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INTRODUCTORY NOTE FROM THE CHAIRMAN OF COMMITTEE E-3.2

This document has a rather long and eventful genesis within the CIE.

Early in 1957 the Scope Committee Σ) asked the committee W-3.2. to "decide on one or a small number of methods of daylight calculation which the CIE can recommend to the various interested professions", and at a meeting in Paris in September, 1957, the committee W-3.2. agreed to prepare a "CIE guide for the calculation of natural lighting (including sunlight)". In November 1957 questionnaires were sent out to the members of the committee, and the British Expert Member Mr. P. Petherbridge accepted to prepare a draft to the guide (Part I, overcast sky). This draft was presented to the committee in Brussels in June, 1959, and a number of amendments were suggested. The amended draft was circulated to the members in October, 1959, and also sent to the National Committees for information. This draft met with some approval but also with considerable opposition, particularly from the French National Committee. The French Expert of E-3.2., Mr. Escher-Desrivieres subsequently agreed to prepare a new draft, which was circulated to the members late in 1960 and met with predominant approval. The then chairman, Dr. A. Dresler, Australia, however, found that the acceptance of this version would have been controversial to the instructions given by the Scope Committee, and he asked this committee for advice.

The Scope Committee from its meeting in June 1961 gave a detailed instruction for the further work (which is quoted in full in the Proceedings from the Vienna session, p. 363). At a meeting in Copenhagen in September 1961, attended by 10 members of the committee and also by the chairman of the Scope Committee, Prof. L. Schneider, Germany, the subject was very thoroughly discussed and it was finally unanimously decided that the guide should put forward an example of a "simple" method based on recently published Australian material, and in the second part of the guide all other available methods of calculating daylight should be listed together with complete references. The Australian expert and chairman of the committee, Dr. A. Dresler, was asked to prepare a draft of this new version of the guide. This draft was circulated to the members in May 1963 and discussed at the presessional meeting in Vienna in June, 1963. A series of amendments were adopted and passed to Dr. Dresler. Shortly after that, Dr. Dresler died, but the Australian committee promised to complete the Σ) former name for the Action Committee.

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work. Mr. James C. Lowson and Mr. D. Hughes kindly took the responsibility for this. It proved necessary to rearrange some of the contents and a general revision was finally undertaken. The revised draft was in the main presented and discussed at the meeting of the committee in Newcastle-upon-Tyne in April, 1965, where 14 members of the committee were present or represented. In the beginning of 1966 the new, completed and revised draft from the present Australian authors was circulated to the members of the committee for their final approval. At this time some new viewpoints on the transmittance factors of glasses had been discussed internationally and had also been introduced in the discussions of the factors used in the guide. These problems were presented to the members in a circular letter and the vote of the experts were requested. The comments received from the experts were partly quite elaborate and particularly Belgium, France, Great Britain and U.S.S.R. had critical comments or suggested amendments. The chairman corresponded with all the experts mentioned and with the authors. This resulted in some minor, but partly essential improvements, which I hope will satisfy all concerned. The final edition, which is presented here, has taken into account the typographical presentation to the users, including a clear-cut indication of the purpose and the limits of the particular method introduced.

Mogens Voltelen
chairman of E-3.2.
(1963 - 1967)

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ErrataContents. After "1.2.1. Corrections Factors" add:

1.2.1.1. Transmittance of Window Glass	18
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Preface, page 1: The three last lines in paragraph 2 should be deleted. and the paragraph read as follows:

..... same time become more complicated.
Part I of the Guide reduces a few of these
techniques into a method simple enough to
apply to everyday lighting design problems.

The first two lines in paragraph 4 should be
deleted and replaced by:

In addition, Part II of the Guide sets out a
comprehensive list of other methods of predic-
ting daylight in buildings. From this list ...

Section 1.1., page 4: "1.1.0. PRINCIPLES OF DAYLIGHT DESIGN" read:
"1.1. PRINCIPLES".

Section 1.1., 3rd last para, page 5: In the second last para-
graph of this section the reference to the 08.00
to 16.00 period should be struck out making the
relevant section read:
..... percentage of working hours between 09.00
and 17.00 for which the lighting level will be ..."

Section 1.1.2, para 3, page 8 and 9: Delete the two last lines on page 8
and the first three lines on page 9 and replace
the following:

It should be noted that values recommended
in most National codes are not fundamental. In-
creasing the illumination on a given task impro-
ves its performance up to a certain point bey-
ond which additional illumination has no effect;
but this theoretical maximum performance level

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is approached asymptotically so that attainment of the last few per cent of the theoretical maximum performance may require an enormous increase in the task illumination and consequently a disproportionate increase in the lighting cost. In practice, therefore, recommended illumination values represent a compromise between theoretical and economic factors; and this results in differences in the values quoted for one and the same visual task in the various National codes and standards. However, if we

Section 1.1.4., a), pages 11 and 12: Delete the last 5 lines on page 11 and the first 3 lines on page 12 and replace with:

a) The transmittance of the glazing. This is governed by the type of material and number of layers (e.g. single or double glazing). The data can usually be obtained from the manufacturer or supplier of the material; and table II shows the effect of varying the glass transmittance.

Glazing materials can also be classified as "clear" or "diffusing". It should be noted

In the third para. on page 12 in the 6th line replace "skylights" with "rooflights".

Section 1.1.4., c), page 13: Line 8: Read "1.2.1.2." instead of "1.2.1".

The end of this paragraph might read more smoothly if changed to the following:

"Compared with other references in the literature, the factors quoted in table III for horizontal and near-horizontal rooflights are probably a little severe."

Section 1.1.4., d), page 13: The last 4 lines run:

"Where the obstructions do not fulfil these requirements, an estimate will have to be made of the equivalent horizontal obstruction of infinite length assumed in fig. 1 and in the relevant diagrams."

Section 1.1.4., e), page 13: Similar, this might read:

"..... particularly the ceiling. This point is dealt with in section 1.2.1.3."

Section 1.2.1.1., page 18: The footnote should be replaced by:

+) Pending international agreement on the stan-

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standardisation of measurement or calculation of the transmittance of light through a window pane, this document employs the diffuse transmittance. (i.e. the transmittance for diffuse incident light). However, it should be noted that (for reasons explained in the Preface) the correction factors are in round figures; consequently, whilst transmittances based on other definitions may differ slightly from the diffuse transmittance, the variation is too small to be of practical importance when applying the simplified system described in this part of the Guide.

Section 1.2.1., page 22, para. 3, line 4: The note in brackets

"See sketch in Section 1.2." should be changed to
"See Fig. 1"

Section 1.7.2., sub-section (h), page 34: The third line of this sub-section should be read ".. or exceeded for 80% of all ...".

Section 1.7.3., Example I, last para. page 36: Here the words "ordinary intermittent" should be deleted making the passage read ".. the performance of tasks requiring at least 7 lm/ft² ..".

Figure 8 :

Under this figure should be added:

NOTE: In all cases the room length must not be less than the room depth.

P r e f a c e

The main purpose of this guide is to help architects, civil engineers, building inspectors and other persons who deal with natural lighting problems in buildings by providing them with a means of computing and checking interior daylight levels simply yet with adequate accuracy.

In recent years techniques for predicting daylight levels have become more precise than they used to be, but have at the same time become more complicated. The object of the guide is to reduce a few of these techniques into a method simple enough to apply to everyday lighting design problems, (Part I).

The CIE method is designed for simple and easy estimation of the sufficiency of daylight in uncomplicated rooms under average conditions.

Consequently, the accuracy to be expected is not the highest obtainable, but still adequate for most purposes.

Users are advised to read the preface and section 1.1. before applying the method.

In addition, the Guide contains a comprehensive list of other methods of predicting daylight in buildings, (Part II). From this list those who would like to specialize in daylight design can select the methods which will best serve their purpose in any one case.

From the many methods available the Daylight Committee of the C.I.E. has selected as an example of a simple method of daylight prediction, techniques that were developed in Australia independently by the Department of Labour and National Service in Melbourne and the Commonwealth Experimental Building Station in Sydney. (1) (2) (3). This method assumes a sky luminance distri-

(1) Industrial Data Sheets L2 - Natural Lighting of Buildings:

Daylight Design Diagrams. Department of Labour and National Service, Melbourne, 1963

(2) Notes on the Science of Building, No.56: Daylighting of Buildings, Comm. Experimental Building Station, Sydney, rev. edition: Nov. 1962.

(3) D. Paix, The Design of Buildings for Daylight. Bulletin No. 7, Comm. Experimental Building Station, Sydney, 1962.

bution defined by the C.I.E., viz. the C.I.E. Standard Overcast Sky[†]). For rooms with vertical windows in one wall or in two opposite walls the method of presenting results adopted by the Station has been applied to the Department's Daylight Design Diagrams. These diagrams give the lowest level of daylight that is available in a room, either at a distance of 2ft. (60 cm) from the rear wall along the centre line of rooms having windows in one wall or at or near the centre of rooms with windows in two opposite walls. Here, the wide variation in daylight level encountered in rooms lit by side windows makes it necessary to base design on the minimum condition. On the other hand, in rooms with overhead lighting it is possible to achieve much greater uniformity and the diagrams dealing with various types of rooflight (i.e., skylights, sawtooth and monitor roofs) give the average level of daylighting that is available over the whole working area under these rooflights.

To make the average level a meaningful figure, the level of illumination over the whole area must be reasonably uniform and the precautionary measures to ensure this are also mentioned.

The diagrams for the various types of window and rooflighting systems enable the ratio of internal to external illumination; i.e. the "Daylight Factor", to be determined. They take into account the light reflected from surfaces inside and outside the building as well as the light coming directly from the sky and make allowance for the effect of exterior obstructions, light transmission properties of the glazing, probable effect of dirt accumulation on the glazing, and other variables.

To relate these daylight factors to the actual illumination levels that will be equalled or exceeded for a specified percentage of normal working hours, a chart is provided giving information on the availability of daylight outdoors throughout the year at various latitudes. It may be noted that whilst this does not take into account the effect of local climatic variations, it is regarded as a reasonably acceptable guide and a considerable improvement on the simple 500 lm/ft.² (5000 lx) sky condition which was for so many years the recognised basis for practical design. As pointed out in the opening paragraphs, the availability of

[†]) For further details see section 1.1.5.

daylight chart and the associated diagrams and tables in Part I of the Guide, provide an easy, practical method which can be applied to rooms of normal shape falling within the limits noted on the various diagrams. In the case of unusual shaped interiors such as long , narrow rooms with a window in one end, or for special conditions such as the greatly increased proportion of reflected light from snow-covered ground, it will be necessary to use one of the more complicated methods set out in Part II. However, it must always be remembered that since the eye cannot normally detect variations in illumination level of less than 20 per cent, there is little point in attempting to achieve a very much higher degree of precision when making ordinary lighting calculations. In other words, the simple and approximate character of the method in Part I of this Guide does not seriously affect its usefulness; moreover, since the method is approximate, it is a waste of time trying to determine individual factors (such as the glass transmittance, or the effect of dirt accumulation) to an excessively high degree of precision.

In cases where:

differ

- + The conditions substantially from those assumed in the method -
- + More differentiated information is wanted -
- + A particularly high degree of accuracy is required -

it is recommended to choose another, suitable method among those listed in Part II.

Typical cases with diverging conditions, calling for use of another method, are:

- + Rooms of irregular shape or very narrow rooms.
- + Rooms with particularly irregular arrangement or uneven distribution of openings.
- + Glazing of another character than those provided in the method
- + Window arrangements with particular screening effect.
- + Complicated outer obstructions.
- + Exceptional reflection-characteristics of surfaces in the room or its surroundings, including ground.

Part II of the Guide consists of an annotated list of other methods of predicting natural lighting in buildings, which have been published in different countries in recent years. Where possible the list contains notes on the purpose of each method, its limitations, accuracy and other relevant details. This part of the Guide has been compiled from information supplied by the following countries (arranged in alphabetical order).

Australia	Germany	Sweden
Belgium	Great Britain	U.S.A.
Czechoslovakia	Netherlands	U.S.S.R.
Denmark	Poland	Yugoslavia
France	South Africa	

It should be mentioned that the methods are not necessarily all different. For instance, methods used in South Africa are basically the same as those employed in Great Britain whilst those used in Poland do not differ significantly from those of Czechoslovakia or the U.S.S.R.

Finally, it should be noted that both Part I and Part II of the Guide are primarily concerned with calculating the quantity of illumination; quality aspects, such as the effect of sky glare on the visual comfort of the occupants of a building, must be considered separately.

PART I: A SIMPLE GRAPHICAL METHOD OF PREDICTING DAYLIGHT BASED ON

THE C.I.E. STANDARD OVERCAST SKY

1.1.0. PRINCIPLES OF DAYLIGHT DESIGN

Even the simplest method of daylight prediction cannot be applied intelligently, unless the user knows something of the principles on which it is based.

Compared with the design of an artificial lighting installation, planning for adequate daylight inside a building is complicated by three facts:

- (a) the source of daylight is outside the room to be lit;
- (b) daylight is extremely variable, not only with time of the day and year, but also in respect of location, i.e. with geographical latitude;

- light
- (c) since sufficient natural light is seldom available during the whole of normal daylight working hours throughout the year it is necessary to decide the percentage of working hours for which adequate lighting is to be provided.

To cope with these difficulties, it has become customary in many countries to base daylighting design upon what might best be termed "tolerable minimum conditions" (NOTE: This procedure is not accepted in the U.S.A. or France).

Apart from special circumstances (such as a sky temporarily darkened by a passing thunderstorm) this "tolerable minimum condition" will only be encountered briefly near the beginning and end of each day; in between, the illumination level will normally rise very much higher. However, the effect of this will be partially compensated for by changes in the sensitivity of the eye and there is therefore a clear-cut distinction between the case where this "tolerable minimum condition" is equalled or exceeded and the case where natural illumination falls below this minimum, and supplementary artificial lighting has to be used.

As pointed out under sub-heading (c) above, for part at least of the normal working hours this "tolerable minimum condition" will not be attained; and it is necessary to relate this minimum illumination level to the percentage of working hours between 08.00 and 16.00 (or 09.00 and 17.00) for which the lighting level will be equal to or greater than the specified tolerable minimum condition.

However, in order to do this for any given geographical location it is necessary to know:

- (a) how much daylight is available outside the building, and
- (b) how much daylight is needed inside the building for the task in hand.

These two points will now be discussed.

1.1.1 External Illumination

Since design is based on the minimum conditions, we are mainly concerned with the value of external illumination which will be at least equalled or exceeded for the required percentage of normal working hours throughout the year.

This minimum value is termed the "reference value" of external illumination and in its determination it has become customary to neglect any contributions from direct or reflected sunlight and to consider only the amount of daylight which is available on a horizontal plane exposed to the whole of a completely unobstructed sky.

Understandably, information on the availability of daylight from the sky is limited. However, daylight recordings have been made over periods differing somewhat in length in the United Kingdom (4), Belgium (5), Germany (6), South Africa (7), U.S.A. (8) and Australia (3). Fournol (9) has shown how to calculate for any location the availability of certain levels of external illumination provided the hours of sunshine are known. It thus becomes possible to correlate measurements and calculations and build up a reasonably reliable picture of the availability of daylight at various latitudes.

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- (4) I.E.S. Technical Report No. 4, Lighting during daylight hours, Illuminating Engineering Society, London, 1962.
 - (5) R. Dogniaux, Données météorologiques concernant l'ensoleillement et l'éclairage naturel.
Cahiers du Centre Scient. et Techn. du Bâtiment, Paris, Cahier 351, No. 44, 1960.
 - (6) See, e.g. Fig. 1 in J. Krochmann, Lichttechnik, (Germany), 13, 1961, No. 7, p. 364.
 - (7) S.J. Richards, W.M.H. Rennhackkamp, Measurement of outdoor lighting conditions and their application in design for interior illumination S.A. Elec. Rev. (South Africa), 50, 1959, No. 494, pp. 39-49.
 - (8) R.A. Boyd, Studies on daylight availability, Ill. Eng. (U.S.A.), 53, 1958, No. 6, pp. 321-330.
 - (9) A.T. Fournol, Resultats français concernant les éclairagements naturels. Extension à d'autres climats.
Proc. C.I.E., 12th Session, Vol. II, pap. Q., 1951.

Figure 6 (after Dresler (10)) gives the external horizontal illumination (expressed both in lm/ft^2 and in lux) from the whole of a completely unobstructed sky as a function of latitude between 5° and 70° North and South. The various curves drawn ^{refer} to different percentages of all hours between 09.00 and 17.00 hours for which the levels of external horizontal illumination are either available or exceeded.

The curves of Figure 6 can also be applied to periods other than 09.00-17.00 but in this case they may need to be re-labelled with new percentage values. The following table sets out a list of the percentage values to use for some alternative periods.

Table I

PERCENTAGES TO USE WHEN FIGURE 6 CURVES ARE APPLIED TO PERIODS OTHER THAN 09.00 - 17.00						
CURVE IN FIG. 6	"95%"	"90%"	"85%"	"80%"	"70%"	"60%"
Alternative Period	Percentage of Alternative Period					
07.00 - 15.00	95	90	85	80	70	60
08.00 - 16.00	100	100	95	85	70	60
07.00 - 17.00	95	85	75	65	55	45
06.00 - 18.00	75	70	65	60	50	40

When using Figure 6 it should be kept in mind that it is based on "average weather" conditions and "typical climates". By "average weather" it is acknowledged that at any one place there are bound to be individual years which are either drier or wetter than the average. Thus in any particular year the actual levels of external illumination may, on the whole, be a little higher or a little lower for a given percentage of working hours than those given in the diagram which have been based on the long-term average of hours of sunshine in each month.

As far as "typical climates" are concerned, and this is of special importance for latitudes between 40°N and 40°S , it should be realised that the data are based on climatic conditions as they occur in places which have a more or less well defined wet season. Where this does not apply the values read off Figure 6 will be on the conservative side by 5 to 10 per cent at the most.

(10) A. Dresler, Availability of daylight at various latitudes, Light and Lighting, (Great Britain), 55, 1962, No. 10, pp.288-290.

Figure 6 shows that an external illumination of 500 lm/ft^2 or approximately 5000 lux, a level which is frequently used for daylighting design purposes in Europe, will be available or exceeded for about 85% of all normal working hours at a latitude of $51 - 52^\circ\text{N}$ (London, Brussels, Berlin) whilst at 38°N (the latitude of Messina or San Francisco) this same reference value of illumination will be available for 92% of the annual working hours. Conversely, if it is desired to obtain adequate daylight for 90% of working hours at $51-52^\circ\text{N}$, calculations must be based on a reference value of approximately 320 lm/ft^2 or 3200 lux.

1.1.2. Internal Illumination

In rooms lit by vertical windows, the level of illumination measured on the horizontal work plane (normally about 3 ft., or 90 cm, above floor level) is comparatively high in the immediate neighbourhood of the window but decreases rapidly as one moves away from it. In these circumstances design has to be based on the minimum level found on the work plane. On the other hand, in rooms lit by rooflights, a fairly uniform distribution of daylight illumination over the horizontal work plane can be readily achieved. Thus with rooflights it becomes possible to take the average level of daylighting as the critical figure for design purposes.

Regardless of whether we are considering minimum or average daylight illumination, the actual value chosen depends largely on the type of work that has to be performed at the point of reference. Here the tables of recommended levels of illumination for the various types of tasks and interiors, published by a number of countries in their artificial lighting codes or standards, may be taken as a guide. Whilst recent work has shown that such a choice may be rather conservative (11) this is in practice offset by the fact that daylight design is based on "tolerable minimum conditions" which will be exceeded for a substantial part of the normal daytime working hours.

As these recommended levels are not fundamentals but various compromises between those required for optimal visual performance

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- (11) For further information on this point, see the literature on Permanent Supplementary Artificial Lighting of Interiors (P.S.A.L.I.) as cited in I.E.S. - Technical Report No. 4 under (4) above.

and the cost of artificial lighting, there are differences in the levels of illumination which are recommended for one and the same visual task in these various Codes and Standards. However, if we exclude the levels recommended in the United States of America, these differences are not very significant. The following figures (based on those currently recommended in Britain and Australia) give a general idea of values likely to be acceptable.

Ordinary tasks (e.g. rough bench and machine work,
intermittent reading,
writing or filing)

Allow: 15 lm/ft²
or 150 lux.

Medium tasks (e.g. medium bench and machine
work, prolonged close office work)

Allow: 30 lm/ft²
or 300 lux.

Severe tasks (e.g. fine bench and machine
work, drawing boards)

Allow: 70 lm/ft²
or 700 lux.

The levels of illumination recommended in the U.S.A. are generally two to three times higher.

As designing for daylight is based on "tolerable minimum conditions" which are known to be exceeded for a substantial part of normal daytime working hours, it should be quite safe to use the lighting levels quoted above as a starting point.

1.1.3. Relationship between External and Internal Illumination

For any given set of conditions the daylight illumination inside a building is strictly proportional to the simultaneous external illumination. If the latter increases by a factor of two, the former is doubled and so on.

This ratio is commonly known as the Daylight Factor, DF, and is simply expressed as:

$$DF = \frac{\text{Internal Illumination}}{\text{External Illumination}} \times 100\%$$

The daylight at any given reference point depends on a considerable number of variables, such as the type of sky ("overcast" in this case), the size and the position of the fenestration, the

type of glazing used, the distance between the point of reference and the fenestration, the extent to which the sky is obscured by external obstructions, the amount of light reflected into the room from such obstructing surfaces and the interior decoration of the room, i.e. the reflectances of ceiling, walls and floor.

There is a great advantage to be gained by introducing the concept of daylight factor into daylight design, since it permits the development of techniques for predicting a level of internal daylight illumination which in themselves are completely independent of the levels of both external and internal illumination that apply to any one case. Once the daylight factor at the point of reference has been determined, its value can be readily interpreted in terms of actual levels of internal illumination and the time for which these levels will be available or exceeded by using the information given in Figure 6.

In practice it is convenient to convert the above equation for daylight factor into a nomogram shown in Figure 7. In this nomogram a straight line drawn from any point on the scale of external illumination on the left to any point on the scale of internal illumination on the right or vice versa will cross the intermediate daylight factor scale at that value of DF that corresponds to the values of external and internal illumination which the straight line connects.

Use of the nomogram of Fig. 7 in conjunction with the diagram shown in Fig. 6 is illustrated in the following two examples:

Example I:

In a building to be erected in Geneva (latitude: 46°N) there is an area in which a type of visual task requiring at least 20 lm/ft^2 or 215 lux is to be performed. What daylight factor must be provided in this area, if the natural lighting is to be adequate or better for 80% of all normal working hours between 09.00 and 17.00 hours?

Proceed as follows:

- (a) From Figure 6 find that for 80% of all hours and a latitude of 46°N the reference value of external horizontal illumination from the sky is 900 lm/ft^2 or 9700 lux .
- (b) Take the nomogram of Figure 7 and draw a straight line from 900 lm/ft^2 (or 9700 lux) of external illumination

on the left-hand scale to 20 lm/ft^2 or 215 lux on the right-hand scale of internal illumination.

- (c) Read off the intermeditate daylight factor scale that the corresponding value of DF is 2.2%.

This is the value of daylight factor which the fenestration has to provide if at least 20 lm/ft^2 (215 lux) are to be made available for 80% of all hours between 09.00 and 17.00 hours.

Example II:

Using the plans of a building it has been calculated (by one of the many suitable methods listed in Part II of this Guide) that the daylight factor at a specified point inside the building will be 2.5%. At and near this point, work is to be done which needs at least 30 lm/ft^2 (320 lux). The building is to be erected in New Orleans, Louisiana (lat. 30°N). For what percentage of normal daytime working hours will the natural lighting available at the specified point be adequate, or better?

Proceed as follows:

- (a) On the nomogram of Figure 7, draw a straight line from 30 lm/ft^2 on the right hand scale of internal illumination to 2.5% on the daylight factor scale and extend this straight line until it reaches the left-hand ^{scale} of external illumination, in this case at 1200 lm/ft^2 .
- (b) Take Figure 6 and find that for an external illumination of 1200 lm/ft^2 and a latitude of 30°N the natural lighting will be adequate or better for a little more than 85% of all normal working hours.

1.1.4. Necessary Allowances

Near the beginning of section 1.1.3. reference was made to certain variable factors which affect the percentage of the external illumination available at a specified point in the building. Prominent among these variable factors are:

- a) The Transmittance of the glazing. The properties of various glazing materials may be expressed in terms of Transmittance (Transmission factor) or degree of Diffusion. These properties are governed by the type of material and the number of layers (e.g. single or double glazing). The data can usually

be obtained from the manufacturer or supplier of the material. (the effect of various transmittances is dealt with in table. II).

It should be noted that the diagrams can only be used when clear glazing materials (glass or plastic) have been used in the windows, or in rooflights having vertical or steeply sloping glazing.

In the case of horizontal or near-horizontal rooflights the diagrams can be used with both clear glazing and highly diffusing glazing materials (obscured glass, glass fibre reinforced plastic, or glass fibre sandwiched between sheets of glass, etc.). The reason is that in the case of horizontal unobstructed skylights under an overcast sky, the luminance of diffusing glazing will be approximately the same as the average luminance of the overcast sky seen through clear glazing material of the same transmittance.

Note that the term "clear glazing" includes all materials in which the luminance is mainly controlled by the luminance of the sky or other surface seen through it, rather than by the illumination falling on the outer side of the glazing (which is of course the main controlling factor in the case of highly diffusing materials.)

The term "clear glazing" consequently in this connection includes wired roughcast glass or other clear materials with a lightly figured surface which may break up images seen through the glass, but which has little effect on the mean luminance of the glass when seen against an overcast sky.

- b) The percentage of the wall (or roof) area occupied by this glazing material. This can be estimated from the drawing and the influence of glazing bars should be taken into account. Depending on the type of construction, bars will generally occupy about 5 to 10 per cent of the glazed area; but the obstructive effect of structural members, ducts etc. inside the building should not be overlooked, especially when designing rooflights in factory buildings. In such cases an additional allowance may be necessary.

- c) The amount of dirt likely to accumulate outside and inside the fenestration. The percentage reduction in light due to dirt accumulation is not easy to estimate accurately. The external accumulation of dirt is governed by meteorological and local conditions, whilst the extent to which dirt is deposited internally largely depends on the kind of work done inside the building. Very little reliable information on dirt accumulation is available in the literature. The actual correction factors introduced in Section 1.2.1. are based on a comprehensive set of experiments carried out in Sydney, N.S.W. in 1948. Compared with other references in the literature the factors quoted for horizontal and near-horizontal roof-lights are probably a little severe (dealt with in table III).

Because dirt accumulates gradually, it becomes necessary to base lighting design on an average-through life "Service Value" of illumination.

- d) Partial obscuration of the sky external obstructions. External obstructions such as opposite buildings or trees greatly affect the amount of daylight entering through vertical or near-vertical windows. The extent of external obstructions is ^{usually} expressed by an angle above the horizontal of a line joining the top of the obstruction to the centre part of the window obstructed. For the simple method of design discussed in 1.2 certain simplifying assumptions will have to be made, e.g. the outlines of the opposite buildings are assumed to be horizontal and of infinite extent parallel to the plane of the window. Where the obstructions do not fulfil these requirements an estimate will have to be made of the equivalent horizontal obstruction of infinite length, (dealt with in fig. 1, and implied in the diagrams).
- e) The reflectance of main interior surfaces. The amount of internal reflected light (and hence the daylight factor) is greatly affected by the colours on main interior surfaces - particularly the ceiling, (dealt with in section 1.2.1.3.).

1.1.5. C.I.E. Standard Overcast Sky

It may be appropriate to conclude this introductory account of the principles of daylight design with some notes on the C.I.E. Standard Overcast Sky and the reasons why it has been adopted as the basis for the present method.

It should be noted that the values of external reference illumination given in Figure 6 are not based on any particular type of sky, they are values which are the cumulative result of what actually happens at any latitude while the sun is obscured, i.e. the sky may be partially or completely overcast or the sun may just be behind a cumulus type of cloud.

Nevertheless the type of sky existing at any one ^{moment} does exercise an important influence on the daylight factor for a given set of conditions. This is due to the fact that the relationship between the external illumination from the whole of the sky and the sky luminance as seen through windows or rooflights (which in turn affects the amount of light entering a room); depends on the luminance distribution of the sky.

Until a few years ago it was customary to oversimplify this problem by assuming the sky, for design purposes, to be of uniform luminance both in altitude and azimuth. However, in practice not only the clear sky, but the completely overcast sky as well, have a non-uniform luminance distribution. In fact, at the zenith the overcast sky is three times brighter than near the horizon. For this reason it is preferable and has now become accepted practice to base daylight design on a sky which, though of uniform luminance in azimuth, varies in luminance between horizon and zenith.

Since the design conditions are those which have already been described as "tolerable minimum conditions" the obvious type of sky to select is the completely overcast one which in many (but not all) climates is likely to exist at a time when these tolerable minimum conditions prevail. Using the completely overcast sky as the "design sky" has the added advantage that the small azimuthal variations of its luminance for a given altitude above the horizon can readily be neglected. This would be impossible if a dark clear sky had been chosen as the design sky. Its luminance distribution depends on the actual position of the sun in the sky and varies both with altitude and azimuth. Moreover, the clear sky, however dark it is assumed to be, never really presents a true minimum condition, since direct and reflected sunlight are nearly always present to augment the internal illumination received from the sky.

In 1955 the C.I.E. adopted the following equation as representing the luminance distribution of the completely overcast sky:

$$L_0 = L_z \cdot \frac{1 + 2 \sin \theta}{3}$$

where L_0 = luminance at angle θ above horizon,

L_z = luminance at zenith ($\theta = 90^\circ$) and

θ = angle of altitude above horizon.

Selecting the completely overcast sky as the design sky for daylight calculations is therefore mainly a matter of convenience; but it is possible to justify its general use, even in very dry climates where a completely overcast sky is rarely seen. The point is that even in buildings with vertical glazing, daylight factors under an overcast sky will be significantly lower than under a clear sky providing the same external horizontal illumination. This is due to the clear sky having an inverted luminance distribution compared with that of the overcast sky: the clear sky is much brighter near the horizon than at the zenith. Thus the use of the overcast sky as the design sky introduces a margin of safety into the design of the vertical fenestration of buildings which are to be erected in dry climates. This safety margin is important, since in such climates windows will frequently be provided with permanently fixed means of sun control. These naturally affect considerably the amount of daylight entering the building.

With horizontal or near-horizontal rooflights, daylight factors will be lower under a clear sky than under an overcast one that produces the same external reference illumination. However, from a practical point of view, this is not very important, firstly because in any case, the sun will be shining on the rooflights when the sky is clear, and true minimum conditions are thus not likely to exist. Secondly the use of horizontal or near-horizontal rooflights in a dry climate would amount to poor design because of the large amount of solar heat that the rooflights would admit into the building.

To sum up: As there are so many other variables that have to be taken into account in daylight design, it is difficult, if not impossible to expect simple routine methods of design to cope with all possible external conditions. What is needed is a well-defined source of daylight producing, for a selected period of time, values of external horizontal illumination which will not fall below a certain minimum. It is for this reason that the completely overcast sky with its luminance distribution as adopted by the C.I.E. has found wide acceptance as the "design sky".

1.2 DAYLIGHT DESIGN DATA - GENERAL

This section introduces practical methods of calculating daylight based on the general principles introduced in the previous sections. It also explains certain correction factors which have to be applied to the calculations for the five distinct types of buildings, discussed in later sections, as follows:

- (a) Ordinary single or multi-storey buildings with flat ceilings and vertical windows in one wall (unilateral lighting), Section 1.3.
- (b) Ordinary single or multi-storey buildings with flat ceilings and vertical windows in two opposite walls (bilateral lighting), Section 1.3 also.
- (c) Buildings with skylights in flat and pitched ^{roofs}, Section 1.4.
- (d) Buildings with sawtooth roofs, Section 1.5.
- (e) Buildings with monitor roofs (single, double and repetitive ridge-type and flat-roof monitors), Section 1.6.

The design diagrams which refer to vertical windows (cases a and b) give minimum daylight factors. With unilateral lighting this minimum daylight factor is assumed to be 2 ft. or 60 cm. from the rear wall on the centre line of the window wall. In the case of bilateral lighting the minimum daylight factor quoted is located at or near the centre of the room. In both cases the daylight factor is measured in a horizontal plane 3 ft. (90 cm) above the floor. As explained in section 1.3 the window sill is also assumed to be at this height.

The design diagrams for buildings with rooflights cases c, d and e) refer to average daylight factor, again measured in a horizontal plane 3 ft. (90 cm) above floor.

This distinction between minimum and average daylight factor is necessary because in rooms that are lit by vertical windows the daylight illumination falls off rapidly as the distance from the window increases and thus the daylight factor at points remote from the windows inevitably becomes the critical design figure. On the other hand, in buildings employing properly designed rooflights, daylight illumination is reasonably uniform and thus the average daylight factor over the whole working area becomes the representative figure.

In every instance the daylight factors quoted in the diagrams refer to the empty room or building. Partitions running parallel to the windows can considerably reduce the amount of daylight available behind them. Normal office furniture, such as desks and chairs, will not affect the daylight level to any significant extent. The same applies in factories to machines and equipment not exceeding about 5 ft. or 1.5 m in height. Equipment of greater heights is, of course, likely to obstruct quite considerably the amount of daylight reaching the reference point. The same applies to cranes and overhead duct work in buildings with rooflights.

As mentioned in 1.1.4 external obstructions such as opposite buildings, trees, etc. greatly affect the amount of daylight reaching vertical windows. For this reason the diagrams dealing with unilateral and bilateral vertical fenestration take into account obstructions of varying height. The extent of the external obstructions is expressed by the angle α between the centre of the window and the outline of the opposite building. (See Fig. 1).

Space for fig. 1

External obstructions affecting rooflights are comparatively rare. Therefore no provision has been made for them in the design diagrams dealing with rooflights.

Except in the case of monitor lights the diagrams do not make allowance for external sunbreaks, such as fixed horizontal overhangs or vertical louvers. The extent to which such sunbreaks affect the daylighting indoors depends on their dimensions as well as their design and also varies greatly with room size. It is therefore impossible to predict with any degree of certainty the losses caused by external sunbreaks. For methods which are capable of handling the effect of sunbreaks on interior daylight see Part II of this Guide.

Where tinted glass is used to control sun or sky glare, this can be readily taken into account provided the transmittance of the tinted glass is known.

1.2.1. Correction Factors

A few of the variables are not taken into account in the Daylight Design Diagrams and must be allowed for separately by multiplying by appropriate correction factors.

In all cases, allowance must be made for:

- (a) The transmittance of the glass (if this is less than 85%) when clean.
- (b) The average loss due to dirt accumulation on the glass between cleanings.

In the case of rooflights, allowance must also be made for -

- (c) The mean reflectance of interior surfaces (if this differs substantially from 20%).

Correction factors to allow for points a), b) & c) are given in Table II, III & IV below.

1.2.1.1. Transmittance of Window Glass: The design diagrams take into account the losses caused by a single pane of clean, clear glass (assumed to have a diffuse transmittance⁺) of 85%. In the case of double glazing or with other types of glass such as heat-absorbing glass, grey or tinted glass, or acrylic plastic materials, special allowance will have to be made for their lower transmittance, the amount depending on the properties of the material employed. (Such data is usually obtainable from the manufacturer or supplier).

Table II

NOTE: The diagrams apply to windows and rooflights with non-diffusing glazing materials, except in the special case of horizontal, or near-horizontal rooflights (See 1.1.4a)

Correction factor to be used if the glazing has a diffuse transmittance of less than 85% when clean.

Diffuse Transmittance ⁺ of Glass	Correction Factor
80%	0.95
70%	0.8
60%	0.7
50%	0.6
40%	0.45
30%	0.35

⁺) Failing at present an international agreement on the standardisation of measurement or calculation of the transmittance of light through a window pane this document applies the diffuse transmittance (i.e. the transmittance for diffuse incident light) and the values given in table II are based on this (and rounded off). Transmittances based on other definitions may differ slightly from the diffuse transmittance but the use of such would hardly affect the results but immaterially, especially regarding the limited accuracy of the method itself.

1.2.1.2. Effect of Dirt Accumulation on Windows & Rooflights: Allowance will have to be made for likely dirt accumulation on windows between cleanings. This depends on (a) the angle of slope of the glass, (b) the location of the building, i.e. the amount of dirt to be expected to settle on the outside window surface, and (c) the class of industry, i.e. the amount of dirt that will settle on the inside surface of the glass. The allowance to be made will also depend on the cleaning cycle. Where cleaning is done every six months the dirt correction factors listed in Table III apply:

Table III

Correction factors to allow for dirt accumulation.

Locality	Class of Industry	Angle of slope (measured to the horizontal)		
		90° - 75°	60° - 45°	30° - 0°
Country or Outer-Suburban Area	Clean	0.9	0.85	0.8
	Dirty	0.7	0.6	0.55
Built-up Residential Area	Clean	0.8	0.75	0.7
	Dirty	0.6	0.5	0.4
Built-up Industrial Area	Clean	0.7	0.6	0.55
	Dirty	0.5	0.35	0.25

1.2.1.3. Reflectance of Interior Surfaces: In side-lit^{rooms} with vertical windows the following reflectances have been used:

Ceiling 70%, Walls 50%, Floor 15%

These reflectances represent average conditions of good interior design for offices and clean workshops. They refer to an off-white rather than a white ceiling, fairly light walls and a rather dark floor. Since penetration of daylight into rooms lit by side windows is greatly dependent on having an adequate reflected component, it is important to use light colours of this kind.

However, in factories lit by rooflights (where lighting is in any case more uniform) lower reflectances will often be employed. The diagrams in sections 1.4-1.6 assume that the interior surfaces of the building have an average reflectance of 20%. Average reflectance is obtained by taking the individual surfaces such as floor, roof, walls and glass areas and finding the products of their reflectance

and their areas, then adding these products and dividing their sum by the area of the whole interior. Thus, if A_R , A_G , A_W and A_F represent the areas of roof, glazing, walls and floor respectively and R_R , R_G , R_W and R_F their corresponding reflectances, the average reflectance R_{av} will be:

$$R_{av} = \frac{A_R R_R + A_G R_G + A_W R_W + A_F R_F}{A_R + A_G + A_W + A_F}$$

If the average reflectance obtained in this way differs significantly from 20% a corresponding correction factor should be used. These factors are listed in Table IV.

Table IV
Correction factors for average
reflectances differing from 20%
(Rooflit buildings only)

Average Reflectance	Correction Factor
15%	0.95
20%	1.00
25%	1.05
30%	1.10
35%	1.15
40%	1.20

1.3 INTERIORS LIT BY VERTICAL WINDOWS

The diagrams for determining daylight factor at a specified reference point in rooms lit by vertical windows are based on the assumptions illustrated in Fig. 2 and described below:

Position of Window Head: It is assumed that the window head is placed 12 in. (or 30 cm) below the ceiling. Other things remaining equal the level of daylight in a room lit by vertical windows greatly depends on the distance between the window head and the ceiling. Best penetration of light is achieved when this distance is kept as small as possible but it is not often feasible for it to be less than 12 in. (or 30 cm). This distance has therefore been selected

and it can be said that it represents good practice without being unduly optimistic.

Sill Height: This has been chosen as 3 ft. (or 90 cm) above the floor. Provided that it does not rise much above the work-plane level, sill height has little, if any, influence on the amount of light entering the window directly from the sky but can influence the amount of light which becomes available by reflection from the ground outside and from opposite buildings. From the daylighting point of view, sill height should therefore be kept as low as possible, compatible with safety.

Width of Windows: This is expressed as a percentage of total room length. 60% Wd, for instance, stands for 60% Window Width, and means that the width of the actual glass area used in the room amounts to 60% of the room length. The design diagram for unilateral lighting (figure 8) takes into account window widths of 30%, 60% and 90% of room length. The design diagram for bilateral lighting (figure 12) refers to window widths of 60% and 90% of room length. It is not difficult to interpolate between these to obtain results for other window widths.

Space for fig. 2

Ceiling Height: The diagrams are valid for ceiling heights between 9 and 15 ft. (or 2.7 m. to 4.6 m).

Length of Room: This dimension is taken parallel to the windows. Fig. 8 provides for room lengths of (a) 20 ft. or 6 m and (b) 40 ft. or 12 m (a) can be used for rooms 15 to 23 ft. (4.6 to 7.0 m) and (b) applies to rooms longer than 33 ft. or 10 m. For room lengths between 7.0 & 10 m a mean value may be used.

Room Depth: This dimension, at right angles to the window wall is expressed in multiples of the window height H above sill level and is one of the two variables to be read off the design diagrams. The other is the minimum daylight factor 2 ft. or 60 cm from the ^{rear} wall in the case of rooms lit by windows in one side only, and near the centre of the room in the case of rooms lit by windows in both walls.

Reflectances of Interior Surfaces: As mentioned above, the following reflectances are assumed - Ceiling 70%, Walls 50%, Floor 15%.

1.3.1 Design Diagrams for Windows in one wall only.

There are four diagrams in this Section, viz. Figure 8, 9, 10 and 11.

Figure 8 is the basic design diagram. It refers to windows glazed with clean, clear glass having a diffuse transmittance of 85%, and with no buildings or other obstructions to block the view of the sky from the standard reference point. The latter is located on a horizontal plane 3 ft. (90 cm) above floor level, and 2 ft. (60 cm) from the rear wall of the room. The method assumes that this is the worst lit part of the room, and therefore has the minimum daylight factor. Figure 8 indicates the maximum permissible room depth and amount of glass required to give a specified daylight factor at this reference point. Conversely, the chart can be used to determine the daylight factor which will be available at the point in question when the room has a specified depth and known quantity of glass (i.e. Percentage Window Width). It should be noted that room depths are expressed in multiples of window height above sill level, and thus define the proportions of the room rather than its actual size.

Figure 9 is an auxiliary chart which has to be used in conjunction with Figure 8 when the view of the sky is obscured by external obstructions seen at an angle of elevation α when viewed from the centre of the window (see sketch in Section 1.2). In such cases, the basic daylight factor figure obtained from Figure 8 must be multiplied by an appropriate correction factor read off the chart in Figure 9.

Where necessary, other correction factors must be applied to allow for the effect of dirt on the glass, and for the transmittance of the glass itself, as explained in Section 1.2.1.

Figure 10 is another auxiliary diagram which need only be used when it is desired to know something about the daylight factor in the better lit parts of the room nearer to the window. Figure 10 gives the distance from the window at which daylight factor will be twice the value obtainable at the standard reference point near the back of the room; i.e., twice the minimum value calculated with the aid of Figures 8 and 9.

Figure 11 is similar to Figure 10, the only difference being that it gives the even smaller distance from the window at

which the daylight factor is four times the minimum value calculated with the aid of Figures 8 and 9.

When a visual task requires more light than is available near the back of the room, the problem can sometimes be overcome by moving the task closer to the window. Figures 10 and 11 enable this possibility to be assessed, after the minimum daylight factor at the standard reference point has been determined.

1.3.2. Design Diagrams for Windows in Opposite Walls (Bilateral Lighting)

There are six diagrams in this section, viz. Figures 12 to 17, inclusive. These are basically the same as those used for windows in one wall only (Figures 8 to 9); the only essential difference being that the reference point is now near the centre of the room, midway between the window walls.

Figure 12 corresponds to Figure 8, and relates building depth and amount of glass to the daylight factor at the reference point near the middle of the room.

Figures 13 and 14 give correction factors with which the minimum daylight factor, obtained from Figure 12, has to be multiplied to take into account the influence of any external obstructions. Figures 13 and 14 thus correspond to Figure 9 in the previous section, but are more complicated because there are two obstruction angles to consider instead of only one. Various combinations of angles in the 0 to 40° range are considered.

Figures 15, 16 and 17 indicate distances from the window at which twice the minimum daylight factor that exists at the centre of the room will be available; they correspond to Figure 10 in the previous section. Note that in the case of bilateral lighting there will be two positions (on either side of the reference point) at which the D.F. is twice that at the reference point. Since angle α always refers to the obstruction angle at the window from which the distance is measured, it is easy to distinguish between the two points.

1.3.3 Method of Use

The method of using the window charts and auxiliary correction factor tables depends upon the information available and required; e.g., the maximum permissible room depth that can be

allowed if a specified daylight factor is to be achieved at the standard reference point, or the minimum illumination level available at the reference point for a specified percentage of daytime working hours in a building at a particular latitude.

The relationships between the relevant charts and Tables have therefore been set out in two summary sheets, one for Unilateral and the other for Bilateral lighting, placed at the beginning of the relevant set of design diagrams. These will make it easy for the user to set about extracting any required item of information, provided that the rest of the required data is available. Some illustrative examples are worked out in sections 1.7.1 and 1.7.2.

1.4 INTERIORS LIT BY SKYLIGHTS

Here we are no longer concerned with the illumination obtained at any specific point in the interior but with average value over the whole of the working plane assumed to be 3 ft. (90 cm) above the floor. To make this average value meaningful it is necessary to achieve a reasonably even level of illumination in practice, and a uniformity ratio of up to 3:1 is acceptable for most purposes. Uniformity is easier to achieve with the aid of skylights than with other forms of rooflight, hence skylights are often chosen when uniformity is particularly important. A uniformity ratio of 2:1 can be achieved by ensuring that the distance between centre of rows (or continuous runs) of skylights, and also between individual skylights in rows is not more than twice the height of the skylights above the horizontal working plane. Similarly, the distance between adjacent walls and centres of skylights should not exceed one-half the above distance (see Fig. 3). Closer spacing will, of course, further improve the uniformity ratio; when a single row (or continuous run) of skylights is used in each slope of a pitched roof, uniformity will be improved if the rows are placed slightly closer to the valley than to the ridge of the roof.

Space for fig. 3