly offset the higher capital cost and thus show an economy in use. However, the architect will still be faced with the problem of absorbing this higher capital cost within the cost limits, and of doing this without unbalancing the cost plan for the building as a whole.

Calculation

134. While the calculation of the levels, brightness distribution, and glare characteristics of a large lighting scheme may normally be carried out by a local authority's electrical engineer's department or by a consulting lighting engineer, it is often useful for an architect to be able at an early stage in the design to make a quick calculation of the number of fittings required to give a certain general level of illumination in a teaching room. He may for instance need this for a preliminary electrical cost check on the number of fittings and points, or he may be designing a ceiling layout into which the light fittings are to be incorporated. Being familiar with methods of calculation will also help the architect to explain more easily to the lighting engineer what characteristics he wants from the lighting scheme.

135. A rule-of-thumb which may give some general guidance at an early stage is that given in B.R.S. Digest No. 70, which states that under average conditions with fittings giving a general distribution of light it is necessary to allow about *$\frac{1}{4}$th of a watt per sq ft for every lumen per sq ft of maintained illumination of tungsten filament lighting* and, *$\frac{1}{15}$th of a watt per sq ft for every lumen per sq ft of maintained illumination of fluorescent lighting*.

136. The standard method of calculation used by lighting engineers is the British Zonal Method,[1] but a convenient method of calculating approximate illumination levels is that known as the *lumen method*, developed by Harrison and Anderson in 1929.

137. This is described fully in a handbook, *Interior Lighting Design*, issued by the British Lighting Council, and in the chapter on lighting in 'Specification' (Architectural Press). This method is based on the assumption that the light emitted by the lamps is spread evenly over the working plane in the room. In practice, some of the light will be absorbed by the fittings and some by the interior surfaces of the room – ceiling, walls, floor, and furniture – according to their reflection factors. This absorption of light in the room is termed its utilization factor, and varies according to the distribution of light from the fittings, the proportions of the room and the reflection factor of its surfaces. An allowance is also made for the loss of light due to dirt collecting on the lamps and fittings. The formula used in the 'lumen' method and its method of application is described in Appendix 5.

138. This calculation will give the number of fittings required but two further points, which are interrelated, have still to be finally decided: the wattage of the lamp, and the spacing of the fittings. One has a broad choice between a small number of powerful lamps, and a larger number of lamps of lower output. The former will save in the wiring costs, but may require rather large shades which will be obtrusive particularly in rooms with low ceilings. The size of lamps and spacing of fittings also affects the evenness of illumination through the room. Some diversity of illumination is inevitable and a layout which gives a minimum level of illumination of about 70 per cent of the maximum is usually considered to be the most which is acceptable. In practice it has been found that this is achieved if the fittings have the following maximum spacing:

Fitting	*Maximum spacing*
General diffusing fittings; unlouvred, open, semi-direct and direct fittings.	$1\frac{1}{2}$ × the height of the lamp above working plane.
Louvred, semi-direct and direct fittings; louvred or diffusing fittings mounted flush with the ceiling.	1 × the height of the lamp above working plane

139. The spacing of the fittings from the end or side walls should not exceed half the height above working plane, because in most teaching spaces work may be done at work benches or desks close to the walls. Another reason for keeping the outer fittings near to the walls is that it has been found that in rooms of a common teaching size, say 500 sq ft to 1,000 sq ft, using fittings of the common semi-direct or general diffusing type, a regular layout with the outer fittings at the maximum permissible distance from the walls leads to a build-up of illumination in the centre of the room (diagram 11 and photographs 17 (a) and (b)). This can be avoided if the fittings are spread out towards the walls, although not so close that distracting splashes of light are thrown on to the walls. Between two and three feet is perhaps the optimum distance.

140. The positions of fittings giving the most even general level of illumination can be checked by the use of equal illumination contour diagrams, sometimes called isolux diagrams. These show the amount of *direct* illumination provided by a given fitting, and can be prepared by the manufacturer of the fitting for a given mounting height above the working plane. The direct illumination at any point in the room can then be estimated, placing the centre of the diagram on the point in question, and then adding up the total from each fitting that falls within the diagram's scope. To obtain the total illumination at this point, one must then add the indirect illumination provided by all the fittings in the room. This may amount to between 20 per cent and 40 per cent of the total illumination and can be calculated by using the B.R.S. Split Flux formula (see p. 92, *Architectural Physics, Lighting*, R. G. Hopkinson (H.M.S.O.)). In practice, the exact positions of fittings will also be affected by the location of convenient fixing points in the ceiling, and perhaps by the desire for a symmetrical layout.

[1]See *Technical Report No. 2*, Illuminating Engineering Society, London.

4 Combined daylighting and artificial lighting

Permanent Supplementary Artificial Lighting of Interiors (P.S.A.L.I.) in schools

General note

141. In most schools it is possible without undue expense to light all teaching spaces to a good standard by natural means, with the artificial lighting installation only being used to supplement daylight occasionally, on the dullest days. With normal ceiling heights, good daylighting can be provided in rooms lit from one side only which are not deeper than 20 ft to 25 ft, or in rooms lit from more than one side (adjacent or opposite) which are not deeper than 30 ft to 35 ft. In rooms which are deeper than this or which have low ceilings it is often possible to provide additional lighting from a roof light or clerestory.

142. However, on some restricted sites or with multi-storey buildings, additional lighting of this kind is only feasible with costly sectional devices, or by planning a building with a lengthy coastline, or with excessive and therefore expensive ceiling heights. There is also a growing need for teaching spaces to suit larger groups and a wider range of activities, and for suites of rooms compactly linked together, such as laboratories for practical and experimental work with their associated demonstration, preparation, reference, and study areas, all of which need to be well lit. While it may be possible in such rooms to get a view through the window, it will be very difficult to get sufficient daylight to the working surface.

143. To meet these needs techniques have been developed[1] to supplement the daylight by the permanent use of artificial lighting. Permanent supplementary artificial lighting can provide excellent lighting conditions which allow the whole area of the room to be used freely and can, in some circumstances, do so more economically than by normal daylighting. It is also possible when remodelling old schools, in which the daylighting is so inadequate that extensive structural alterations would be required to improve it, that P.S.A.L.I. may prove to be the most economic and effective way to improve the lighting and, therefore, the value and usefulness of the old buildings.

144. The general use of P.S.A.L.I. in schools would conflict with the building regulations as the daylight factor in deep rooms would be below the prescribed 2 per cent. A note is given in paragraphs 157 to 163 on the experimental use of this technique in the new Science Department of a grammar school in Oxford which was designed by the Development Group of the Department of Education and Science in collaboration with the local education authority. Other authorities are also experimenting with this technique and in the light of knowledge and experience gained from these experiments, the requirements of the building regulations will later be reviewed. Meanwhile, a revision of the regulations will enable the Department to consider on their merits and approve individually proposals to combine daylighting at less than a 2 per cent daylight factor with permanent supplementary artificial lighting, where lighting which is suitable to the normal use of a room can be provided more appropriately in this way.

145. An interior which is lit by a properly designed combination of day and artificial lighting is preferable to wholly artificial lighting for three main reasons:

(1) Light from a window, even a small one, falls horizontally across the room, making a useful contribution to modelling, and softening the shadows cast by overhead lighting.
(2) A view through a window provides a distant visual release, and avoids an oppressive sense of enclosure.
(3) The sun and sky, the clouds and wind, and the play of light and shade outside are never static, and a window is a link with the interest of the constantly changing world out of doors.

146. The chief aim of P.S.A.L.I. is to produce an integrated lighting scheme in which natural and artificial lighting is combined so that the predominantly artificial lighting at a distance from the window does not appear to the users of the room to be deficient in quantity or quality when compared with the predominantly natural lighting near to the windows. To achieve this aim careful attention needs to be given to a number of points in the course of the design.

Window design

147. The size and position of the window(s) should be chosen so that as much as possible of the interior receives a horizontal component of daylight. A significant contribution can be made at the back of the room by a horizontal component of daylight factor on the vertical plane of 1 per cent, and as little as 0·25 per cent on the horizontal plane. One of the incidental advantages of these small windows is that more wall space is made available inside the room for shelving, pin-up boards, etc. and the most should be made of this when relating the position of the window to the use of the room and the layout of the furniture. One should also be able to see out through the window from as many parts of the room as possible. The window should have proportions which give a natural view of part of the exterior scene; exaggerated vertical or horizontal slits appear to restrict the view out, and should be avoided.

148. Special care should be taken in the detailed design of the windows to reduce glare and to give a comfortable grading of light from the outside to the inside. Splayed reveals, deep sills, and tapered glazing bars will help here, as they do in a normal window. In some circumstances it is worthwhile introducing some device to reduce the brightness of the sky seen through the top of the window, as this will lower the level of supplementary illumination which the occupant of the room will require. There are various ways in which this may be done: opaque or semi-opaque louvres fitted at the top of the window; prismatic or neutral tinted glass in the upper portion of the glazed area; outriggers fixed outside the windows; or translucent blinds for curtains. With any of these methods it is also necessary to consider such matters as cleaning, re-painting, ventilation, sun control, and possibly blackout.

[1] See B.R.S. Digest No. 135, July, 1960, *The Permanent Supplementary Artificial Lighting of Interiors;* and I.E.S. Technical Report No. 4, 1962, *Lighting during Daylight Hours.*

Design and layout of the supplementary installation

149. The supplementary installation should be designed so that all parts of the room seem to be equally well lit, and so that the occupants are not concerned that a part of their working light comes from an artificial source. This calls for inconspicuous, glare-free fittings with a source of light whose colour closely matches daylight (see paragraphs 124-129). These fittings should be positioned so that the supplementary lighting comes sufficiently far forward in the room to overlap the daylight and to avoid the risk of a trough of low illumination in the centre of the room. It may be possible, with suitable switching, to use some of the fittings for lighting after dark as well, thus simplifying the installation and saving money. To do this it is necessary to select a fluorescent tube whose colour is acceptable both in the day and at night. A good match between the colour-rendering properties of the P.S.A.L.I. and of the light coming through the window is particularly important. It has been found that the best in this respect are, first, the 'Colour Matching' tubes, and then the 'Daylight' tubes. If a tube with a warmer colour is used the sense of a daylit interior is lost, and the deep room is divided into two zones. To unify the room it seems important to ensure that the appearance of a colour remains constant throughout the room, and that whites always read as true white. One additional problem is that the sources which give the best colour-rendering are themselves rather cold to look at. This suggests that the design of the fittings should conceal a direct view of the tube and of its own colour.

The need for lively interiors

150. P.S.A.L.I. can lead to interiors with an even, high level of brightness which may tend to be monotonous unless care is taken to incorporate in the details of the design some features which will add sparkle and vitality to the room. It may be possible for local lighting of the type discussed in paragraphs 100-102 to make a contribution both by the sparkle of the fittings themselves and by the pools of brighter light which will add variety to the general illumination. The detailing and colouring of the room can also play a major part in producing a lively interior. High degrees of contrast in light and shade or in colour, confined perhaps to small areas; the use of glossy white finishes on trim, shelf edging, etc; the glint of metallic fittings on doors, windows and benches – all these will help to add sparkle to the scene.

151. In educational buildings, the need for P.S.A.L.I. is likely to be confined to a small proportion of the total accommodation in any one building. The brightness levels to which the users are adapted in the smaller, fully day-lit classrooms and in corridors in other parts of the building will often be very much higher than in the P.S.A.L.I. rooms, particularly on bright days. The design of lighting in areas which are near to, and are used in conjunction with the P.S.A.L.I. rooms should be kept to low brightnesses, so that there are no sharp contrasts.

P.S.A.L.I. in practice

Harris College, Preston[1]

152. Examination of the educational brief for this college of further education showed that a number of large rooms of about 1,200 sq ft would be needed, spread through each of the main departments. Site restrictions meant that much of the accommodation would have to be in multi-storey buildings and for this reason very few of the large rooms could be lit by roof lights. The client also asked for a building in which it would be possible at a later date to re-arrange the departments, the sizes of their rooms and the layout of the partitions. This last requirement led to buildings with a simple rectangular plan in which most of the rooms could be lit from one side only.

153. Each department had to contain a number of large rooms of 1,200 sq ft or more. The only way to have provided a 2 per cent daylight factor for these large rooms, some of which were 44 ft long by 28 ft deep, would have been to raise the ceiling heights generally to 14 ft. Quite apart from the prohibitive cost of doing this, it would have created severe problems of glare, heat loss, etc.

154. All these factors led to the conclusion that P.S.A.L.I. would provide the best type of lighting for the deep rooms and would at the same time be the most economical solution that would meet the client's requirements.

155. In a series of model studies carried out at the Building Research Station, it was found that in a room 28 ft deep, with windows which gave a 1 per cent daylight factor at the back of the room, the need was felt for supplementary lighting of 35 to 40 lm/ft^2 to achieve a comfortable balance of brightness across the room while at the same time preserving the predominantly daylit character of the interior (diagram 12 and photographs **22** (a) and (b)). This level of supplementary lighting was chosen when the average sky brightness was about 1,000 foot-lamberts, as this was considered to be representative of the sky conditions likely to be encountered during the year. The supplementary lighting is provided by 'daylight' fluorescent tubes in a laylight with plastic louvres which for structural reasons had to be suspended beneath the ceiling rather than flush with it. Permanent white louvres mounted on the upper part of the window reduce the amount of bright sky visible from within the room. This lowers the adaptation level of students sitting at the back of the room and thus lowers the level of P.S.A.L.I. that is felt to be necessary to achieve a comfortable balance of brightness.

156. In the completed College, the main aim of the P.S.A.L.I. has been achieved, with a good level of illumination and an acceptable range of brightness across the deep rooms. However, it was felt that there were a number of lessons which could be learned for the benefit of future P.S.A.L.I. installations:

(i) The concentration of the P.S.A.L.I. in the laylight at the back led to a noticeable dip in illumination down the centre of the room. This would have been prevented if the supplementary fittings had been spread further towards the windows.

(ii) Some users found the laylight too prominent a visual feature in the room, both in size and brightness.

(iii) The attempts to economise by using some of the high efficiency 'warm white' tubes from the after-dark installation as part of the P.S.A.L.I. as well was a mistake, for there was a very marked division between the daylit areas and the part which was artificially lit.

(iv) The client found it difficult to understand why windows had been provided and then covered up with louvres – a smaller window in the first place

[1] For a full description of this building, see Building Bulletin No. 29, *Harris College, Preston*.

might have seemed more logical. This difficulty was accentuated because the form of plastic louvre chosen proved awkward to maintain.

The Oxford School, Science Department

157. The experience gained at the Harris College indicated a number of ways in which the technique of P.S.A.L.I. in schools might be developed (see paragraph 156). To explore these a further series of model studies was initiated in co-operation with the Building Research Station.

158. The first stage in this was to examine a theoretical situation with a model of a room 24 ft × 48 ft × 10 ft high in which it was assumed there was a small window at one end only. In this extreme case, it was found that under certain circumstances a visual environment that was just acceptable could be created with a window which was only about 5 per cent of the floor area. The window had to be carefully detailed with splayed reveals, and the permanent supplementary lighting was provided by an array of recessed and louvred fluorescent fittings evenly distributed through the room, which gave an illumination of 25-30 lm/ft² from colour-matching tubes. There were also some indications of features of the decorations and detailing of the room that would be necessary to produce a lively interior, especially after dark.

159. The second stage was to apply these tentative conclusions to a chemistry laboratory which was to be part of the Science Department of a grammar school in Oxford. The reasons for selecting this particular room were entirely experimental – the room could have been fully daylit and the rest of the building for the department is in fact lit to the 2 per cent minimum daylight factor standard. The design was developed through a series of model studies, and the final model was fully detailed, as it was found that quite small details such as light fittings, white-painted shelf edges, and even the laboratory glassware, all contributed to the visual character of the interior (diagram 13 and photographs **23** (a) and (b)).

160. The laboratory is 912 sq ft (24 ft × 38 ft) × 9 ft high with a preparation room adjacent to the end. The laboratory is used for a combination of theoretical work and detailed practical work which may be done in any portion of the room. The daylighting is provided by two small windows with a combined area of 1/15th of the floor area. The larger window is in the wall adjacent to the display area, but is placed so that the main splash of light is thrown along the wall to the chalkboard area. The smaller window is at the other end of the room in an adjacent wall and gives a measure of cross-lighting. Both windows have deep reveals and are detailed to grade contrasts from outside to inside. The two windows are large enough to give a sense of release and to maintain visual contact with the outside. They give a valuable horizontal component of light but it is not sufficient to work by over the whole area of the room. The small size of the windows freed extra wall space for storage and display.

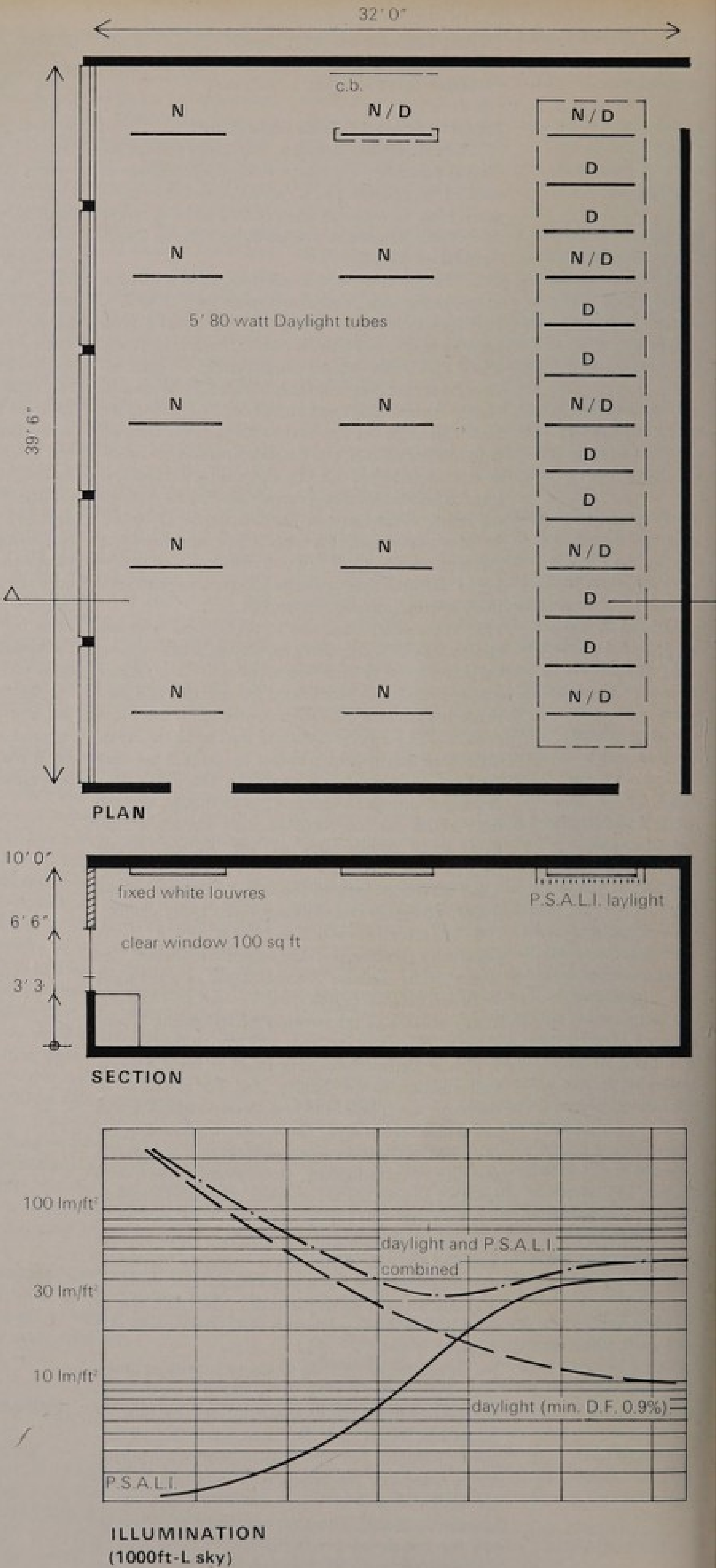
161. It was found that supplementary artificial illumination to about 25-30 lm/ft² provided a good working illumination, gave a satisfactory balance of brightness throughout the room, and relieved any sense of gloom. The unobtrusive fluorescent fittings are recessed into the ceiling with light grey louvres (Munsell reference N 8) in a one inch grid made of translucent plastic. These are not too bright when lit, and not too dark when switched off (the fittings by the windows may be switched off optionally). In addition to the general supplementary lighting, local lighting is provided over chalkboards and display areas, and in fume cupboards and combustion hoods. This not only improves working illumination at these points but also brightens surfaces at some distance from the windows and adds sparkle and variety to the scene. The local lighting also makes it a more lively interior after dark, for the overhead lighting by itself tends to be rather dull. The use of white paint and metal trim and the careful placing of colours also help in creating an interesting scene.

162. The supplementary installation, which is also used for after-dark lighting, has 'colour-matching' tubes (Philips 55, colour temperature 6500°K). These were found to give an accurate colour rendering and the most satisfactory match with daylight.

163. The level of daylighting in parts of the building adjacent to the P.S.A.L.I. laboratory was kept as low as working requirements allowed, so that there was not an unfavourable contrast with the level of illumination in the supplementary room. The level of artificial illumination in the rest of the building was designed at 20-25 lm/ft² with 'daylight' tubes, in surface-mounted fittings (diagram 11 and photographs **17** (a) and (b)). While it would have been better to have used colour-matching tubes in recessed fittings at 25-30 lm/ft² throughout the rest of the building, in order to ensure good match with the after-dark illumination in the P.S.A.L.I. room, this would have been prohibitively expensive and the more efficient 'daylight' tubes were used as a reasonable compromise. The problem of blending P.S.A.L.I. with normal day and artificial lighting in other parts of the building is one of the most difficult of those posed by this new technique.

Diagram 12 and Photographs 22 (a) and (b) P.S.A.L.I. at the Harris College, Preston

Deep laboratories at the Harris College are lit by a combination of daylight and artificial lighting designed to give comfortable working conditions in any part of the room. The brightness of the upper part of the window is reduced by fixed opaque white louvres, giving a minimum daylight factor of 0·9%. This is supplemented by 5 ft 80 watt 'daylight' fluorescent tubes installed in a laylight of white plastic cellular louvres, adding about 40 lm/ft² at the back of the room. After dark, the switching is arranged so that some of the tubes above the laylight (those marked N/D) come on with the other fluorescent fittings in the room (marked N) (paragraphs 152-156).



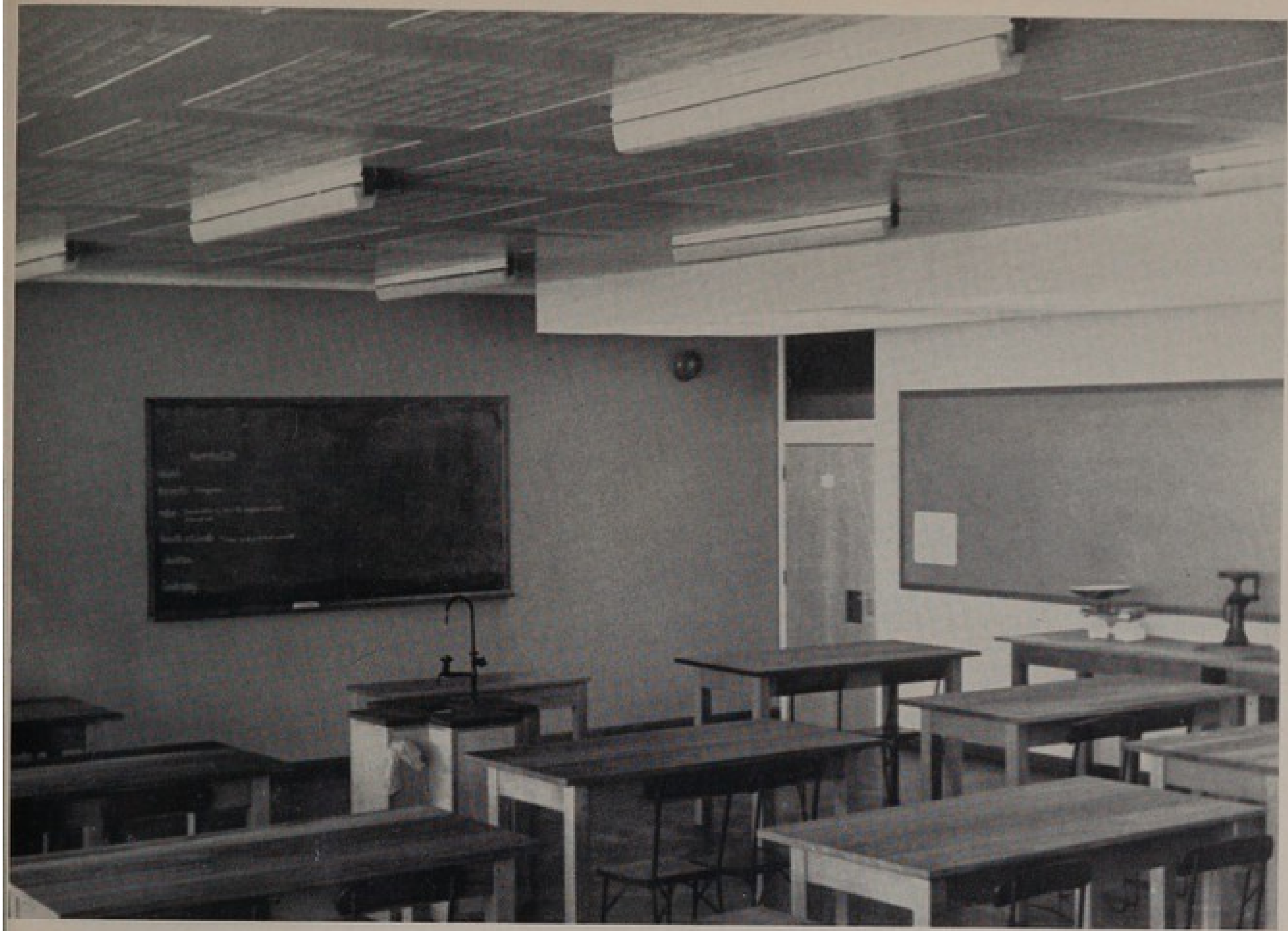
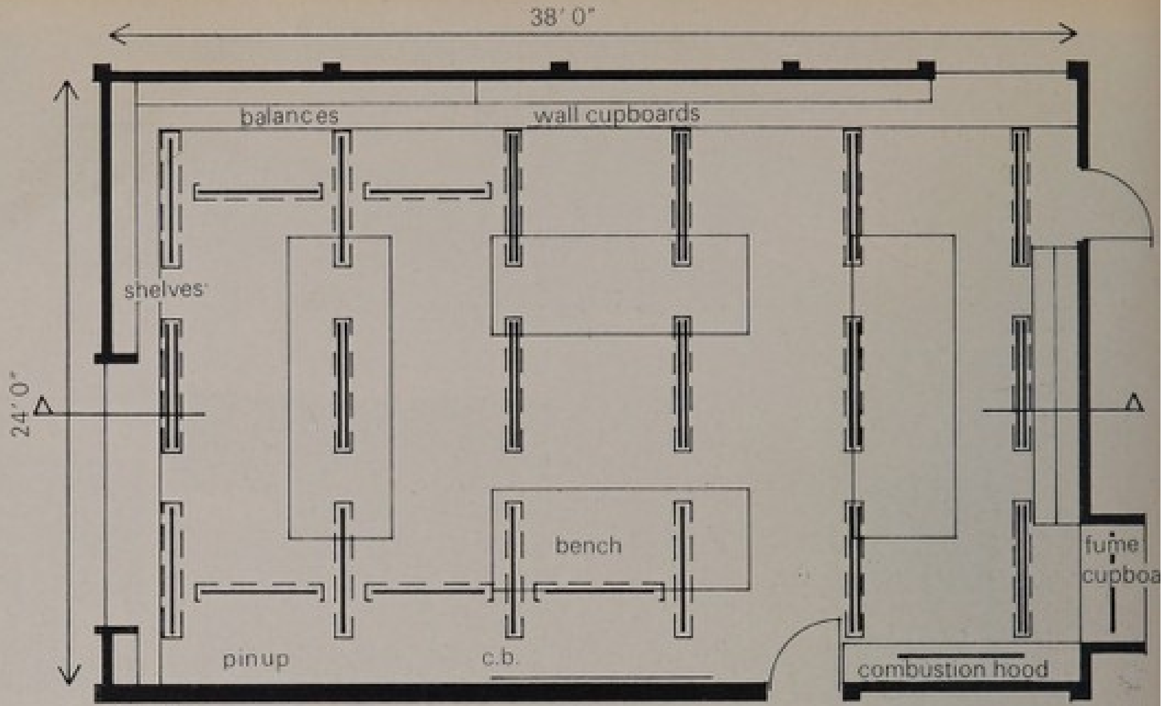


Diagram 13 and Photographs **23 (a) and (b) P.S.A.L.I. at the Oxford School.**

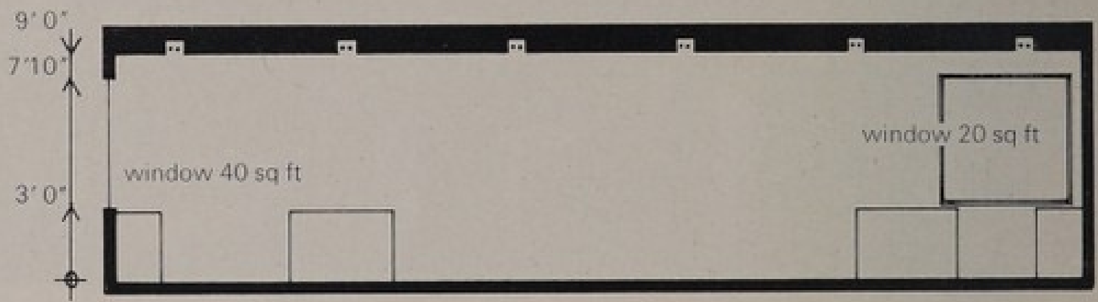
The use of P.S.A.L.I. was carried further in a new laboratory at the Oxford School. Model studies showed that two windows with a combined area of about 1/15th of the floor area placed as shown were sufficient to give a sense of visual release and an appreciable horizontal flow of light across the room. The minimum daylight factor of 0·25% is supplemented by light fittings recessed into the ceiling with light grey louvres, fitted with Philips 55 colour-matching fluorescent tubes which give accurate colour rendering and the most satisfactory match with daylight. Additional fittings brighten the walls. It was found that white-painted trim, metal accessories and even the scientific glassware are all important in creating a lively scene (paragraphs 157-163).

(a) View from the larger window

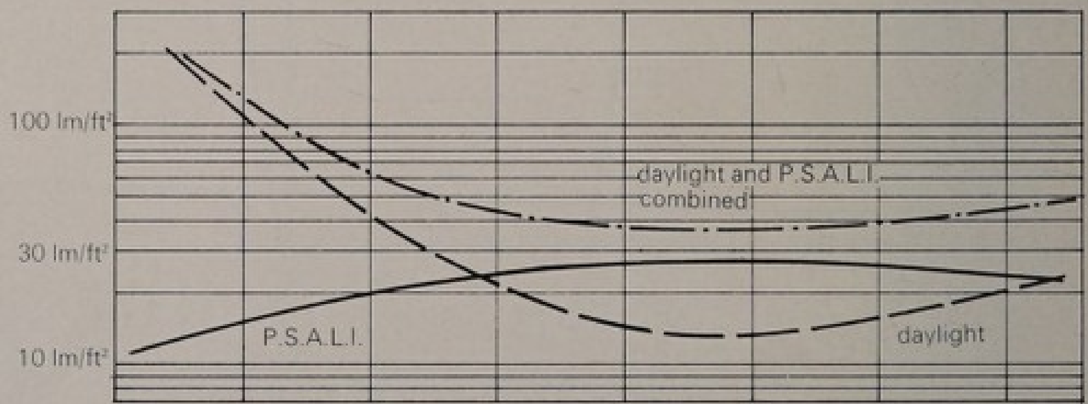
(b) View toward the larger window



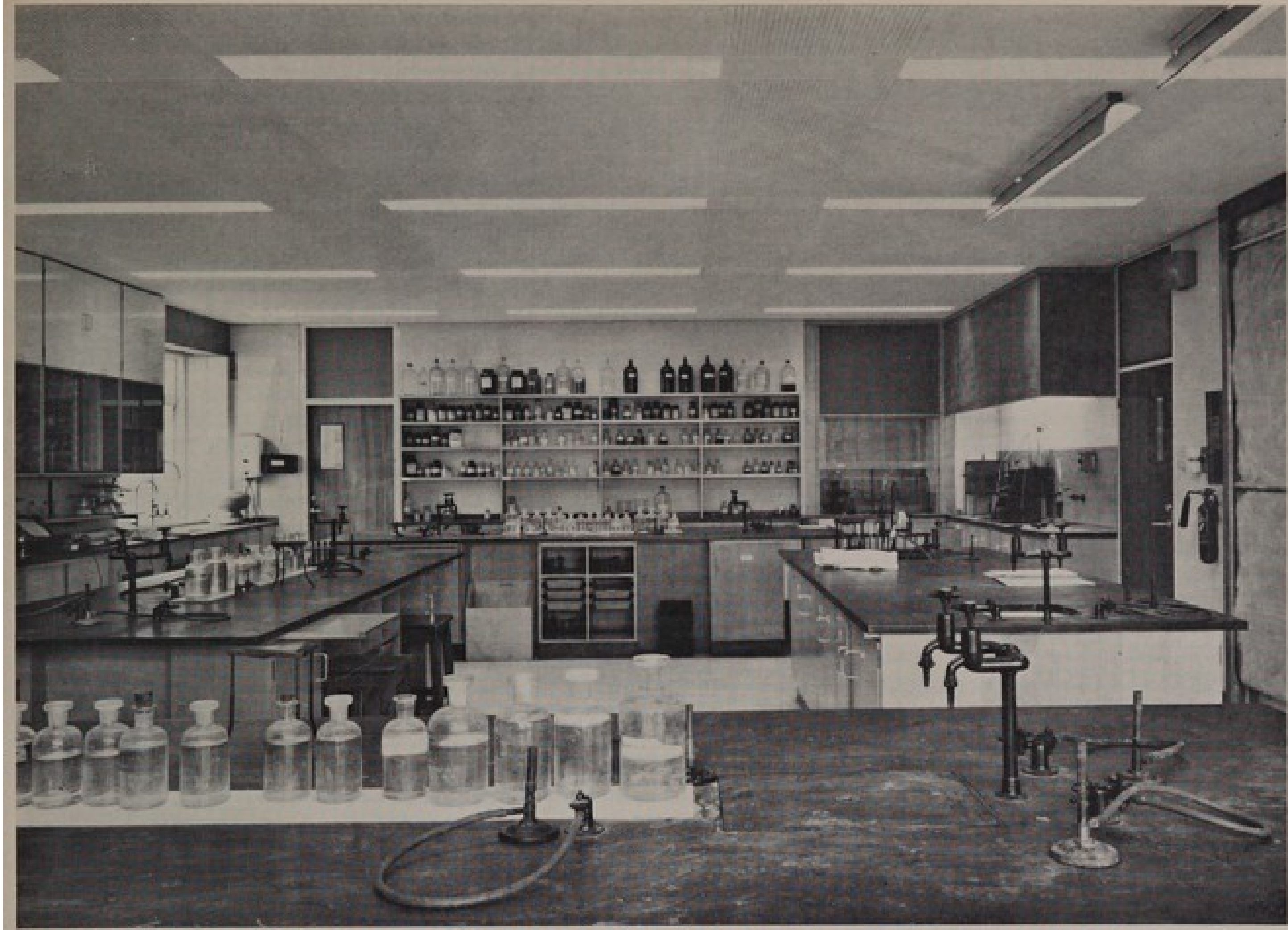
PLAN



SECTION



ILLUMINATION (1000 ft-L sky)



5 Particular applications

General note

164. This section discusses the application of the general principles set out in Sections 1 to 3 to the various parts of a school in turn. It does not pretend to be comprehensive, or to deal with every corner of the school. The examples given are merely illustrations of some of the solutions to a number of the more common lighting problems that arise in school design. There can be no substitute for the designer in each case finding out how the various spaces in the school are to be used, and then designing appropriate lighting from first principles.

165. The headings under which the different activities will be dealt with are as follows:

- The School as a Whole
- General Teaching Spaces
  - General lighting
  - Local lighting
  - Reduction of glare
  - Visual character
- Practical Work
  - Art
  - Housecraft
  - Light crafts
  - Workshop crafts
  - Technical drawing
- Science
  - Physics/Chemistry/Biology
- Visual Aids
  - Chalkboard and display areas
  - Demonstration work
  - Projection equipment
- Communal and Assembly Areas
  - Assembly hall
  - Dining areas
  - Common rooms
  - Administration
- Physical Education
  - Gymnasiums
  - Sports halls
  - Swimming pools
  - Outdoor floodlighting
- Circulation Areas

Lighting and the design of the school as a whole

166. The lighting of the various parts will of course have to be considered in the context of the planning and design of the school as a whole, which will be determined by three main factors: existing site conditions, educational needs, and economic considerations. These three influences on the design may not always be compatible. For example, the educational brief may be satisfied best by a compact plan on one level, but the restrictions of the site may nevertheless dictate a multi-storey building. At the same time the need for high standards of lighting during the day can be met in two ways: (a) full daylighting which will require a building with a complicated coastline and section – in itself inherently expensive, or (b) by the use in the deep rooms of P.S.A.L.I. which, although also costly, may still be the most satisfactory lighting solution, considering the building as a whole. Such conflicts will have to be resolved in the course of each design. In the same way, the lighting requirements of the individual rooms will interact with the overriding needs of the whole school. The starting point for lighting design must always be the activities of the users of the school and an understanding of their visual needs. The designer should know the likely mode of use of the various spaces in the building, and thus the character required in them, which the design of the lighting and colour should help to develop.

167. At the same time, the lighting will be considered alongside other aspects of the physical environment, such as heating (e.g. solar heat gain through windows, or heat emitted by artificial light fittings). The light fittings will also be designed and positioned in relationship to other elements, in particular the ceiling. It may, for example, be possible and economic to design the light fittings as an integral part of the ceiling (see paragraph 114).

General teaching spaces

General note

168. The majority of classrooms in existing schools were designed for groups of thirty to forty children in rooms of 500 sq ft to 650 sq ft, arranged mainly for formal teaching with the children seated at their desks and facing in one direction. The use of the room is, therefore, static and the lighting problem a relatively simple one.

169. However, general teaching spaces are not always as predictable as this, and increasingly new teaching requirements are calling for rooms of a great variety of shapes and sizes. At one end of the age range, a 'classroom' to meet the needs of forty of the youngest children in an infants' school may be a large area of 700 sq ft to 900 sq ft, designed with bays and corners, and subdivided temporarily or permanently to contain a wide range of activities which are going on at the same time: reading, painting, making things, sewing, acting. At the other end of the scale, a common room for sixth-formers will need to be a large space or group of spaces suited to their many-sided activities: debates, discussion groups, lectures, private study, table tennis, dances, conversation, chess, and relaxation.

170. The character of the lighting suitable for these two extremes is unlikely to be the same; for the younger children a homely atmosphere may be the aim, while for the older ones a more sophisticated character will be preferred. But both have a number of important lighting requirements in common, based on the fact that each room will be used in a variety of different ways. However, the work done in them is unlikely to include the most difficult visual tasks. These main lighting requirements have been discussed earlier in this Bulletin and, while they apply to any teaching space in a school, they may be summarised usefully here:

General lighting

171. An adequate level of lighting is required with a good spread to all parts of the room. Light interior surfaces, particularly on the floor, with an average reflection factor of about 40 per cent, will make the most of inter-reflected light, and will help to avoid unrelieved shadows and silhouetting. Windows should be placed so as to give cross-lighting wherever possible. For the main artificial lighting, fittings which give a good general distribution of light onto the walls, floor and ceiling should be chosen.

Local lighting

172. In addition to the general lighting, preferential local lighting will help to draw attention to particular focal points, such as a chalkboard, map rail, or display board, or to define an area within the room as a whole. Methods of lighting the chalkboard are discussed in paragraphs 195-196.

Reduction of glare

173. The risk of discomfort from glare should be reduced to the minimum. Windows should be placed and the room layout arranged so that bright windows are not immediately adjacent to the chalkboard or the teacher's normal standpoint. Adjustable blinds should be provided to cut out the sun and views of bright skies, in particular on windows facing south and west. The walls in which the windows are set should be brightened by cross-lighting and light decorations, and the surrounds to the windows detailed and painted to give contrast-grading. Light fittings should conform with the building regulations on cut-off and brightness, and should be seen against light backgrounds. The irritation caused by reflected glare can be avoided by using matt finishes for walls floors, and working surfaces.

Visual character

174. The visual character of rooms in which pupils will spend most of their day should preferably be stimulating without being restless.

Examples

175. The examples given in diagrams 4 to 7 and photographs **11** to **14** illustrate a number of different solutions to the lighting problems discussed above.

(1) A classroom in a junior school where natural lighting was available from three sides and from above.

(2) A classroom in a secondary school where natural lighting was available from two adjacent sides.

(3) A classroom in a secondary school on a very exposed northern site lit from one side only with minimum glazing.

(4) A classroom in a 50-year-old grammar school which was remodelled to modern standards.

Practical work

General note

176. This portmanteau term is used here to cover the art, craft and workshop activities found in a school, although 'practical' activities will be found in other rooms as well. Although these will occur mainly in secondary schools, there may also be some points of application for younger children. Primary schools will require rooms lit so that both 'chalk-and-talk' teaching and the particular subject's practical work can be carried out equally easily.

Art

177. A good spread of daylight over the whole room is the main need. This will be provided more easily by high-level roof or clerestory lights, rather than by side windows which can then be kept for views out. For some drawing and painting, the steadier daylight given by north-facing windows may be preferred, although this does not mean that windows facing the sun need be excluded altogether, as long as they are fitted with suitable sun-blinds. Good general lighting is the main requirement of the artificial installation. Some work may benefit from a powerful modelling light used to maintain the shadowing on a particular object or group. Strong, directional lighting is often preferred in drawing and painting studios in art schools, with walls of a subdued, neutral colour as background. If fluorescent lighting is installed, colour-matching tubes are available which give a well balanced colour rendering, comparable with daylight, and their use will make it easier to continue under artificial lighting colour work started by day. Extensive display areas will be needed, and these will probably require some additional local lighting.

Housecraft

178. The main points that should be considered are that the chief working places – sink and worktops – should be as well lit as in a domestic kitchen, and that it should be possible to see easily into cookers and cupboards. In view of the heat generated in the room, south-facing windows should be kept as small as possible, and should be provided with efficient blinds. If dining or living areas are included, this will be an opportunity to provide good lighting of a domestic character with pendant, table and wall fittings.

Light crafts

179. The general run of craft work will need good overall lighting making it possible to work in any part of the room, including by the walls. This may be provided most conveniently by high-level roof or clerestory lights, thus freeing most of the low-level walls for work and display. This general lighting may need to be supplemented by local lighting to help the close, detailed work involved in some aspects of bookbinding, weaving, etc. Rooms used for sewing and dress-making are a special case, as needlework can be a most exacting visual task. In rooms for needlework, a general level of illumination which is twice that provided in normal classrooms will be required, and at the same time special care must be taken to reduce distraction and glare. In addition, individual lights may be needed for the most intricate work. Sewing machines are now often fitted with their own lights, fixed in the most appropriate position (see page 30 – photograph **20**). A welcome feature is a fitting mirror with lighting arranged so that the light falls on the person standing in front of it.

Workshop crafts

180. Woodwork and metalwork will have the same requirements for general lighting, with local lighting in certain key places where particularly critical work is done, such as on engineering lathes (photograph **21**). In the larger workshops in technical schools or colleges, where work that is the equivalent of industrial practice is carried out, it may be helpful to consult the I.E.S. Code, where appropriate standards for a wide variety of processes are given, and the B.R.S. Factory Building Studies No. 2, *The Lighting of*

Factories, Workshop and Industrial Lighting (H.M.S.O.) which discusses more fully the problems of such lighting. Where workshops containing machinery with visible rotating parts are lit by fluorescent fittings, it can happen that the stroboscopic effect of alternating current makes it difficult to assess the speeds of moving parts. This can be avoided by wiring adjacent fittings on the 'lead-lag' principle or off different phases of the supply, and the electrical engineer's advice should be taken on this.

Technical drawing

181. For architectural or engineering drawing, it is necessary to provide a level of illumination of at least twice that in normal classrooms. Where only a few boards are involved, individual adjustable lights may be the best answer. But where there is a larger group of students, good general lighting over the room as a whole will be more appropriate. Artificial fittings which do not cause excessive reflected glare off tracing paper should be chosen.

Science

General note

182. An essential feature of scientific work and teaching is *observation* of experiments and of natural phenomena. It follows that lighting conditions which promote good vision must be created in school laboratories. Apart from more everyday considerations, crucial examination results may depend on an accurate reading of a micrometer or on being able to detect a colour change in a chemical titration experiment. In general, much of the work done in science departments is more visually exacting than that done in normal classrooms (photograph **25**), and will therefore require rather higher standards of lighting. A general level of illumination of 20 to 25 lm/ft^2 should be looked upon as an average working figure; higher levels will be required for advanced work and for particularly intricate jobs, such as dissection. The arrangements for both natural and artificial lighting should allow work to be done in any part of the laboratory, including the areas close to the walls. Preparation rooms and workshops should be lit to the same level as the main laboratories, for preparation itself is often intricate, and advanced work is sometimes done in the preparation rooms.

183. Daylight is as desirable in laboratories as in other rooms in the school – and may be considered essential in biology laboratories – but there are particular circumstances which must be dealt with. First, laboratories in schools will be larger than many other teaching spaces, and may range from 750 sq ft to 1,000 sq ft, and may be larger still in technical colleges. This will mean that windows on two sides, or alternatively roof lighting, will be needed to maintain a good level of daylighting. At the same time, the size and position of the windows will have to be considered carefully as there will be many other demands on the wall for cupboards, shelving, and display space.

184. Excessive sunlight in summer can be an embarrassment and main windows facing south or west should if possible be avoided, except in the special case of biology. Blinds allowing effective control of the sun should be installed (see paragraphs 91 to 94), not forgetting any roof lights. These blinds should also be considered in relation to the probable need for some dim-out to allow for the use of visual aids (see paragraph 95). Full blackout is very costly and may in fact be needed less than is often assumed. Optical work in physics teaching can often be done in a specially darkened recess off the main laboratory, or perhaps in a separate dark room which may also be used for other purposes. Blackout techniques are discussed further in paragraphs 206 and 207.

185. Additional lighting will be needed preferentially directed at both the chalkboard and any associated display areas, and at the demonstration bench. It will often be possible for the same fitting(s) to do both jobs simultaneously.

Physics

186. The most exacting visual tasks in physics will be in reading vernier scales on micrometers and similar instruments, and in constructing and manipulating small-scale apparatus. Good overall lighting is the first essential, but additional local lighting – perhaps in the form of adjustable bench lights – will make this detailed work easier, and the provision of suitable socket outlets on benches should be considered at least for advanced work. For safety's sake, these should be on a low-voltage supply (24V or 12V).

187. Balances present another awkward lighting problem. In the standard type of school balance, the incised figures on the beam are usually very small, and the case in which the instrument stands will often cast inconvenient shadows – pupils should be discouraged from putting books on the glass top, for this reason as well as others. Working light should come from fittings (which may well be the general room fittings) placed so that shadows are not cast by either the balance case or the operator's head. The more elaborate types of balances may have their own internal lights.

Chemistry

188. Much detailed work in chemistry laboratories is of the same order of intricacy as in physics as, for example, judging precisely the levels of liquids in pipettes; watching for the moment of boiling or precipitation; distinguishing colours or changes in colour.

189. One small point which can cause inconvenience or even danger is that bunsen burner flames can be invisible in direct sunlight or against a very bright surface. The architect cannot guarantee that these situations will not occur, but this is one of the reasons why proper sun control is needed. Bench tops will normally offer a dark background to bunsens, and some scientists also find it helpful if windows do not come right down to bench level but an upstand is left against which the bunsens can be silhouetted.

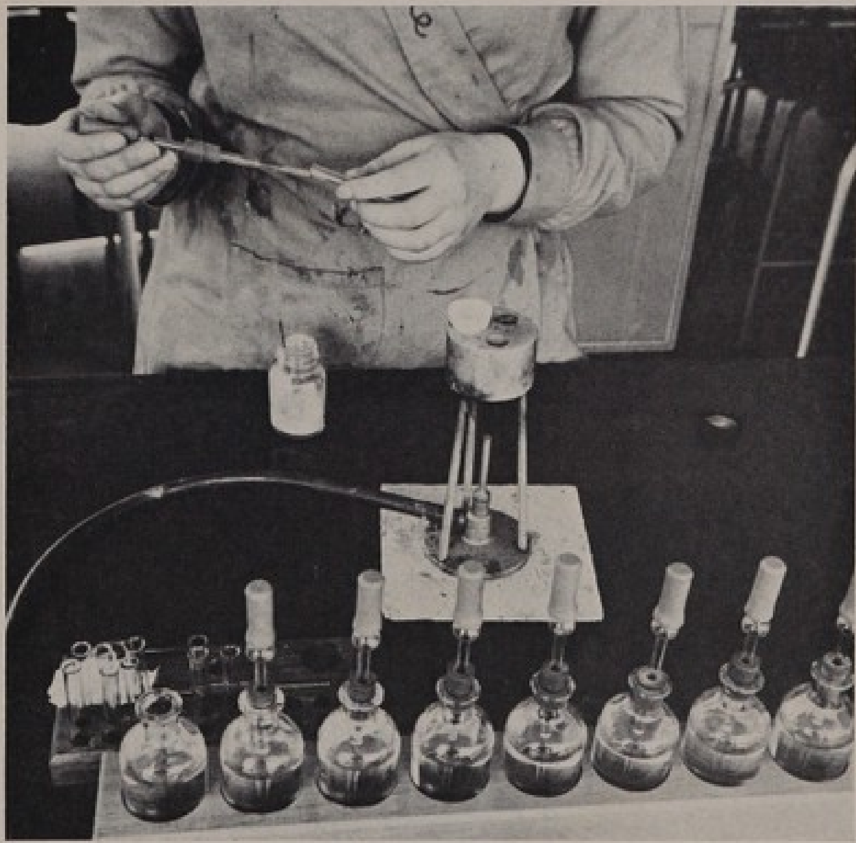
190. Fume cupboards need a separate internal light sealed against fumes, both to enable pupils working at them to see clearly what may be a potentially dangerous experiment, and for the class to follow when the fume cupboard is being used for demonstration purposes. The fumes which may at times be present in some chemistry laboratories may call for artificial fittings with non-corrodible parts.

Biology

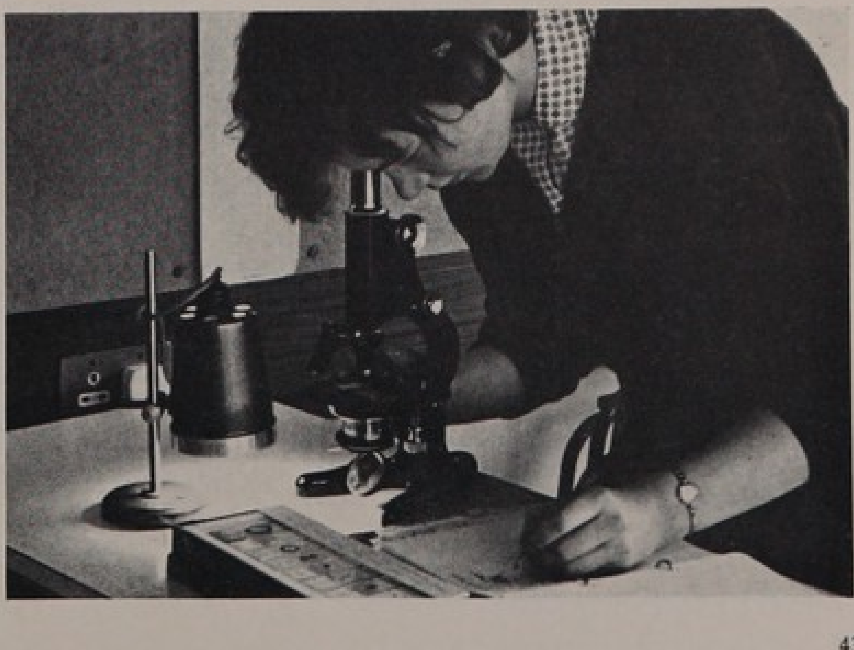
191. Many of the lighting needs of biology are common to the other types of laboratories, although here observation will often be of the subtle variations in colour, form and texture of living things. Much work will be done on microscopes and, although some are now self-illuminating, it will normally be necessary to provide small bench lamps which should for safety's sake be on a low voltage supply (photograph **26**). Socket outlets should as a rough

24 Fine needlework
Sewing – here with fine stitches in a dark thread on a dark cloth – can be a most exacting visual task, and requires a level of illumination above that provided in a normal classroom (paragraph 179).

25 Small-scale work in science
Small-scale methods are now being used for much science teaching, and good standards of lighting are required (paragraphs 182 *et seq*).



26 Microscope lighting
Some scientific work, particularly in biology, requires adjustable bench lamps for use with microscopes and in dissection. For safety's sake, these should be on a low voltage supply. Some microscopes are now self illuminating and also require a suitable supply.



guide be provided on the scale of one for every two pupils in elementary laboratories, and one for each student doing advanced work. These bench lamps will also be used for dissection work and will be useful, even when good daylight is available, to probe cavities and throw details into high relief. One problem arising in the use of many types of dissecting lamps is that the heat of the lamp dries up the specimen. There is a need for a dissecting lamp designed with miniature fluorescent tubes which have a lower heat output than tungsten filament lamps.

192. For the study of photosynthesis in plant growth, day and sunlight (under strict control) will be required. This may be done either on benches and ledges close to the normal windows, or in a Wardian window in the laboratory itself, or in a separate greenhouse. Sun blinds will be required in any of these cases, and draught-free ventilation will be needed in Wardian windows or greenhouses. It may be desirable to continue some experiments under artificial photoactinic light, produced by fluorescent or mercury vapour lamps, and suitable socket outlets should be provided.

193. Blackout may be required for micro-slide projection (see also paragraphs 206-207).

Visual aids

General note

194. This section examines some of the problems of lighting and vision that are met in the use of visual aids to teaching. It treats the subject broadly, and includes the chalkboard, charts and diagrams which are pinned up, the demonstration of scientific experiments and other practical work, as well as projection equipment of various kinds and the associated problem of black-out. All these situations are encountered from time to time in general-purpose classrooms and practical rooms, as well as in specially equipped lecture/demonstration theatres, an example of which is illustrated (photograph **2**).

Chalkboards and display areas

195. The successful use of chalkboards and of any associated display areas used for charts and diagrams depends upon the pupils being able to see them easily. But all too often, even in some new schools, the matter written up cannot be seen because of inadequate lighting on the board, or because it has been fixed too near a bright window. Even where chalkboards lights are provided, they are often not of the right type or are wrongly positioned.

196. The most acceptable use of the chalkboard will occur when the following conditions are met:

(1) The apparent size of the writing on the board will be large enough if the height of the small letters, for example, a lower case 'a', is not less than ¾ inch, and if no pupil is more than 25 to 30 feet from the board. Wall charts which are pinned up alongside chalkboards should have details of equivalent size and good tonal contrasts.

(2) The writing will show up well with sufficient contrast if white or yellow chalk is used on a board whose reflection factor, after some use, is not more than about 15 per cent. If a colour other than black is used it should, when new, have a Munsell value of not more than 3 or 4.[1]

(3) The chalkboard and any associated display areas should be well lit by comparison with the room. By daylight, this may be done with a roof light immediately above. In any case, a properly designed chalkboard fitting should be provided (photograph **27**). The chalkboard should if possible be fixed to avoid a splash of light immediately above the top of the board. If this is unavoidable, the distraction caused by this will be lessened if the wall above the board is painted a dark, matt colour. Reflected glare from the board itself can also be troublesome, and a sure way of avoiding this is shown in diagram 14. The board should never be allowed to become shiny.

(4) The wall on which the chalkboard is fixed should not provide too sharp a contrast with it: a colour with a value and chroma rather lower than the other walls should be chosen, and a paint with a matt finish should be used.

(5) On no account should a window be placed in the wall either above or beside the chalkboard.

Demonstration work

197. Watching the demonstration of scientific experiments, or of the techniques of craft work or cooking will often call for sustained attention. It will be easier to concentrate if there is additional lighting on the demonstration bench, and the chalkboard fitting will often light the demonstration areas as well. In addition, an adjustable light may be useful to highlight key parts of the demonstration. It will also be easier to see if the demonstration is viewed against a background of a fairly dark, even colour.

198. The critical details in the demonstration will often be much smaller than in the case of writing on the chalkboard and in such circumstances the audience will have to come closer in order to see well. The seating arrangements in the room will have to be planned to allow for this, especially if groups of twenty-five to thirty have to be accommodated at one time.

199. However, for much demonstration work pupils will see well enough from their normal places, although it will be easier for them if they look down on the demonstration bench. For this reason, lecture-demonstration theatres are sometimes designed with tiered seating rising 4 in to 6 in for each row, and an example of this is given in photograph **2**. This arrangement will of course also improve sight lines when using other visual aids.

Projection equipment

200. Visual aids which throw an image on a screen include film-strip and slide projectors, with either front, overhead or rear projection. For the sake of convenience, television will also be included here, as it is a form of rear projection.

201. The ease with which the projected image is seen will depend upon four main factors:

(1) the size of the screen and thus of the details of the picture on it;
(2) the brightness of the picture, which will depend upon the output of the projector lamp and its distance from the screen;
(3) the position of the audience in relation to the screen;
(4) the general background brightness in the room to which the audience is adapted.[2]

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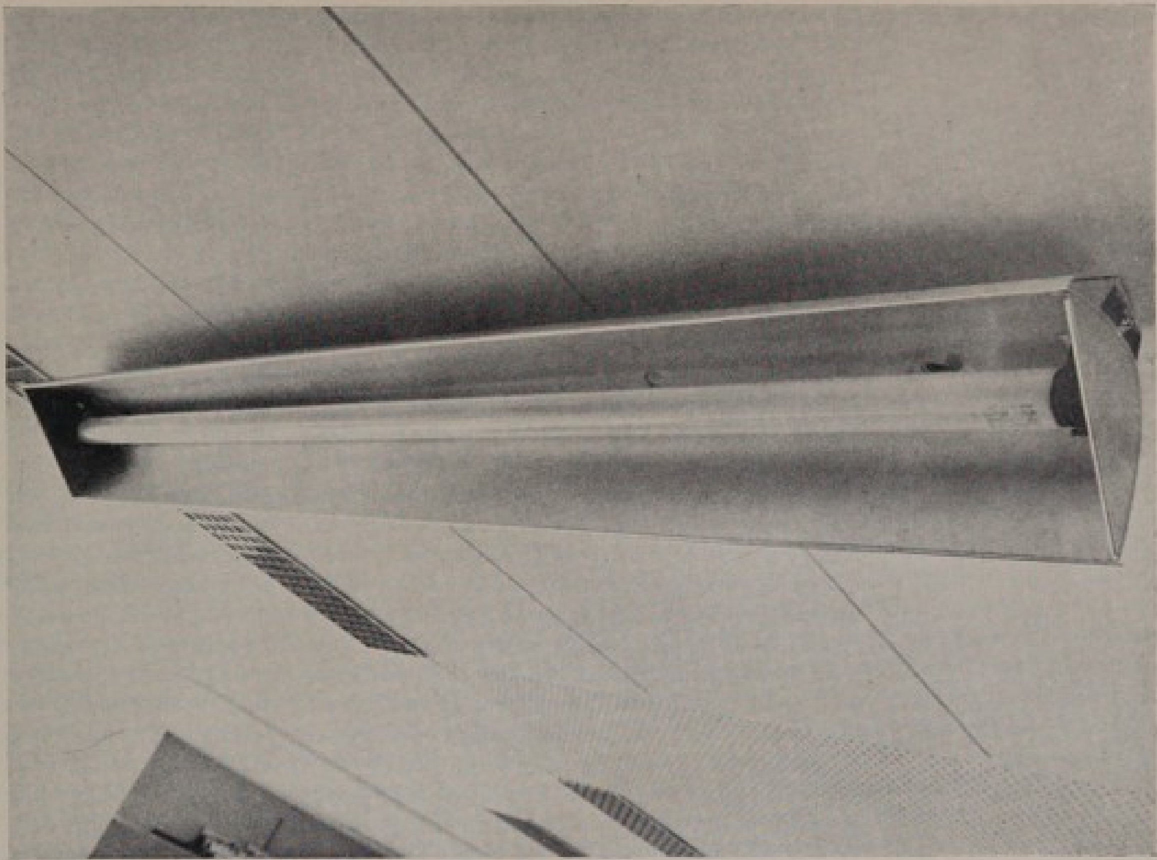
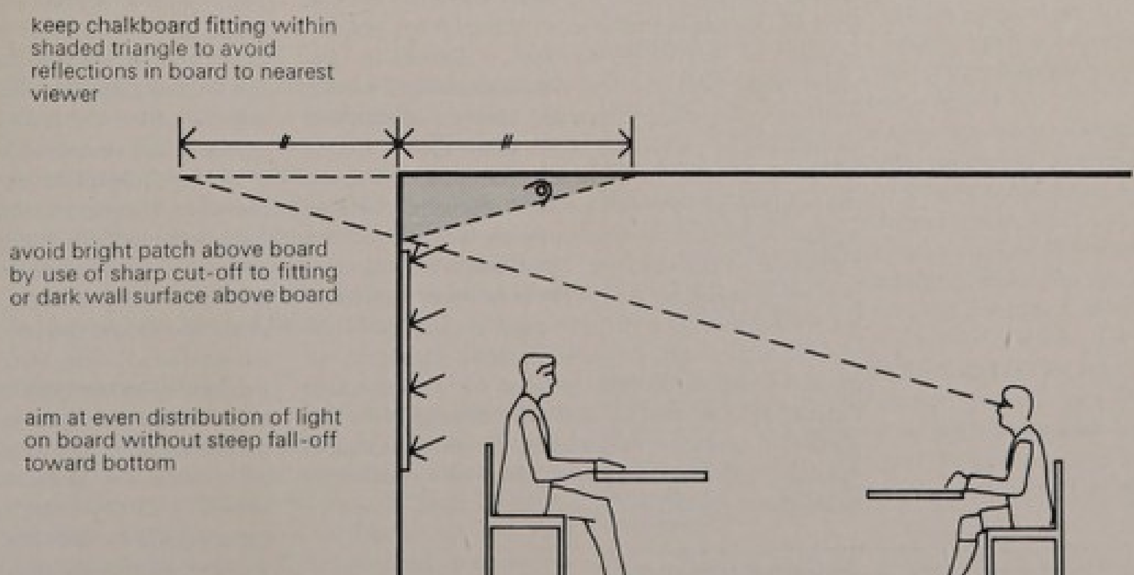
[1] For further details about suitable chalkboard colours and materials, see Building Bulletin No. 9, paras 20 to 25.

[2] Further information can be found in *Performance of Projection Equipment in School*, Howden (Visual Education, September/October/November, 1962) available from the Educational Foundation for Visual Aids, 33 Queen Anne St, London, W.1.



27 Fluorescent chalkboard fitting
A fluorescent chalkboard fitting with a parabolic aluminium reflector. When mounted at 4 ft from the chalkboard and level with the top of it, this fitting provides about 25 lm/ft² over an area of about 5 ft × 5 ft with a clean cut-off at the top of the board and without serious fall-off toward the bottom. This fitting in use is shown in diagram 14.

Diagram 14:
Chalkboard fittings – principles of design and mounting (paragraph 195).



202. In practice, these four points are inter-related. The first two are closely linked, for the choice is broadly between a small, bright picture and a larger, less bright one. A useful rule of thumb applicable in most viewing conditions is that *the screen width should be about one-sixth of the distance from the screen to the back of the audience*. So a screen 4 ft wide (or 4 ft square) will suit a room 24 ft deep, and a 5 ft screen will suit a room 30 ft deep (the maximum distance from a chalkboard – see paragraph 196 (1)). Television and back-projection screens are exceptions to this rule, for they have much greater brightness contrasts but even then none of the audience should be seated more than ten times the screen's width away, that is, 20 ft from a 24 in television set. Television sets should not be placed in front of a window.

203. For general purposes use in schools, screens with a matt white surface are preferable, as they reflect light more or less evenly in all directions. Glass-beaded or silvered screens will give a brighter image viewed along the axis of projection, but the brightness falls off rapidly outside an angle of about 30° from the axis. If the projector is placed at least as far away as the back row of the audience, this will ensure that none of the audience is distracted by the stray light from the projector. A 16 mm projector with a lens of 50 mm (2 in) focal length will fill a 48 in screen from 20 ft, or a 60 in screen from 25 ft. A 2 in × 2 in slide projector with a 100 mm (4 in) lens will fill a 48 in screen from 12 ft or a 60 in screen from 15 ft. Screens which are square will allow slides which have horizontal or vertical (or square) formats to be shown most conveniently. To avoid a distorted picture, projectors should be set up square to the screen and in line with its centre point. Viewing conditions will in the first place depend upon the quality of the equipment used, but even the most elaborate equipment will be ineffective if it is not set up properly and if it is not used in the correct lighting conditions.

204. For the present purpose it may be convenient to divide projection equipment into three groups: *first*, those which may be seen in normal lighting conditions; *second*, those which are seen best in a partially darkened room; and *third*, those which require full blackout. In the notes that follow, it is assumed in each case that a 48 in screen will be used, viewed from a distance of not more than 24 ft.

Normal lighting

205. At present, equipment that can be used in normal lighting conditions, where there is a general level of illumination of about 10 lm/ft² but not full sunlight or very bright daylight, is limited to television, some back-projection equipment, and certain overhead projectors. There are obvious educational advantages in visual aids which allow the teacher to see the class (and vice versa), and in being able to use the equipment for brief periods in normal lighting without interrupting the lesson each time with the rigmarole of blacking-out. There may also be economic advantages, for it is likely to be more sensible to use the substantial sum that would be spent on blackout for a powerful projector instead. However, although more equipment suitable for projection in normal lighting will no doubt be developed in due course, at present arrangements for some degree of blackout must be made in rooms where visual aids will be used regularly.

Partial blackout

206. Much of the normal projection equipment used in schools can be viewed quite satisfactorily in partial blackout (or 'dim-out') conditions where the general level of illumination in the room can be reduced to 1-3 lm/ft². These conditions could be brought about – on days without full sunlight – by drawing opaque curtains, or by turning flat the slats of normal white venetian blinds, or – after dark – by switching off all but one or two of the lights at the back of the room. Such conditions enable the pupils still to see their teacher, and to take notes. Equipment used in these circumstances should preferably be slide or cine projectors with 1,000 watt lamps, or their equivalent with an output of 300 lumens or more.

Full blackout

207. Full blackout will be necessary where low-powered projectors must be used, or where the effective brightness of the projected image is low (as with many micro-projectors, or episcopes which rely upon a reflected image), or where it is important to be able to discriminate close differences in tone or colour. Some optical work will also need full blackout, but a bay off the main laboratory may be all that is required to be blacked-out. Full blackout will need light-proof blinds of the types described in paragraph 95. Special arrangements for ventilation will have to be made. Complete blackout has the drawback that notes cannot be taken.

Communal and assembly areas

General note

208. In addition to the rooms used primarily for teaching, a school will contain many areas used at times for teaching, and at times for general social activities. These will include assembly halls, dining areas, common rooms and some larger circulation spaces, such as entrance halls. Often the problems of planning and lighting these parts of a school will spring from their multi-purpose use: the hall which is used at times for physical education will also be the setting for dramatic work; dining may take place in part of a spacious entrance hall.

Assembly hall

209. The main hall, with its associations with special occasions in the life of the school, its generous dimensions with the opportunities of long vistas, its many uses – formal and informal – for drama, music, dance, debate, gives scope for imaginative and varied contributions to the whole design by both day and artificial lighting. Because of the wide variety of uses to which the hall will be put, and the many planning and structural solutions which are possible, it is very difficult to generalise about the lighting. However, there are a number of recurrent problems that can be usefully discussed.

210. First, the sheer size and height of the hall tempts architects into providing unnecessarily large window areas, sometimes glazing all of one wall. This may be a dramatic solution, but it rarely leads to good lighting conditions and can create other problems of excessive solar heat gain in summer, of thermal losses in cold weather, and of blackout which will probably be needed for dramatic performances and film shows. In a hall of, say, 3,000 sq ft, about 600 sq ft of glass should be sufficient, if distributed in the right manner, to provide an adequate level of lighting. As in other rooms, cross lighting will help to reduce ex-

cessive differences in the level of daylight through the room, and will reduce contrasts between the areas of wall surrounding the window and the view of the bright sky through it. The hall should be designed and furnished so that the head teacher or other speaker does not have to stand with a window behind or immediately above him, nor is it desirable that the speaker should be subjected to glare from a large window facing him. In a hall, the colours and textures can be richer and more varied than in other rooms to give a character which captures the imagination.

211. Stage lighting is outside the scope of this Bulletin, but the relationship between the general artificial lighting and the use of various parts of the hall for dramatic work needs to be considered carefully.

212. The types of fitting selected and their placing in the hall can allow for their use for informal drama: for example, the emphasis given by a group of spot or floodlights could allow the centre of the hall to be used as an acting area; similar fittings in an aisle could light an impromptu 'stage' framed by curtains or screens. This approach might be thought to be sufficient for primary schools, although something more may be preferred if small professional groups are to perform for the children. In secondary schools, the lighting equipment for drama should allow more scope, and specialist advice should be sought.[1] In general the aim should be to concentrate on providing wiring that is flexible enough to allow the hall to be used in many different ways – not just for 'picture frame' productions – with socket outlets positioned in the hall as well as on the stage proper and connected back to the stage switchboard. When the hall is used for dramatic productions with an audience, the means for efficient blackout and adequate ventilation must be provided. If the hall is licensed for public performances, emergency lighting and illuminated 'EXIT' signs on an independent circuit may be required.

213. If the hall is used at times for physical education, then the requirements discussed in paragraphs 221-230 need to be given due weight. The architect may wish to bring the glazing down to floor level so as to give better lighting and a sense of visual release, linking the hall with the outside. But, if this is done in a hall used for P.E., some physical barrier such as guard rails (detachable to allow for cleaning of the glass), or low bench seats, should be placed in front of the windows, which may be required to be of toughened glass.

Dining areas

214. Dining areas are often used for other purposes as well, which may make it difficult to design the lighting solely to suit a dining layout. In such circumstances the best solution would probably be general overall lighting, but it may be possible at the same time to arrange some local lighting, for example, a row of pendant fittings along a window or internal wall over fixed table positions which at other times could also be used for private study.

Common rooms

215. Common rooms or house rooms in schools or colleges of further education are likely to have a very wide variety of uses: lectures, informal discussions, private study, table tennis, record 'hops', dining, morning assemblies, and so on. The layout and daylighting of the rooms will be arranged to cater for these diverse activities; the artificial lighting can be more varied and sophisticated than is appropriate to normal teaching areas.

Administration

216. The head teacher's room is likely to have the character of a study rather than an office, and the lighting should be in keeping with this, using fittings of a domestic character – table or standard lamps, and wall fittings – in addition to any more general lighting.

217. The school secretary's room, on the other hand, is an office in which a great deal of intensive clerical work is done. A level of illumination of at least 20 lm/ft^2 will be appreciated, in particular on the desk tops and working surfaces.

218. The room used for medical inspection should have lighting of a restful character, so that a child who is not feeling well may lie down without being bothered by glare from windows or light fittings. However, the medical staff will want an adjustable inspection lamp in a convenient position.

219. There should be proper conditions for children to view the Snellen and other charts used for testing eyesight. As these have to be viewed from distances of up to 20 ft, it may be difficult to provide a sufficient 'run-back' in the M.I. room (unless it can be arranged that they are seen through an open doorway), but mirrors should only be used as a last resort. It should be possible to see the charts in good lighting and against an even background without glare. The School Medical Officer should be consulted about local requirements.

Physical education

General note

220. This section deals with the lighting required in gymnasiums and sports halls and also touches on swimming baths and on floodlighting for physical education out of doors.

Gymnasiums

221. One must be able to see well in a gym. To miss a ball because it has crossed a dazzling window may only mean the loss of a game, but a misjudged leap can result in a serious accident. The variety of activities which may be carried out in a school gymnasium – ball and racquet games, leaping, vaulting, swinging, climbing, balancing – all need good timing and sure judgement, and create particularly exacting lighting requirements (photographs **3**, **8** and **28**). Pupils will have to make precise judgements about the speed and position of rapidly moving objects – say, a swinging rope or a flying shuttlecock – and a fairly high level of illumination is needed.

222. At the same time, the users may need to look in any direction – downwards, sideways, and even straight up – and yet they will be particularly vulnerable to momentary dazzle from the sun, from a view of the sky, or from light fittings which are too bright. Steps must, therefore, be taken to reduce the risk of glare. Reflected glare from a shiny floor is a common fault in a gym, and dark, highly polished floors should be avoided. It is also desirable for the level of illumination to be as even as possible over the whole of the room, for a game of netball, for instance, will move rapidly from one part to another and big fluctuations in, say, the daylighting could be disconcerting.

[1] See Building Bulletin No. 30, *Secondary School Design: Drama and Music*.

28 Lighting in gymnasiums
Gymnasiums have particular lighting problems. Most of the activities are fast moving. In games such as netball the players will need to look in all directions, including upwards, and special control over glare is needed. (paragraphs 221-230).

223. The speed and intricacy of many of the activities in physical education will be performed more safely and easily under a rather higher level of illumination than that suitable for general teaching spaces. An overall level of 3 per cent to 5 per cent D.F. would provide good conditions but, as in other parts of the school, equable and glare-free lighting even of a lower level will be more acceptable than higher intensities of illumination which do not succeed in avoiding uneven and glaring conditions.

Daylighting

224. A common solution is to place the main window along one wall with perhaps a clerestory window in the opposite wall. While this will give adequate general lighting under many conditions, it can give rise to a number of problems. First, the level of lighting will fall off sharply near the wall opposite the main window. Second, even if the main window faces north, direct sunlight will at times strike across the room unless special precautions are taken. Internal blinds are of course rather vulnerable in a gym, although light curtains or woven fabric spring-roller blinds will not be damaged as easily as venetian blinds. Third, there is the likelihood of direct glare from bright skies seen through the windows, and perhaps also of the nuisance of reflected glare from polished floors. Here again blinds may be needed to counter this. Fourth, the windows will have to be protected against breakage. Wall bars can be used to do this, but they may not be required in all gymnasiums.

225. An alternative approach which avoids many of these problems is to use high-level lighting only in the form of clerestory or roof lights. Clerestory lights may still lead to some difficulties with glare, especially if placed just above netball goal back-boards. Roof lights with deep reveals can avoid this. A gymnasium lit wholly by roof lights is shown in diagram 15 and photograph **29**. The users of this gym like the even, glare-free lighting: they make good use of the free wall space and are not bothered by the lack of outlook. The desire for a view out does not appear to be as strong in gymnasiums as in other rooms, possibly because the room itself is spacious, and the activities are intensive and physically energetic. However, some people may feel depressed at the lack of the visual release. If a view window is provided, care should be taken to control the brightness from it, for a brilliant splash of light may upset the balance of lighting in the gym.

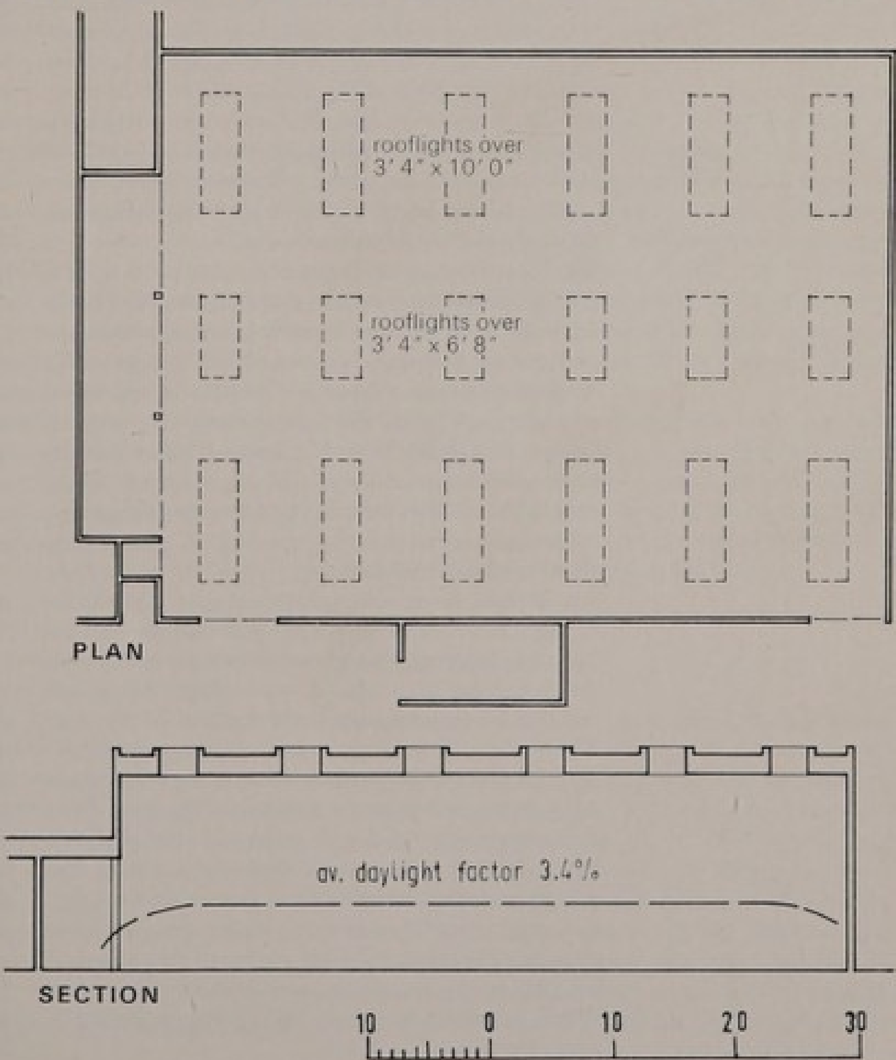
Artificial lighting

226. The main requirement is for a good spread of light through the gym, including the walls and ceiling with a direct downward component sufficient to ensure that apparatus and moving balls are highlighted and well modelled. For this reason wholly indirect, 'shadowless' lighting is not appropriate to gymnasiums.

227. As with the natural lighting, a level of artificial lighting which is rather higher than normal classroom levels is desirable; an average level of 20 lm/ft^2 may be considered a suitable target.

228. The need for freedom from glare should be borne in mind when selecting light fittings and positioning them in the room. They should at least satisfy the requirements for limiting brightness between the horizontal (pupils may climb ropes to near the ceiling) and a 45° viewpoint; it may also be worthwhile to shield the bare lamp from a direct upward view although this is of course likely to reduce the efficiency of the fitting. It is also desirable that the

Diagram 15 and
Photograph **29**
A top-lit gym
A gymnasium lit by day wholly by roof lights with deep louvres which cut out direct sunlight. This gives an even distribution of lighting and the absence of windows removes the normal problems of sky glare. A light maple floor throws reflected light back on the ceiling. The artificial fittings are of the type shown in the detail photograph with robust metal louvres protecting the lamp and reducing glare. Alternatively, the artificial lighting could have been contained unobtrusively within the roof lights (paragraph 225).



fitting should throw some light on the ceiling; if a recessed fitting is used the designer should be satisfied that the floor is light enough to reflect light back on to the ceiling.

229. The fittings need to be robust and protected from damage by flying balls. They should be positioned so that they do not interfere with the movements of ropes, or beams which swing out.

230. Fluorescent lighting can be used in gymnasiums provided the fittings satisfy the requirements discussed above. One minor problem has been that the alternating current may make rapidly-moving objects appear to flicker. This can be minimised if the fittings are connected to alternate phases (para 180).

Sports halls

231. An increasing number of sports or games halls are being built to provide a covered space that can be used for athletics, games practice and other physical activities for which a normal gymnasium is too small. The lighting requirements of these sports halls are in most respects similar to those of normal gymnasiums, containing a wide variety of activities with perhaps a bias towards fast-moving ball games, such as cricket in practice nets. For this reason a minimum daylight factor of 3 per cent to 4 per cent and an artificial level of 15 to 25 lm/ft² will give good playing conditions, as long as care is taken to keep glare to a minimum. This is particularly important as the users will need to be able to look comfortably in any direction, including upwards – for example, a pole vaulter judging his turn over the bar, or a footballer jumping to head a ball.

Daylighting

232. The sizes of sports halls will range from 50 ft to 80 ft wide and 90 ft to 120 ft long. The larger ones are often constructed with a portal frame rising from about 12 ft to 15 ft at the eaves to 20 ft to 25 ft, or even higher, at the ridge. The walls will act as a retaining screen for the games, and some walls will be played against for stroke practice in tennis. This needs a tough, smooth surface and daylighting will thus have to be from the roof only.

233. In a pitched roof probably clad with a light corrugated sheeting continuous strips of roof lights are likely to be the most economic and effective form of lighting, although louvres should be provided down their length to reduce glare. The spotty effect of a large number of small lights should be avoided. Having sun blinds in such a space is really impracticable, and the use of a diffusing material in the roof lights will avoid the inconvenience of direct rays of sunlight striking across the hall. A glazed area equal to about 12 per cent to 15 per cent of the floor area should, if correctly positioned, give a minimum daylight factor of at least 3 per cent to 4 per cent using a glazing material whose transmission factor is the equivalent of roughcast wired glass. Roughcast wired glass transmits about 75 per cent of the light that would pass through a clear opening, and allowance for this should be made when using the daylight protractor appropriate to the pitch of the roof. Glass fibre sheeting bonded with polyester resins may be used, within certain limitations imposed by fire regulations. The diffusing types have a transmission factor in use of 60 per cent to 70 per cent of a clear opening. However, in some grades of this sheeting, weathering can reduce the transmission by as much as one quarter or one third, and allowance should be made for this.

234. Diagram 16 and photographs **30** (a), (b) and (c) show a simple hall lit in this way. For halls with other roof shapes, some relevant advice can be found in *The Lighting of Factories*, Factory Building Study Number 2 (H.M.S.O.).

235. The colour of the walls should have a medium reflection factor (Munsell Value 6 or 7) to give a suitable background for ball games. Most materials used for the floors at present are unfortunately dark, but if there is a choice the lighter red-browns and greys are to be preferred. The average reflection factor of the interior as a whole is likely to be low, and this should be taken into account when calculating the reflected component of both day and artificial lighting.

236. To reduce glare the underside of the roof, or at least the surrounds to the roof lights, should be kept as light as possible. It will also help if louvres can be provided, at least down the length of the roof lights. The structural members themselves may help to give some shielding when viewed from a distance. Photographs **30** (a), (b) and (c) show the games hall at the Harris College, Preston, which is used for physical recreation and examinations, as well as for social occasions. The saw-tooth roof section acts as a cut-off to the roof lights.

Artificial lighting

237. As in a gymnasium, general dispersive fittings which throw some light up on the ceiling will be more comfortable and less glaring than industrial shades of the pattern which throws all the light downwards. The fittings must be proof against flying balls, and access for cleaning and re-lamping needs to be considered.

238. Although a general level of 15 to 25 lm/ft² will be adequate for most activities, additional lighting may be necessary for such areas as cricket nets, over both the batsman's and bowler's ends. A sight screen, or at least a plain wall surface, behind the bowler's arm will be helpful. If such games as badminton or table tennis are to be played to a reasonable standard, perhaps by clubs in the evening, additional directional lighting will also be required. The aim here is to make the ball or shuttle appear to be luminous, and this may be done by placing columns of lights opposite one another in line with the net. Specialist advice on this should be sought from the appropriate national games association. The provision of elaborate equipment of this kind in a school may only be possible with the financial co-operation of a local club. However, the original design might include electrical socket outlets in waterproof traps set in the floor at suitable positions, so that additional lighting can be plugged in when required.

Swimming pools

239. The level of illumination used need not be as high as in gymnasiums, although it should not fall below an average of 15 lm/ft², particularly if water polo is to be played. It should be possible to see easily to the bottom of the pool at any point, and this indicates roof lighting. The diving boards and the area of pool beneath them should be particularly well lit. A sight of the sun, and a view to the outside through low-level windows will help to relieve the dark, shut-in atmosphere of some pools. Very large windows should be avoided, however, as they create problems of reflected glare in the water (photograph **31**). Large areas of glass will also lead to excessive solar heat gain during summer and severe heat losses during the cold weather. Condensation is a common

problem, and any light fittings used should be proof against corrosion by chlorine fumes, and the manufacturers should be consulted on this matter.

Outdoor floodlighting

240. The floodlighting of outdoor areas for games and recreation is required only for a very short period of the year during normal school hours. However, it is now being realised that both in day schools, in youth clubs, and in colleges of further education the use of the facilities offered by the grounds and playing fields can be extended in a most valuable way if they can be floodlit in the evenings.[1] This enables them to be used after school hours, during the evenings at the weekend, and in the holidays by both the pupils or students, as well as by other young people and by members of the local community in general, among whom there is a growing demand for such facilities. If the areas used in this way are grassed, consideration must be given to the maximum wear and tear they can stand. Some local authorities are considering negotiating an agreement with local clubs over a contribution towards the capital cost of the installation and a charge for their use.

241. The technical problems involved in this sort of outdoor floodlighting may be grouped conveniently under three headings.

(i) playgrounds for casual recreational use;
(ii) games on small courts, such as tennis or netball;
(iii) games on large pitches, such as football or athletics.

242. The types of installation described below are intended primarily for the convenience of participants, rather than spectators whose requirements may be different.

Playgrounds for casual recreational use

243. The level of illumination sufficient for general recreational activities and for knockabout football or netball practice need not be more than 1 to 2 lm/ft², as long as the light fittings are mounted up out of the normal line of sight so that glare is minimised. In London it has been found that an area of 150 ft × 120 ft could be lit to this standard with eight 1,000 watt open area floodlights mounted on 25 ft high poles spaced about 50 ft apart along each side (diagram 17 and photograph **32**).[2] The cost of this in 1960 was about £550. Wire guards will protect the lamps from accidental breakage. Sealed units using tungsten iodine lamps are now being introduced; these make for easier maintenance.

Games on small courts

244. The intensity of illumination required for various games increases as the speed of the game goes up and the size of the ball goes down. In practice, therefore, a level of 6 to 10 lm/ft², which has been found to be adequate for tennis, will also be ample for netball. The most satisfactory arrangement for either game is for the lights to face each other across the width of the court, mounted on poles of a height sufficient to avoid serious glare when playing across the court and to allow an overlap of light in the centre of the court. The Lawn Tennis Association recommends the layout shown in diagram 18 (a) for single courts. The cost of such an installation should be between £400 and £500, depending on the length of the supply cable. For double courts the layout may be modified as shown in diagram 18 (b). Free-standing obstructions between pairs of courts should be avoided. The lamps should be mounted 18 ft to 20 ft above ground level. 1,000 watt lamps should give an illumination of 6 to 10 lm/ft²; and 750 watt lamps an illumination of 5 to 8 lm/ft.² The shades used should be exterior quality, vitreous enamelled reflectors with a mouth which is wide enough to allow some light to spill upwards so that lobbed balls may be seen easily. Further information, including details of suitable wiring techniques, is given in *Floodlighting Lawn Tennis Courts*, (Lawn Tennis Association, 1961).

Games on large pitches

245. The lighting of large areas for games such as football played to a reasonable school match standard will need an average illumination of 5 to 8 lm/ft² on the horizontal plane at ground level. This will demand an installation which will be very much more elaborate and costly than the one described in paragraph 243 which is sufficient for football practice. It is also desirable that the lighting for any ball game should be distributed as evenly as possible over the ground, for a ball moving through patches of uneven lighting will appear to change speed in a disconcerting manner.

246. The tall corner lighting towers used by professional grounds will be out of reach financially (unless the co-operation of a wealthy local club can be obtained). The best arrangement will probably be to use 1 to 2 KW floodlights mounted on poles 30 to 40 ft high, spaced down the side of the pitch and facing each other across its width. A total loading of 40 to 50 KW will be needed for a pitch of normal size. An example is given in diagram 19, but this is by way of illustration and should not be taken as an actual design. The costs of this type of installation are likely to range between £2,000 and £5,000. Further details are given in the N.P.F.A. booklet referred to in the footnote to paragraph 243, and a lighting engineer with experience in this type of work should be consulted about the design.

247. Athletics grounds can also be lit in the way described above. An alternative arrangement, which may in some circumstances prove to be more economical and satisfactory, is to light the running track and jumping pits with fittings suspended above them. The cost is likely to be £3,000 to £4,000.

Circulation areas

248. The members of a school should take pleasure in moving about their building. The architect will design the circulation areas so that they are not just traffic routes and in a way that will give variety and interest in the sequence of spaces. Their lighting and colouring can afford to be more stimulating with sharper contrasts than is appropriate in classrooms. Views out through carefully placed windows can alternate with distant views within the building itself, though avoiding the interminable, parallel-sided corridor. Lighting can be used to emphasise changes in spatial enclosure: a lobby of low bright-

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[1] See also Building Bulletin No. 28, *Playing Fields and Hard Surface Areas*.

[2] For further details see *Floodlighting of Playing Facilities*, Belcher and Hazell (National Playing Fields Association 1960), and *Lighting for Sport*, I.E.S. Technical Report No. 7, March 1965.

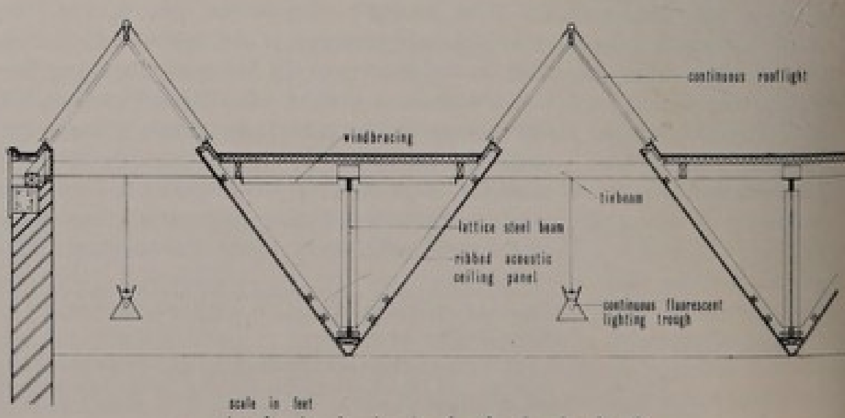


Diagram 16 and Photographs **30 (a), (b) and (c)**

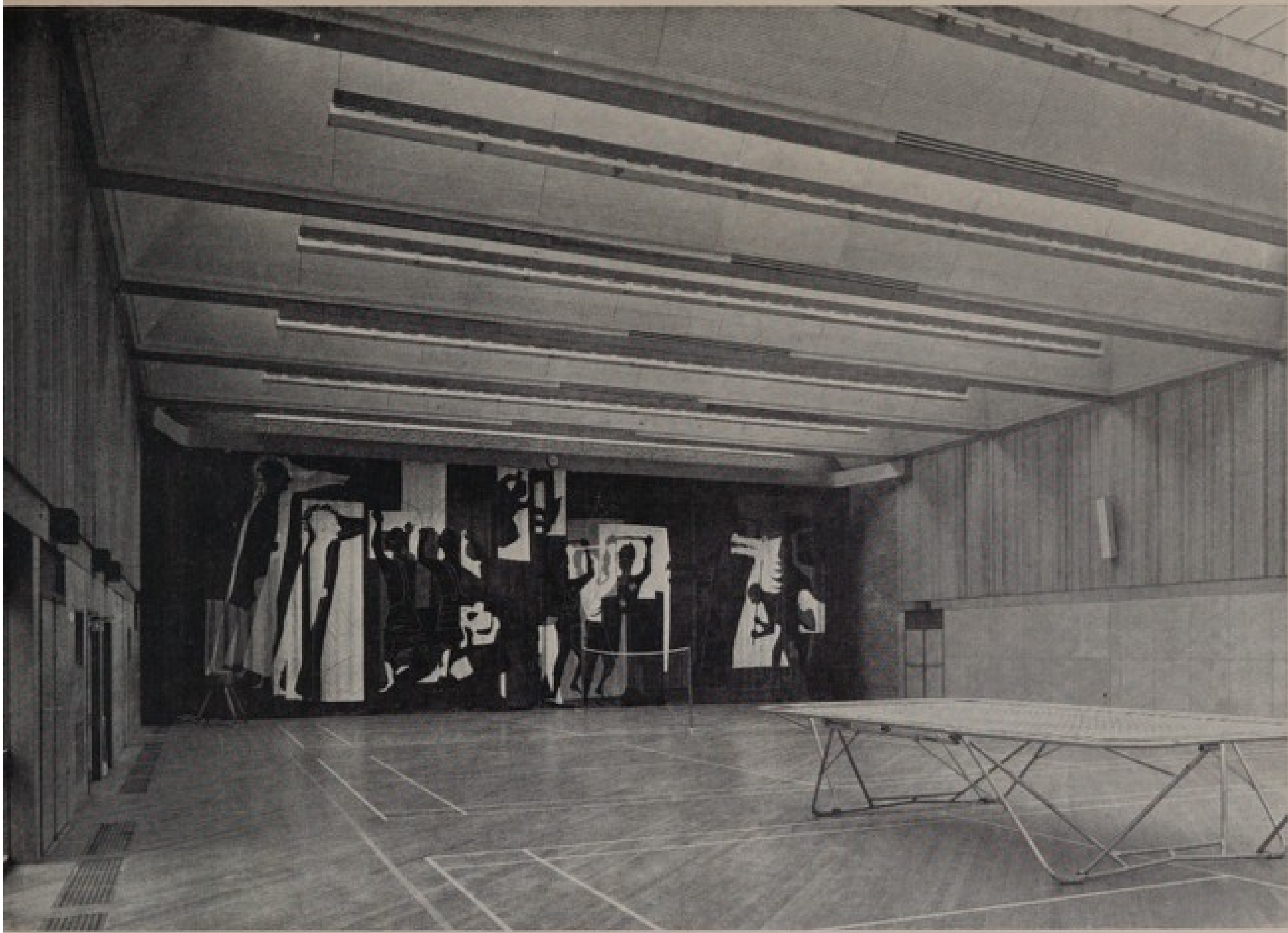
Games hall at the Harris College, Preston

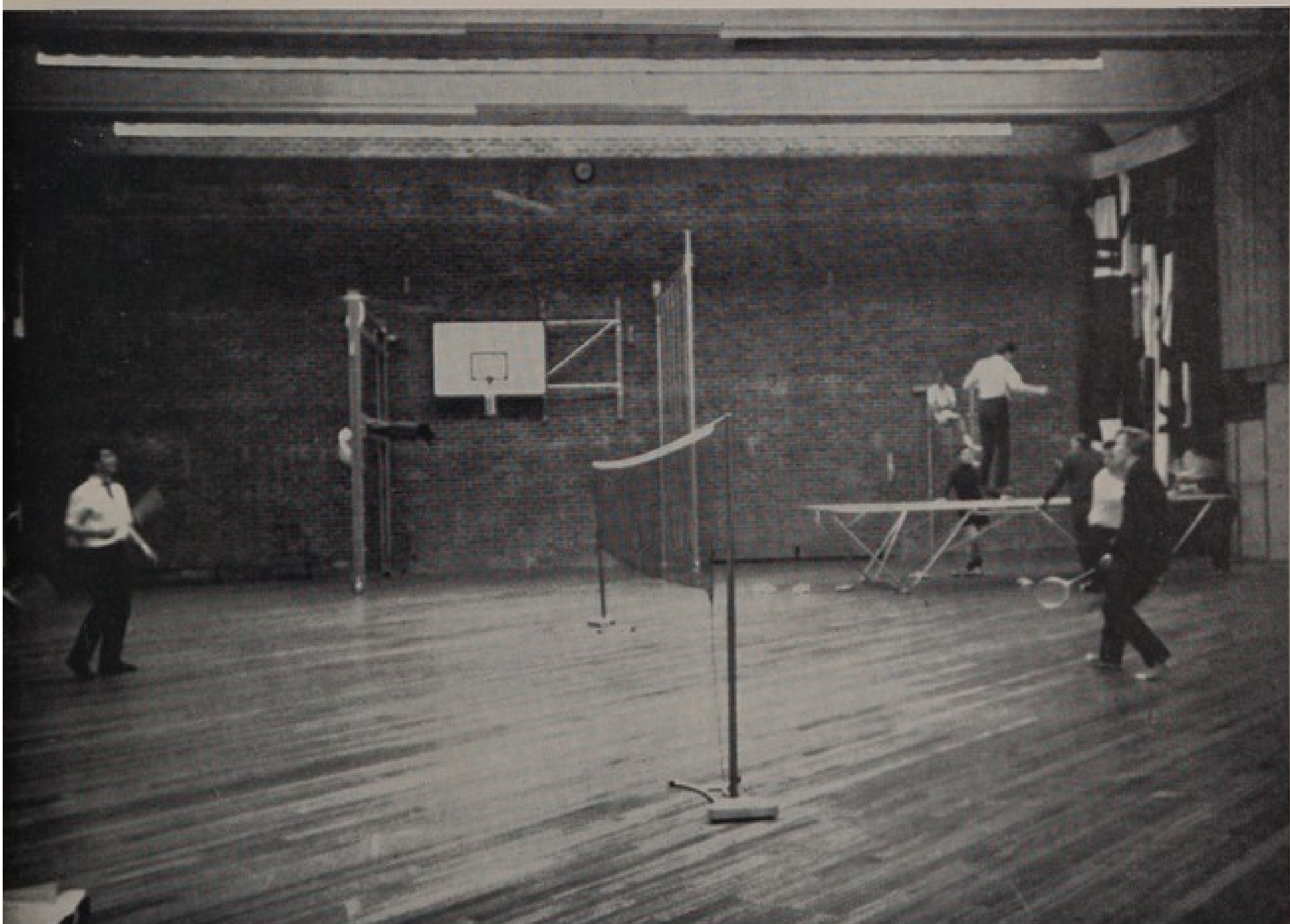
This hall in a college of further education is used for social gatherings and occasionally for examinations, but its chief use is for recreational physical activities. The saw-tooth roof section reduces glare from the roof lights, and a low window gives a view into a courtyard. The finishes are more sophisticated than would normally be required in a hall used entirely for sports (paragraph 236).

(a) General view by day

(b) Detail of roof light

(c) General view by night





ness may be set against the spacious, brilliant assembly hall beyond it. To prevent a long vista from petering out vaguely, it is important to try and contain it in an area of bright lighting and vivid colouring – perhaps a mural – which can act as a visual stop (diagram 20 and photograph 33).

249. In the interests of safety, there are certain minimum requirements in the lighting of corridors and stairs. The level of artificial illumination should not fall below 5 to 7 lm/ft^2, and can sensibly be rather higher on staircases and at critical points such as fire escape doors. It should be possible easily to read typed notices on the doors of rooms. The lights over the stairs should be placed so that the nosings are not left in shadow. Strong contrasts between the teaching and circulation areas should be avoided; the ratio should preferably be not more than 3:1. In the same way the process of adaptation can be assisted by making the entrance hall and other access points more brightly lit, so that they act as a transition from the daylight which can be very much brighter than the interior of the building. One should be careful about placing a window at the end of a corridor or opposite the head of a staircase, as the glare it can cause will always be annoying and may sometimes be dangerous.

250. Beyond these basic requirements there are many ways in which imaginative lighting can enhance lobbies, entrance halls, stairs, and passages. Schools will welcome opportunities for using parts of circulation areas for notice boards, displays of work, exhibitions, and the showing of pictures and sculpture, and the preferential lighting of these areas will assist this. A lobby or passage might even be fitted up as a small informal art gallery for showing school work, reproductions, or original work by local artists. In such cases the floodlighting of the works of art on walls could also be the general lighting of the space. In addition to the installed lighting, electrical socket outlets – perhaps provided in the first place for the cleaners – can be placed strategically at points in lobbies, bays and corners to allow the staff to set up their own illuminated displays and showcases from time to time.

251. Parts of the circulation area in a school may also be used for private study and tutorials; convenient bays and corners with a window and a suitable local artificial lighting being devised for the purpose.

31 Reflected glare in swimming baths
It should be possible to see easily to the bottom of a swimming pool, but very large side windows should be avoided as they can create problems of reflected glare in the water. Large areas of single-glazed windows will also lead to excessive solar heat gain during the summer, and severe heat losses during cold weather (paragraph 239).

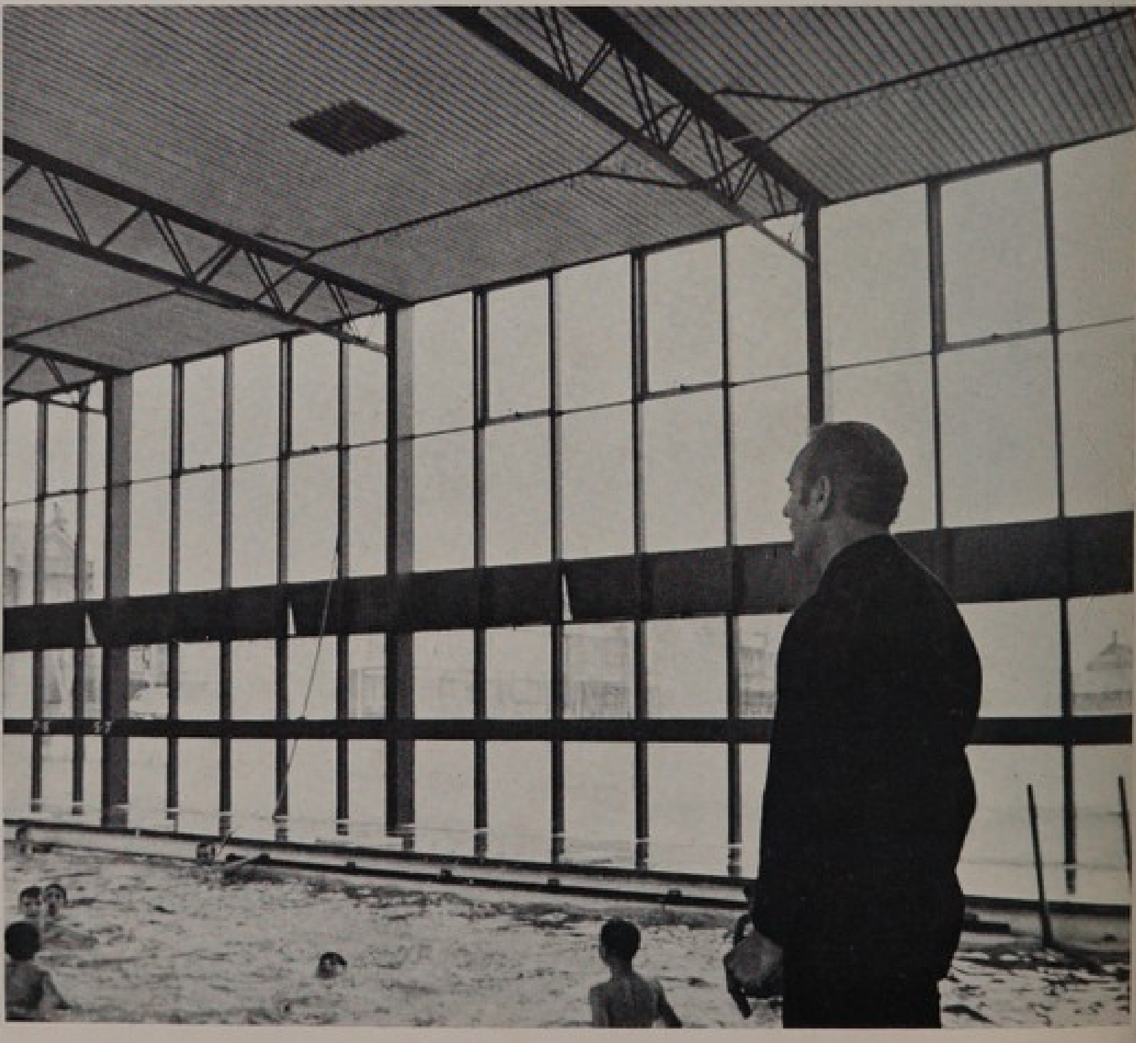


Diagram 17 and
Photograph **32**
Lighting playgrounds after dark
A general recreation ground lit to about 2 lm/ft² by eight 1000 watt lamps in open metal reflectors of the type shown on the left mounted on 25 ft high posts. The photograph shows a playground lit by similar fittings.

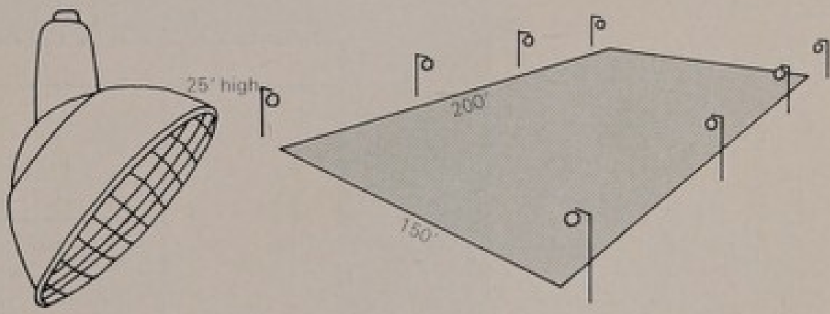


Diagram 18
Lighting outdoor tennis courts
(a) Lighting layout for outdoor single tennis courts with 750 or 1000 watt G.L.S. lamps in open metal reflectors mounted on 18 ft to 20 ft high posts (paragraph 244). A similar arrangement may be used for netball courts.
(b) Lighting layout for outdoor double courts without a central net. The number of central fittings is reduced to avoid the risk of collisions.

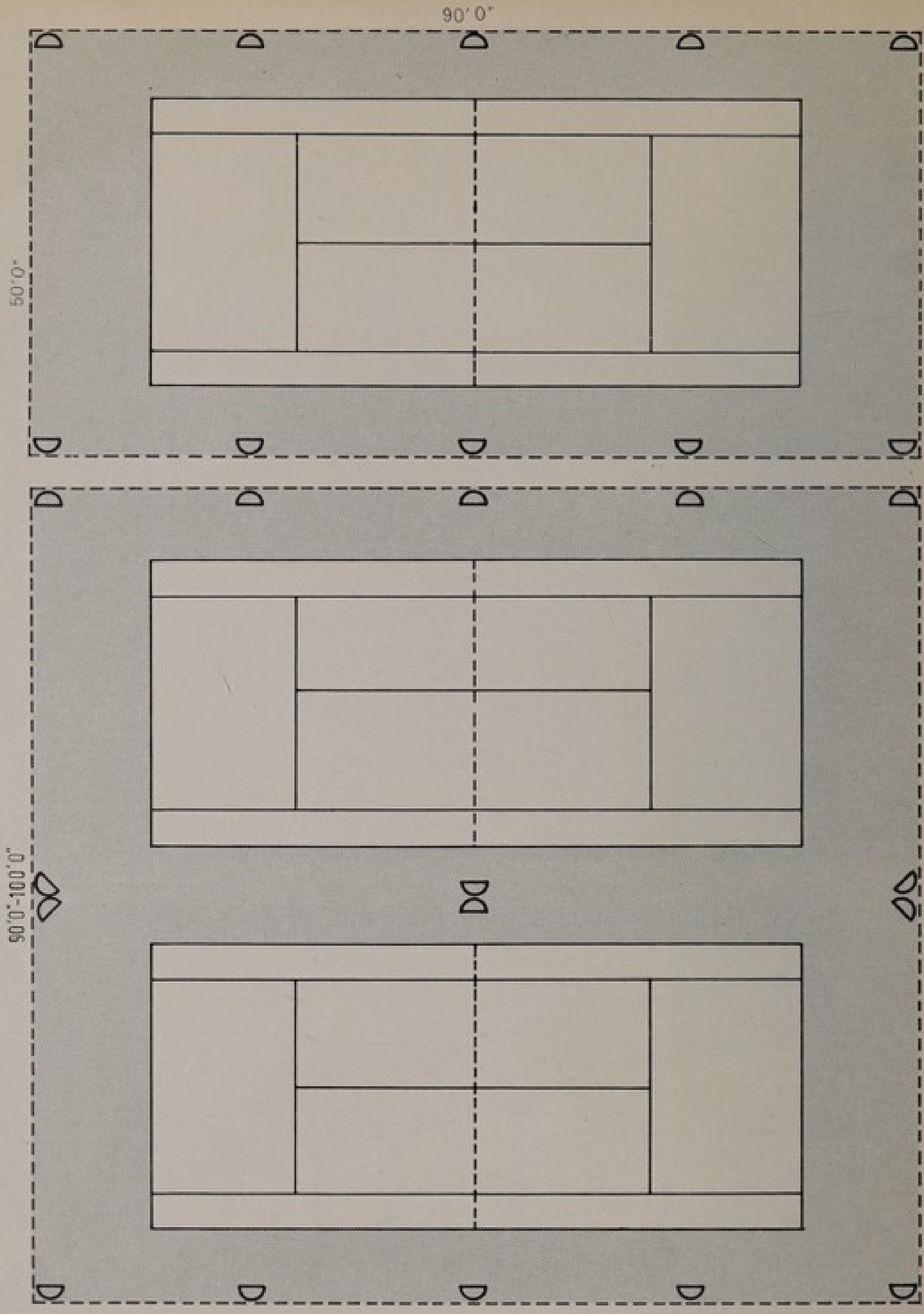
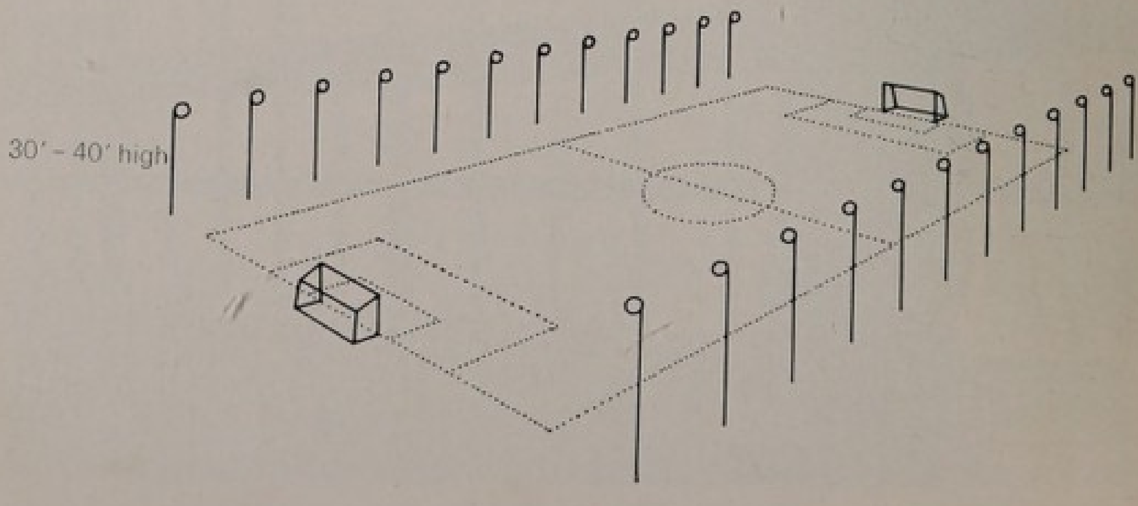


Diagram 19
Lighting football grounds
Diagram indicating a possible lighting layout of a football ground to a school match standard, with 1 Kw to 2 Kw floodlights mounted on posts 30 ft to 40 ft high. (paragraphs 245-247).



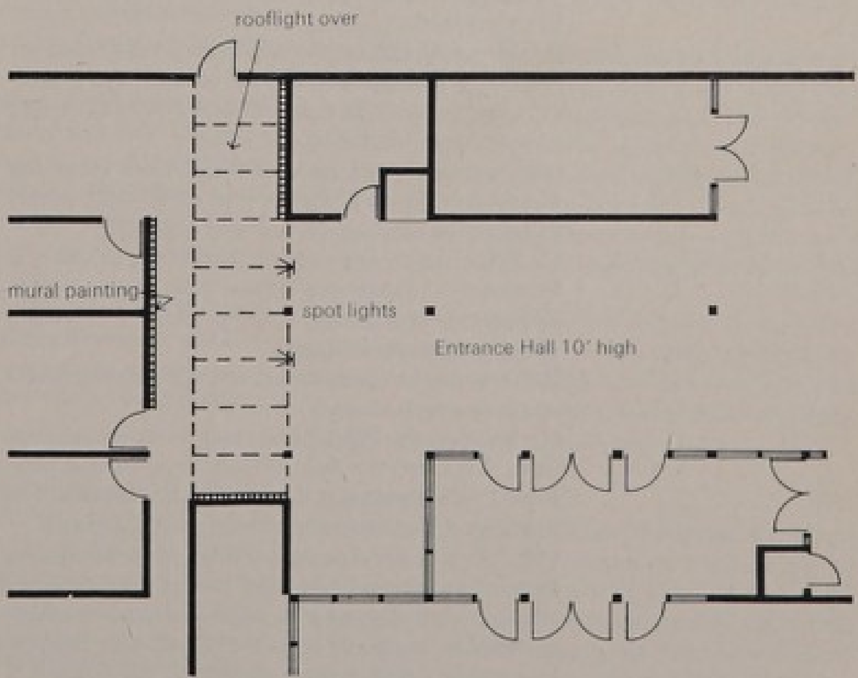


Diagram 20 and
Photograph **33**
Lighting in circulation areas
Circulation areas can be enhanced by the imaginative use of lighting and colour. In this school a series of murals have been placed at the ends of long views down circulation spaces which meet at the entrance hall. The murals are brightly lit by a long roof light, and at night by floodlights (paragraph 250). Mural by Fred Millett.

6 Notes for the user

252. This brief part is addressed particularly to the users of the schools: teachers, caretakers and other maintenance staff. It was thought that it might be helpful to draw together in one place various do's and don'ts which have been mentioned in the course of this Bulletin and which aim to encourage the most effective use of the lighting – both day and artificial.

(1) Teachers should – if the planning of the room gives them this much choice – avoid the temptation of placing their desks in front of a window (photograph **9**). The children will follow more easily if they do not have to strain to make out their teacher's face against a bright background. The same applies to movable chalkboards, maps, and projector screens.

(2) Use window blinds when necessary, both to keep out the direct rays of the sun and thus avoid heat exhaustion and dazzling, and also to prevent glare from bright cloudy skies. Venetian blinds should be adjusted so that they just cut-off a direct view of the sun or glaring sky, although this need not prevent a view out at low level. Remember that the children sitting at their places will see more of the sky than the teacher does standing up, and they will probably be doing more difficult visual tasks.

(3) Keep a continual look-out for children with poor eyesight; encourage them to sit nearer to the windows and to the chalkboard, and see that the school medical staff are informed. Myopia (short sight) may develop at any age; it often runs in families, and is more common among intelligent children.

(4) Use the inner rows of artificial light fittings to supplement the daylight on dull winter mornings and late afternoons.

(5) Always switch on the chalkboard light when using the board, for it will help to keep the pupils' attention on the board during days which are bright outside, as well as during dull ones.

(6) Try and prevent the chalkboard from becoming too shiny with use or loaded with chalk dust, as this will decrease the visibility of the writing on it.

(7) Write clearly and not too small – the height of a lowercase 'a' should not be less than 1 inch. Words will be read more easily when printed in lowercase rather than in capital letters.

(8) Deter the caretaker from putting a dazzling polish on the floor.

(9) See that the light fittings and windows are kept clean. To clean the light fittings three times a year should suffice except in the dirtiest atmospheres. The windows will of course be cleaned more frequently.

(10) When re-lamping light fittings, make sure that a lamp of the correct type, size and wattage for each fitting is used. Lamps of a higher wattage or which are smaller in size (such as the 'mushroom' shapes) may overheat and damage the fitting. The colours of fluorescent tubes should be followed on replacement – one 'warm white' stranger in a roomful of 'daylight' tubes can have a most disconcerting effect.

(11) Make sure the control gear of fluorescent fittings is adjusted carefully to avoid flicker and hum. Insist on having replacements for any fittings that continue to give trouble.

(12) When redecorating, maintain the reflection factors of the main surfaces in the teaching rooms, either by using exactly the same colour scheme or at least by using colours of the same reflection factor, that is, of the same Munsell value (assuming that the colour scheme is not capable of improvement along the lines suggested in this Bulletin).

Appendix 1

Lighting schools for partially sighted children

General note

1. The lighting of schools for most groups of children with mental or physical handicaps will be similar to that for normal children,[1] but in schools for the partially sighted there are lighting problems that deserve special consideration. While the principles of good lighting will remain the same, they need in these circumstances to be applied with particular care to give the children visual surroundings in which the effects of their disabilities are minimised. The main aim is to develop their confidence and self reliance.

2. There are – happily – only a small number of partially sighted children in the community. Suitable teaching facilities are provided by the various educational authorities in different ways, according to their local circumstances.

3. Some will set aside specially equipped accommodation in an ordinary school; others will provide separate schools, and even boarding schools where distances are great. Teaching groups are small – 15 or less – but each child will need plenty of space.

4. The first lighting problem arises from the fact that children with a wide range of disabilities will normally be taught in the same room, with as much individual attention as possible. In the majority of the children the defective vision is due to myopia or to congenital cataracts, the numbers affected by each of these causes being approximately equal. The next commonest causes are congenital nystagmus, optic atrophy, albinism and coloboma or maldevelopment of various parts of the eyeball. Due to the impairment of vision, all these will benefit from a high level of illumination, although some children affected with albinism can at times be distressed by high brightness.

5. The most workable solution seems to be to provide a good overall level of lighting with the maximum regard for visual comfort in its design, and then to allow the child to choose the position in the room that suits him best. Some children, such as albinos, may benefit from wearing the tinted glasses they will already use out of doors.

6. A Joint Committee of the Medical Research Council and the Building Research Board has considered this matter and has prepared a memorandum from which many of the following points are drawn.

Levels of illumination

7. A high level of illumination of between 75 and 100 lm/ft², and in any event not less than 50 lm/ft², is recommended. It has been explained in Part 1 (paragraphs 33 to 36) that for normally sighted children these very high levels are not usually considered worthwhile since they result only in a relatively small improvement in visual performance. However, among partially sighted children even a small improvement in their ability to make out details quickly and easily may bring them across the threshold of vision, and thus help to give them confidence to comprehend the world around them. To encourage the children to move around the school with confidence, levels of illumination in circulation areas and cloakrooms should not be less than two-thirds that provided in the teaching spaces.

8. To provide this level of illumination by daylight alone would be very difficult without creating severe glare problems and the light from the windows will usually have to be supplemented with permanent artificial lighting (see also Part 4). When this is being designed, great care should be taken to provide the maximum visual comfort, for the beneficial effects of a high level of illumination can easily be lost if the lighting is of poor quality.

Visual comfort

9. Many partially sighted children are particularly sensitive to glare caused by excessively bright light sources and harsh contrasts within their field of view, and the methods of reducing glare already described in Part 3 (paragraphs 116 to 123) should be employed where individual artificial light fittings are used. The bare tube should be screened from normal angles of view, and the average brightness of the fitting at these angles reduced to 300 foot-lamberts or less. The fittings should be seen against a well lit ceiling.

10. To achieve these high levels of illumination, one solution may be the use over a substantial area of the room of a luminous ceiling consisting of either a diffusing plastic membrane, prismatic panels or a small-scale louvred grid. Such large light sources tend to become the brightest parts of the interior, and their surface brightness should be low if discomforting glare is to be avoided. It is recommended that their average luminance as seen by a pupil looking up at an angle of not more than 45° above the horizon should not be more than 150 foot-lamberts. Luminous ceilings can be rather expensive, compared with rows of louvred fittings set in or on the ceiling. There are also cleaning problems that need to be considered.

11. Care should also be taken to see that the windows do not become sources of glare. Their size, height and position should be chosen so that views of large areas of sky can be avoided, and efficient window blinds should be installed. The brightness of the scene outside the window can be controlled by the use of overhanging eaves, projecting walls, paving of medium reflection factor, and well placed trees and shrubs.

12. As with normally sighted children, it is important to avoid specular reflections which could dazzle the child or swamp what he is trying to see. As far as possible, desk and table tops, wall surfaces and floor finishes should be matt and light in colour.

Local lighting

13. For certain activities such as handicrafts, where solid objects are handled, it may be worth providing some additional directional lighting, so that highlights and shadows model the objects in a way that allows them to be identified and handled with ease. This may be done by planning the room so that such

[1] In schools for deaf children care should be taken to provide strong directional lighting of a good standard to help the children's lip reading.

work can be done at the window, or by providing local lights.

14. Chalkboards and other demonstration areas to which the children's attention is to be drawn, should have additional local lighting to make them rather brighter and more contrasty than their surroundings. Self-illuminated chalkboards have also been found helpful in some circumstances.

15. Other optical aids such as portable and desk magnifiers are available for children who feel they need them, but experience has shown that when good lighting of the type described above is provided, the children often find they can dispense with such optical aids.

34 Remodelling old schools
The assembly hall in a 50-year-old school remodelled as a library. The existing windows with 5 ft high sills have been retained, and a new low level window inserted to give light on the tables and a view out. An adjustable pendant fitting gives local lighting after dark (Appendix 2, paragraph 10).

35 Daylighting in old schools
The daylighting in some old village schools can possess unexpected qualities. This example shows the advantages of deep, splayed reveals to windows, of cross lighting and of painting walls around windows in light colours (Appendix 2, paragraph 4).

Appendix 2

Remodelling old schools

General note

1. An increasing amount of work is under way for remodelling those existing schools that still have a good expectation of life and can be brought up to modern standards at reasonable cost. Improvements in both day and artificial lighting are almost always needed in such buildings. Thirty years ago a standard text book on school building recommended a 1 per cent Daylight Factor and an artificial level of 5 lm/ft^2, and schools older than this are likely to have even lower standards.

2. Each remodelling job will present its own particular problems, depending on the period in which it was built and on the degree to which it has already been modernised. The best approach is therefore to apply in each case the principles of good lighting which have been discussed earlier in this Bulletin, but it may be helpful in this section to describe some common problems and to suggest possible solutions.

3. Methods of improving lighting during remodelling work are also dealt with in paragraphs 115 to 124 of Building Bulletin Number 3, *Village Schools;* in Appendix 6 of Building Bulletin Number 9, *Colour in School Buildings;* in paragraph 158 of Building Bulletin Number 29, *Harris College, Preston;* and in paragraphs 154 to 161 of Building Bulletin Number 21, *Remodelling Old Schools*.

Daylight

4. In the earliest schools the windows were usually small and often ecclesiastical in character with Early English proportions. Although the level of illumination they provided was usually low, the quality of lighting was often better than one might expect, as splayed reveals and mullions were common and the buildings were small enough for windows to be placed in more than one wall (photograph **35**).

5. In the later Victorian and Edwardian schools, lighting conditions in general did not improve. Theories about ventilation led to excessive room heights with tall windows which induced conditions of glare that more than cancelled out any advantages of the higher levels of illumination. Heavy transoms and mullions, high sills, dark dados, and dingy decorations accentuated this gloomy atmosphere.

6. The first step in remedial action is therefore to assess the severity of the glare conditions that exist, and to measure the quantity of light throughout the room in terms of the Daylight Factor.[1] This will indicate whether or not radical improvements are needed.

[1]A suitable instrument is the B.R.S. Daylight Factor Meter, available from Evans Electroselenium Ltd., Halstead, Essex. Alternatively, a normal incident light meter or even a photographic light meter may, with some care, be used to compare readings taken out of doors with those taken at the worst lit part of the room.

7. Remedial action can usually be considered in three successive stages:
   (1) lighter decorations and finishes;
   (2) improvements to existing windows;
   (3) major structural changes.

8. Redecoration in lighter colours, in addition to being the least expensive remedy, will often prove surprisingly effective in improving both the quality and quantity of daylighting in a room. Painting window frames white will help to reduce glare. Lightening the walls, and in particular the floor, will raise the level of inter-reflected light. This can amount to as much as half the total illumination at the back of the room. For example, a room with windows whose glass area is about 10 per cent of the floor area may be found to have a minimum D.F. of a little over 1 per cent. If its walls – a dingy paint and dark dado – have an average reflection factor of about 20 per cent, and its old wood floor and furniture have an average reflection factor of 10 per cent, then from Table 4 in Appendix 3 one can see that the minimum indirect component of D.F. will be only 0·1 per cent. By repainting the walls so that they have a reflection factor of 60 per cent, and by providing a light-coloured floor finish and new furniture with an average reflection factor of 40 per cent, one can expect that the indirect component will be raised to 0·8 per cent, bringing the total D.F. very close to the required 2 per cent. However, the original minimum D.F. may well be much less than 1 per cent and it will then be necessary to increase the area of glass in the room in order to reach a 2 per cent minimum D.F.

9. In many old windows, much of the structural opening – perhaps up to 30 per cent – will be taken up with a heavy frame, transoms, mullions and glazing bars. So a substantial gain in glazing area can be made if the existing windows are replaced within the existing structural openings by new windows with lighter framing sections.

10. Further gains in glazed area can be made only by inserting new windows or by enlarging the structural openings of existing ones. Any new windows should be placed so that they make a contribution to the quality of lighting and the amenity of the room. For example, many old schools have sill heights of 4 ft or more, the original intention apparently having been to prevent the children being 'distracted' by the world outside. To lower these sills – a simpler operation than raising the head or increasing the width of the window – will contribute to the lighting in the room and will at the same time give the children a view out. For example, an old assembly hall, with sill heights of 5 ft, was being remodelled as a library. The old tall windows were not touched, apart from being painted white, and new low-level windows were inserted at table-top height under the existing stone sills, giving good light on the tables and a view out into a grassed court (photograph **34**). If a new window is required, it may be possible, in order to give some cross lighting, to put it in a wall adjacent or opposite to the main window. Or, in a room facing north, a new window may be added in a wall facing the sun. In single storey buildings the addition of roof lights may be the most effective way of raising the level of daylight and rounding it out, provided that they are designed to avoid glare from a bright sky.

11. Structural alterations of this kind are of course costly and one must be sure that the improvements in lighting that result are sufficient to justify the expense. If extensive structural work in most of the

teaching rooms is necessary to achieve good daylighting, then the use of P.S.A.L.I. might be considered (see Part 4). Alternatively, it may in fact throw doubt upon the wisdom of remodelling that particular school. If only a few of the existing classrooms are seriously underlit, then it is worth considering at the planning stage whether they can be used for some non-teaching purpose for which a 2 per cent D.F. is not essential.

12. It may be possible to reduce obstructions to light outside the room. Trees should be thinned with discretion and only felled as a last resort. It is worth bearing in mind that the obstruction from deciduous trees is less in winter when the light is least.

13. It may be decided for various reasons that the ceiling height in a room should be reduced by putting in a suspended ceiling. This may threaten to mask the light from the upper part of the windows. If it is felt to be necessary to retain the light from the tops of these windows, then forming louvres in the part of the ceiling nearest to the windows can help to do this.

Artificial lighting

14. It is usually easier to improve sub-standard artificial lighting than poor daylighting, especially if a new electrical installation is being carried out at the same time.

15. The typical classroom in an old school will often be found to have only six lighting points with open-bottomed metal or plastic shades and with perhaps only 100 watt lamps – sometimes even clear lamps which create the most severe glare. The average reflection factor of the room is often low, and the level of illumination when measured may be found to be less than 10 lm/ft² in any part of the room. There may be no chalkboard light.

16. Remedial action can, as with daylighting, be considered in stages:

(1) redecoration
(2) new fittings
(3) a new installation with more lighting points

17. Inter-reflected light can be as much as 40 per cent of the total illumination at any point in the room, and an appreciable increase will result from lighter decorations, finishes and furniture. A high reflection factor for the floor is particularly desirable.

18. If there is a reasonable number of lighting points, and if the wiring is of adequate capacity, it may be possible to achieve satisfactory results by replacing the existing fittings with new ones which conform to the building regulations and which have more powerful lamps. Alternatively, fluorescent fittings may be used to obtain a higher illumination without an increase in electrical loading.

19. If none of these steps are sufficient to produce a good level of illumination, or if the uses and/or shapes of the rooms are changed, then it is likely to be necessary to provide a new installation. The design of this should follow the same principles as in a wholly new school, with the quality and character of the scheme being considered at the same time as the necessary level of illumination.

20. A final point is that the careful design of the artificial lighting installation along with the colour scheme can do a great deal to bring out the good features and play down the bad ones in an old school which is being remodelled.

Appendix 3

B.R.S. daylight factor protractors – worked example

Calculation of daylight

1. The total daylight at any point in a room (see diagram 3) consists of a direct component (A) coming straight from the sky, and an indirect component made up of light reflected from objects outside the window (B_1) and light reflected within the room (B_2). The method given below for calculating the minimum daylight factor in a room with vertical glazing from scale plan and section drawings is based on that given in Appendix A of the British Standard Code of Practice 3, Chapter I, Part 1, 1964, on *Daylighting*. It consists, *first*, of determining the direct sky component and the externally reflected component by the use of daylight factor protractors and, *second*, of determining the internally reflected component by the use of tables. The B.R.S. Daylight Factor Protractors are based on the standard C.I.E. Sky, and the regulations are to be amended to conform to this standard.

(A) Determining the sky component – using the B.R.S. daylight factor protractors

2. (i) Choose the working position in the room which it is thought likely to receive the least light.

(ii) Mark this reference point on a scale drawing and draw sight lines connecting it with the extremities of the windows in section and plan, allowing for any obstructions (diagram 21).

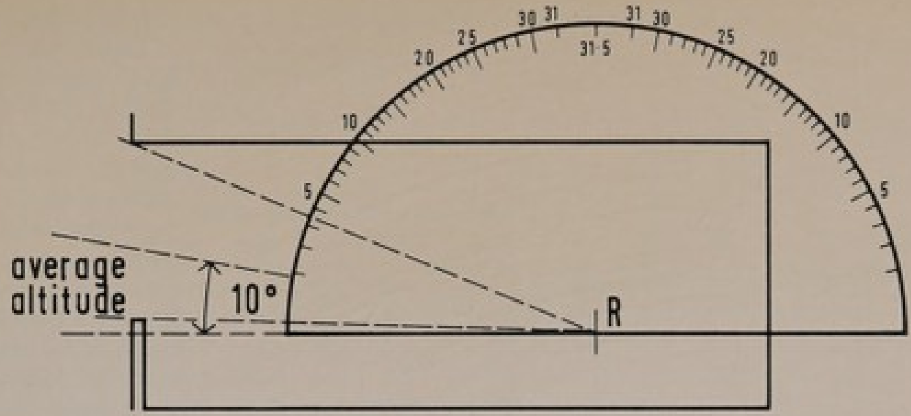
(iii) Lay Protractor No. 1 on the sectional drawing with its centre on the reference point and with its base line on the horizontal working plane. Note the values where the two sight lines intersect the scale. The difference between the two readings (2·5 minus 0·25 equals 2·25 per cent) gives the sky component for a window of infinite length. Note the average angle of altitude of the visible patch of sky (10° in the example).

(iv) For a window of limited length (as in this case) this must be corrected by applying the auxiliary Protractor No. 2. This should be placed on the plan with its centre on the reference point and with its base parallel to the plane of the window. Read off the values at the points where the sight lines cross the lines running around the scale which mark the angle of altitude. Lines for 0°, 30°, 60° and 90° altitude are given – other values will have to be interpolated. The two readings should then be added together (0·45 plus 0·1 equals 0·55) to give the correction factor by which the sky component should then be multiplied (2·25 times 0·55 equals 1·2).

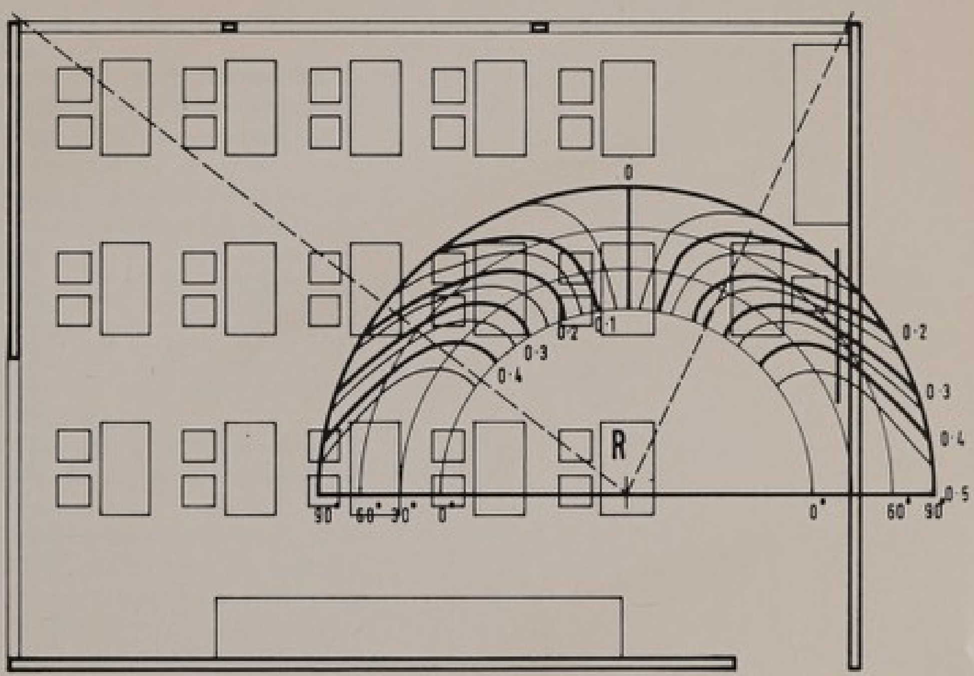
Therefore the sky component for the main window in diagram 21 is 1·2 per cent.

(v) This process should then be repeated for the other window in the room, which gives a sky component of 0·4 per cent. The total sky component from both windows is thus 1·2% + 0·4 = 1·6%.

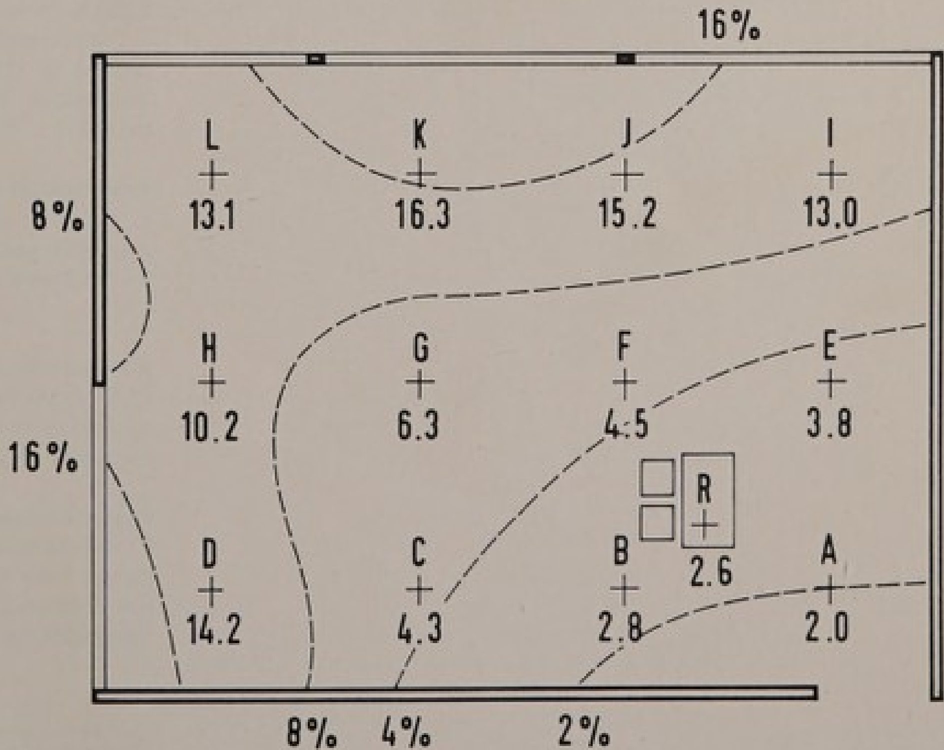
Diagram 21:
Calculation of daylight factor using protractors



SECTION Use of Protractor No 1



PLAN Use of Protractor No 2



PLAN Distribution of Daylight Factor

(B1) Externally reflected component

3. Light reaching the reference point after reflection from external obstructions above the level of the working plane is treated as if it were light coming direct from the sky, but with an allowance for the reflection factor of the obstruction, which for most purposes may be assumed to be 10 per cent. Therefore to determine the externally reflected component, calculate the equivalent sky component (uniform sky) for the area of the obstruction, and divide by 10. In the example, the obstruction is taken as one-eighth of the whole scene through the window. The externally reflected component is therefore 10% of $\frac{1}{8} \times 1{\cdot}6$ (the component from the unobstructed sky). This equals 0·0225 per cent, which is so small that it may be disregarded.

(B2) Internally reflected component

4. The internally reflected component may be determined by the use of Table 4. In order to use the table it is necessary first to know the ratio of glass area to floor area,[1] the reflection factors of the ceiling and floor, and the average reflection factor of the walls.

5. The values in Table 4 can be applied without significant inaccuracy to most rooms, provided that:

(i) the length-breadth ratio does not exceed 2:1;
(ii) the ceiling heights are between 8 ft and 12 ft;
(iii) where the room has walls of unequal length, the windows are either on the longest wall or are on two adjacent walls; if the only windows are on one of the shorter walls, the minimum indirect component will be about 20 per cent less than that predicted by Table 4.

6. For rooms which do not satisfy these conditions reference should be made to the British Standard Code of Practice referred to above.

7. In the example in diagram 21, the clear glass area is 27% of the floor area. The reflection factor of the floor is assumed to be 40 per cent, that of the walls to be 40 per cent, and that of the ceiling to be 70 per cent (white with sound absorbent panels). From Table 4, the minimum internally reflected component is 1·2 per cent. A correction factor of 0·8 should be applied to this to allow for deterioration of the decorations. Thus the internally reflected component is $1{\cdot}2 \times 0{\cdot}8 = 0{\cdot}96\%$ (say, 1%).

Total daylight factor

8. The total daylight factor at the reference point is then determined by adding A, B1 and B2 together. In the example in diagram 21: $1{\cdot}6 + \text{nil} + 1{\cdot}0 = 2{\cdot}6\%$.

Allowance for dirt on glass

9. To allow for the effect of dirt on window glass a correction factor of 0·9 should be applied for clean atmospheres, and 0·7 for industrial atmospheres.

Daylight factors from sloping glass and roof lights

10. When it is necessary to determine the daylight factors from rooms incorporating sloping glass or roof lights, reference should be made to the British Standard Code of Practice referred to above.

[1] It should be noted that this is the net glazed area through which light can pass. If this is not known at this stage in the design then it may be assumed that the glazed area is 75% of the structural window opening.

Table 4 Minimum internally reflected component of daylight factor.

Actual glass area as % of floor area	Ceiling reflection factor 70% (2)											
	Floor reflection factor (%)											
	10				20				40			
	Average wall reflection factor (%) (3)											
	20	40	60	80	20	40	60	80	20	40	60	80
5	0·1	0·1	0·2	0·4	0·1	0·2	0·3	0·5	0·1	0·2	0·4	0·6
10	0·1	0·2	0·4	0·7	0·2	0·3	0·6	0·9	0·3	0·5	0·8	1·2
20	0·2	0·5	0·8	1·4	0·3	0·6	1·1	1·7	0·5	0·9	1·5	2·3
30	0·3	0·7	1·2	2·0	0·5	0·9	1·5	2·4	0·8	1·3	2·1	3·3
40	0·5	0·9	1·6	2·6	0·6	1·2	2·0	3·1	1·0	1·7	2·7	4·2
50	0·6	1·1	1·9	3·1	0·8	1·4	2·3	3·7	1·3	2·1	3·2	4·9
Conversion factor to obtain average value of I.R.C.	1·9	1·5	1·3	1·2	1·8	1·4	1·3	1·2	1·6	1·4	1·2	1·1

Notes

(1) The values given in the table are the *minimum* indirect components of daylight factor, i.e. at points farthest from the window and are calculated for an angle of obstruction at the centre of the window of 20°

(2) For ceilings of reflection factor other than 70% the following conversion factors should be applied to the values given in the table:

Ceiling R.F.	40%	50%	60%	70%	80%
Conversion Factor	x 0·7	x 0·8	x 0·9	x 1·0	x 1·1

(3) This includes all surfaces except actual glass areas through which light is coming.

(4) To obtain the *average* values throughout the room multiply the values in the table by the conversion factors given at the bottom of the table.

(5) The basic room to which Table 4 applies is 20 ft square with a 10 ft ceiling and a window in one wall extending from a 3 ft sill to the ceiling. Changes in the height of the sill and of the window head will not, in most cases, affect the internally reflected component; neither will the shape of the room, so long as the ratio of length to breadth of the room does not exceed 2:1 and the length to height ratio does not exceed 3:1.

Appendix 4

Fluorescent and tungsten lighting installations – a comparison of their relative costs in use

1. The decision on whether or not to use fluorescent lighting for higher levels of illumination will depend to some extent on the question of cost. Fluorescent fittings are more expensive than tungsten ones, but they are much more efficient, producing at least three times as much light for every unit of current consumed. A comparison set out below of the costs in use shows that the lower running costs of a fluorescent installation are likely to overhaul its higher capital cost within a relatively short period. The length of time that will elapse before savings begin to show themselves will depend chiefly upon the hours of use per annum of the installation, and upon the cost of electricity per unit. The latter varies widely in different parts of the country. The longer the hours of use and the higher the cost of electricity, then the sooner will the economy of a fluorescent installation show itself. The user should substitute in the formula their local data for capital costs, hours of use, and cost of electricity. The prices given below are those current in 1965.

2. The architect still has the problem of containing the higher capital expenditure within the cost limits without reducing standards on other aspects of the building. The additional capital cost of a fluorescent installation at the level of illumination given below would be of the order of 2d. to 3d. per sq ft, allowing for the fact that stores, etc, would probably still be lit with inexpensive tungsten fittings.

A comparison of the cost in use of fluorescent and tungsten lighting

Aim To light a typical classroom of 600 sq ft to a minimum illumination of not less than 15 lm/ft² by the most economical method, taking into account both capital and running costs (but not the cost of cleaning). The actual level of illumination chosen will not affect the comparison appreciably. Where circumstances differ, other figures of cost, area, hours of use, etc, should be substituted for those given below.

Classroom
Length : 30 ft
Width : 20 ft } Area: 600 sq ft
Height : 9 ft
Reflection factor of ceiling : 70 per cent
Reflection factor of walls : 50 per cent
Reflection factor of floor : 25 per cent
Light fittings are ceiling mounted.
Room Index : F
Average Illumination : 18 lm/ft² (assuming diversity of + 15%)
Maintenance Factor : 0·8
(to allow for some dirtying of decorations and fittings)

Fluorescent
Fittings: 5 ft 80 watt batten with clip-on plastic louvres[1]; Daylight tube, 4400 lumens average output through life.
Utilization Factor : 0·5

Then by the 'lumen' method,[3]
total number of fittings required:

$$\frac{18 \times 600}{0{\cdot}5 \times 0{\cdot}8 \times 4400}$$

= *6 fittings*

Capital cost of Installation	£ s. d.
6 fittings (£4 14s. 0d. list incl. tube, less trade discounts, plus cash discounts to electrical and general contractors, plus fixing and profit, say £5 15s. 0d. each)	34 10 0
Wiring to points, 6 @ 40s.	12 0 0
Switches, 2 @ 12s. 6d.	1 5 0
	47 15 0
say,	£48

Tungsten
Fittings: Opal plastic shade;[2] 200 watt pearl lamp, 2720 lumens average output through life.
Utilization Factor : 0·55

Then by the 'lumen' method,[3]
total number of fittings required:

$$\frac{18 \times 600}{0{\cdot}55 \times 0{\cdot}8 \times 2720}$$

= *9 fittings*

Capital cost of Installation	£ s. d.
9 fittings (£2 6s. 0d. list incl. lamp and batten holder, less trade discounts, plus cash discounts to electrical and general contractors, plus fixing and profit, say £2 12s. 6d. each)	23 12 6
Wiring to points, 9 @ 40s.	18 0 0
Switches, 2 @ 12s. 6d.	1 5 0
	42 17 6
say,	£43

Therefore excess of fluorescent capital cost over tungsten = £5 (or 2d. per sq ft)

Running costs of installation

Let

H = hours of use of installation per annum – in this case assumed to be 300 hours,[4] made up of 200 hours to supplement failing daylight during school hours; 50 hours by cleaners (= half an hour per room during winter); and 50 hours by evening classes (= one 2-hour class for one evening per week, autumn and spring).

N = number of lamps.
r = cost of replacing lamps, including labour (in pence).
L = life of lamp in hours.
W = wattage of lamp.
d = cost of electricity in pence per kilowatt hour (in this case 3d. is assumed, but this can vary from 2d. to 6d., according to the tariff and the hours of use).

Then, according to a formula worked out by the Building Research Station, the running costs in shillings per annum will be:

Fluorescent

$$\frac{HN}{12}\left(\frac{r}{L}+\frac{1\cdot 4\,Wd}{1000}\right)$$

Substituting:
W = 80
N = 6
r = 138
L = 5000 hours (minimum rated life B.S.S. 1853-1956)

Substituting:

$$\frac{300\times 6}{12}\left(\frac{138}{5000}+\frac{1\cdot 4\times 80\times 3}{1000}\right)$$

$$= 150\left(\frac{138}{5000}+\frac{336}{1000}\right)$$

= *54s. 6d. per annum.*

Tungsten

$$\frac{HN}{12}\left(\frac{r}{L}+\frac{Wd}{1000}\right)$$

Substituting:
W = 200
N = 9
r = 34
L = 800 hours (figure published by M.P.B.W. based on service life tests)

Substituting:

$$\frac{300\times 9}{12}\left(\frac{34}{800}+\frac{200\times 3}{1000}\right)$$

$$= 225\left(\frac{34}{800}+\frac{600}{1000}\right)$$

= *144s. 6d. per annum.*

Therefore the excess of tungsten running costs over fluorescent
= 144s. 6d. less 54s. 6d.
= 90s. 0d.
or *£4 10s. 0d. per annum.*

Conclusion

The higher capital cost of the fluorescent installation will be overhauled by the higher running costs of the tungsten installation within two years. If the excess capital cost of £5 is amortized at 5 per cent over 15 years, this represents an annual payment of 9s. 8d., making a net annual saving of £4 10s. 0d. – 9s. 8d. = £4 0s. 4d. p.a.

Notes: (1) Fluorescent gear may have a power consumption of between 25 per cent and 40 per cent above the nominal lamp wattage. If the engineer is satisfied that the lower figure applies to the particular gear to be supplied, the multiplying factor for W in the formula above would be 1·25 instead of 1·4.

(2) Price of lamps (r) is based on local authority bulk purchases, but includes M.P.B.W. estimates of labour cost for replacement (1s. 11d. fluorescent, 1s. 0d. tungsten). This may be lower for maintenance work in schools.

(3) The lighter load of the fluorescent installation can mean economies in cables and gear back to the main switchboard and a reduction in the estimated maximum demand. However, power factor correction should be incorporated.

[1] of the type shown in photograph 17(a)
[2] of the type shown in photograph 16.
[3] see Appendix 5
[4] for secondary schools; primary school hours of use would be about 50 hours less.

Appendix 5

Calculation of artificial illumination

Calculation by the 'Lumen' method

1. This simple method for calculating the average level of illumination is described more fully in *Interior Lighting Design*, a handbook issued by the British Lighting Council, and in the chapter on Lighting in *Specification*, published by the Architectural Press. This method is based on the assumption that the light emitted by the lamps is spread evenly over the working plane in the room.

2. It can be expressed by the following formula:

$$I = \frac{L \times N \times U \times M}{A}$$

Where

- I = average level of illumination in lumens per sq ft
- L = average output through life of each lamp in lumens
- N = number of fittings
- U = utilization factor
- M = maintenance factor (allow 0·8 for normal cleaning of fittings three or four times per year).
- A = area of working plane in sq ft

3. Thus to find the number of lamps required in a room the procedure is as follows:

(i) Knowing the use to which the room will be put, decide upon the average level of illumination (I) required (see Part 1, paragraphs 33-36).
(ii) Choose the type and size of lamp to be used and look up in appropriate B.S. or in manufacturers' literature its average output through life in lumens (L).
(iii) Choose the type of light fitting which satisfies the building regulations and suits the use of the room, find out its light distribution from manufacturers' literature and choose a suitable mounting height.
(iv) Knowing the type of fitting, i.e. the proportion of upward and downward light, its mounting height, and the dimensions of the room, look up the room index in the publications referred to in paragraph 137.
(v) Knowing the room index, the distribution of light from the fitting, and the reflection factors of the surfaces in the room, look up the utilization factor (U) in the tables given in the publications referred to in paragraph 137.
(vi) Assume, unless one has other information, a maintenance (M) factor of 0·8.
(vii) Measure the area of the horizontal working plane (A).
(viii) Insert all these figures in the formula, rewritten as:

$$N \text{ (number of fittings required)} = \frac{I \times A}{L \times U \times M}$$

This gives the number of fittings required; the distribution of these fittings in the room is discussed in paragraphs 138 to 140.

Appendix 6

Terminology

1. The terms given below are explained simply rather than defined precisely.

Adaptation

2. Visual adaptation is the automatic physiological process by which the eye adjusts itself (by changes in the size of the pupil, and in the sensitivity of the retina) to its environment, in particular to the prevailing brightness and colouring.

Brightness (subjective) and **Luminance** (physical)

3. The brightness of a surface as seen by the eye is measured physically in terms of its luminance. The luminance is governed by the illumination on the surface and the reflection factor of that surface, and will be affected by the texture of the surface (i.e. matt as opposed to gloss) and by the angle of viewing. If the luminance is measured in foot-lamberts (ft-L) it will be given by the product of the illumination falling on the surface and the reflection factor of that surface. The luminance of lamps and translucent fittings is also measured in foot-lamberts.

4. The apparent brightness of a surface is a measure of how bright it appears to the human eye, and this will vary according to the general level of brightness in the environment to which the eye is adapted. Thus a light fitting will appear brighter in an otherwise darkened room than in daylight.

Contrast

5. Contrast occurs when adjacent areas of different brightness are seen together. Details are seen by virtue of the contrast of one boundary of light and colour with another.

Daylight factor

6. The daylight factor at a point in a room is defined as the total indoor illumination on a reference plane at that point, expressed as a percentage of that simultaneously obtained out of doors, under a completely unobstructed hemisphere of sky having a luminance distribution in accordance with the definition of the International Commission on lighting (C.I.E.) for a standard overcast sky, the effects of direct sunlight being excluded.

7. The daylight factor includes both light direct from the sky (see Sky Factor), and light reflected from surfaces inside and outside the building.

Illumination

8. This is the amount of light (or luminous flux per unit area) falling on a surface. It is measured in lumens per square foot (lm/ft^2), formerly called foot-candles.

Light output ratio

9. This is the ratio between the light which is finally emitted from a light fitting after inter-reflection and absorption within the fitting, and the light produced by the lamp.

Lumens per square foot

10. See Illumination.

Luminance

11. See Brightness.

Munsell system

12. This is a colour reference system of particular value to architects and lighting designers in which colours are arranged systematically according to properties of *hue* (red as distinct from yellow), *value* (the lightness or darkness of a colour, directly related to its reflection factor), and *chroma* (the strength or intensity of a colour). For a further explanation of the Munsell system, see Appendix 4 of Building Bulletin No. 9, *Colour in School Buildings*.

Sky Factor and **Sky Component**

13. The sky factor at a point in a room is the ratio, expressed as a percentage, of the illumination on a reference plane at that point due to light received directly from the sky through an unglazed aperture, to the illumination due to an unobstructed hemisphere of sky of uniform luminance (i.e. brightness) equal to that of the visible sky. In practical calculations of Daylight Factor (q.v.) the sky component is used (see Appendix 3). This takes into account the non-uniform distribution of the C.I.E. overcast sky, which is brighter at the zenith than at the horizon.

14. The sky component is a geometrical property of the building design and of external obstruction to light and as such it does not include light reflected from the ground outside or from surfaces within the room. It does take into account transmission losses in window glass.

Utilization factor

15. This is the ratio of the light reaching the working plane in a room, to that emitted by the light fittings. It does not normally allow a maintenance factor for the dirtying of the light fittings or decorations. Sometimes called 'coefficient of utilization'.

Appendix 7

Short bibliography

General Principles of the Lighting of Buildings	Building Research Station Digest No. 70 (1st series) (H.M.S.O., 1954)
Estimating Daylight in Buildings	Building Research Station Digest Nos. 41 and 42 (2nd series) (H.M.S.O., 1963, 1964)
Artificial Lighting of Building Interiors: Lamps and Fittings	Building Research Station Digest No. 81 (1st series) (H.M.S.O., 1955)
Integrated Daylight and Artificial Light in Buildings	Building Research Station Digest No. 76 (2nd series) (H.M.S.O., 1966)
Daylighting (British Standard Code of Practice CP3: Chapter 1: Part 1 (1964))	British Standards Institution
Daylighting	R. G. Hopkinson, P. Petherbridge, J. Longmore (Heinemann, 1966)
Architectural Physics – Lighting (which has an extensive bibliography)	R. G. Hopkinson (H.M.S.O., 1962)
Colour in School Buildings	Department of Education and Science Building Bulletin No. 9 (3rd Edition, H.M.S.O., 1962)
Hygiene, public health: Internal environment: Lighting	The Architects' Journal, 20th February, 1963.
Recommended Practice for Good Interior Lighting (The I.E.S. Code)	Illuminating Engineering Society (London), 1961.

Appendix 8

The lighting of school kitchens

Natural lighting

1. The Standards for School Premises Regulations, 1959, put the required standard of lighting in kitchens on a par with that in teaching spaces; that is, a 2 per cent daylight factor must be ensured on all working planes. A kitchen is a work room and it is as essential to safeguard comfortable and efficient vision here as in any other space in the school where individual tasks demanding concentration are carried out.

2. It would be possible to achieve a satisfactory level of lighting by roof lights alone, but a view window is clearly needed. Some sunlight, too, will be welcome, but in moderation. Large south facing windows must generally be avoided, particularly in the neighbourhood of the preparation area. Venetian blinds are not a suitable defence in kitchens against occasional intensities of heat and sunlight.

3. Light colours in decoration, glass partitions wherever practicable, glass rather than metal for ventilation hoods and the avoidance in planning of small recesses will all help to improve the standard of natural lighting.

Artificial lighting

4. The artificial lighting of kitchens throws up special problems not encountered elsewhere in the school. During the winter months it will be used more frequently and for longer periods than in the rest of the school because the kitchen staff start their day an hour before everyone else. Even though a general level of lighting of 10 lumens per square foot is achieved, it does not follow that this will be adequate in each working area. For example, general lighting often results in a member of the staff working in her own shadow at a sink or at a preparation bench. The safest course is to light individually and preferentially all working positions, stores or recesses and then to light generally the remaining parts of the kitchen.

36 Tailpiece

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