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Please note

Adequate lighting is an essential element in the creation of a habitable environment and the most satisfying means of attaining this is surely by the proper use of natural daylight. It is the purpose of this Digest to outline some of the technical information which is available as a guide to the more efficient use of daylight and to describe briefly the simpler of the design techniques which may be used.

Many well designed interiors have achieved the highest quality of natural lighting through the experience and imagination of the architect. Georgian architecture produced some very well balanced interior illumination because the tall narrow windows of that period contributed toward good penetration of daylight while the splayed reveals and mouldings helped to create a gradual transition from exterior to interior brightness without uncomfortable contrasts. With the technical advances made in structural design and equipment it is now possible to make a comfortable environment in even a windowless building or an all-glass enclosure. There seems to be a place, therefore, for more knowledge about the nature and function of natural daylight, as interior illumination.

Much research has been done throughout the world on the study of natural illumination and on the development of methods of prediction, so that a variety of design systems are available to the architect for predicting with a reasonable degree of accuracy the quality and quantity of natural interior lighting. A committee of the C.I.E. (International Commission on Illumination) is at present preparing an international design manual which will set out the basic principles and compare the various methods used in daylighting design. This mill be of great value in bringing together in one publication information needed for the practical application of daylight design.

The task of predicting natural interior illumination is made more difficult by the constantly changing nature of the light source. There are two stages in daylighting design: the meteorological study of the quantity of light from sun and sky (sky brightness) available at all unobstructed locations the means by which the desired level of illumination can reach a specific interior location.

Sky Brightness

Estimates of sky brightness are based on readings taken at regular intervals over a number of years. Two observed sky conditions which are assumed to be typical are generally used as the basis of design. These are

1. the totally overcast sky
2. the clear sky with direct sunlight.

The Totally Overcast Sky

The brightness distribution of an overcast sky is not uniform. It is normally lightest at the zenith and darkest at the horizon and is generally not affected by the position of the sun. Observations of sky brightness by Moon and Spencer[1], working in the United States, led to the development of a formula to describe the overcast sky:

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

where B_θ = luminance of the sky at altitude θ

B_z = luminance of the sky at the zenith

Observations in different parts of the world have served to confirm the applicability of the formula, at least in the temperate zones, and the "Moon and Spencer sky" has been adopted internationally by the C.I.E. as a standard overcast sky. The light distribution is such that the brightness at the horizon is approximately one third that at the zenith and one half the average sky brightness.

Though the distribution of light in the overcast sky may be expected to conform to the standard pattern, the average illumination level will vary depending on local climate. Average illumination from an overcast sky is assumed to be the quantity of light falling on a horizontal plane in an unobstructed location. The selection of suitable design figures may be determined from local meteorological records.

In Canada there are three meteorological stations measuring direct illumination at regular intervals; the total illumination from sun and sky on a horizontal plane is recorded hourly in Toronto, Scarborough and Ottawa. There are, in addition, approximately twenty stations across the country where total radiation is recorded. An approximate conversion from radiation to illumination units appropriate to overcast sky conditions can be made by assuming 1 gram calorie/sq cm/second to be equivalent to 7000 lumens/sq ft. This figure has been used in other countries in order to obtain information useful for daylight design and to supplement direct readings of illumination. The lowest recorded figure cannot, however, be used for design purposes, and a compromise bas to be accepted similar to that used in design for winter heating.

In Australia design values have been established for the principal cities based on the illumination level which will be exceeded during 90 per cent of the daylight working hours, that is, from 8 a.m. to 4 p.m. This seems to be a suitable approach, although for some types of occupancy a different period of the day may be more appropriate. The design figures recommended for Australian conditions vary from 350 lumens/sq ft in Hobart, Tasmania, to 1100 lumens/sq ft in Darwin. In Britain, which bas a maritime climate, 500 lumens/sq ft has been used as the basis of British standard for daylighting.

Climatic variations throughout Canada may be expected to give rise to a significant range of design values appropriate to each region. Records are published in the *Monthly Radiation Summaries* by the Meteorological Branch, Department of Transport[2], and may be used as the basis of appropriate design levels for Canadian conditions.

The Clear Sky with Direct Sunlight

In order to design for conditions of clear sky and direct sunlight, information is required not only of the quantity of light falling on a horizontal plane but also of height on vertical planes and planes perpendicular to the sun's rays. There are at present few records of this nature being kept in Canada, although in Ottawa readings are being taken on a regular basis of total radiation on vertical surfaces facing the principal points of the compass. Tables of daylight illumination appropriate to the United States are included in Recommended Practice of Daylighting, published by the Illuminating Engineering Society[3]. The information appears to be of a rather general nature, giving the solar illumination as a function of latitude, and it is doubtful whether it can be applied precisely to Canadian conditions.

Daylight Factor Method

The problem in designing a building to take advantage of natural light is that of determining how much of the light available ontdoors can be expected to reach a specified position indoors. The "daylight factor" which is commonly used as a yardstick in European practice is a measure of the daylight illumination at a point, expressed as a ratio of the illumination on a given plane, and the simultaneous exterior illumination on a horizontal plane in an unobstructed location. For example, if the interior illumination is 10 lumens/sq ft and the exterior illumination on a horizontal plane 500 lumens/sq ft the daylight factor would be 10/500 or 2 per cent.

The calculation of the daylight factor may be broken down into its component parts as follows:

> Daylight Factor = Sky Component + External Reflected Component + Internal Reflected Component

The sky component is a measure of the direct light from the sky reaching the interior point under consideration; published tables and charts may be used to obtain this value. One that is relatively easy to use, and particularly appropriate in the preliminary design of a building, is that contained in the Simplified Daylight Tables published in 1958 by the Department of Scientifie and Industrial Research, England[4]. The tables are arranged to show the proportion of sky seen from the point for which the daylight factor is being calculated, and have been modified to include the effect of an overcast sky and the reduction in light transmission caused by single glazing. Additional corrections may be made for double glazing and for the effect of dirt on the glass.

The external reflected component is a measure of the light reaching the point after reflection from exterior surfaces such as opposite buildings which probably obscure part of the direct light from the sky. The procedure to be followed is similar to that used in calculating the sky component. The area of the opposing wall, as seen from the point, is obtained and multiplied by a figure appropriate to the brightness of the reflecting wall surface. It is commonly assumed to be one tenth of the average sky brightness.

The internal reflected component is the amount of light reaching the working plane after reflection from walls, floors and roof. In many instances this can be quite a large proportion of the total light available. The magnitude of the internal reflected component is obtained by taking into consideration the average reflectance of interior surfaces and the sizes of rooms and windows. The Simplified Daylight Tables include figures for the reflectance of common building materials and a table which may be used to estimate the value of the internal reflected component in rectangular rooms.

The Lumen Method

In the United States, particularly during the last ten years, a considerable amount of study has been devoted to the problem of designing for clear skies. As a result a lumen method of design has been developed along lines similar to those used in artificial lighting design. The quantity of light falling on a window from sun and sky and reffected light from the ground and other exterior surfaces is calculated and multiplied by a coefficient appropriate to the transmission factor of the window and the reflections from interior surfaces onto the working plane. The principles involved are very similar to those used in the daylight factor design, but the end point of the calculation is the quantity of light at the desired location expressed in illumination units.

A booklet, Predicting Daylight as Interior Illumination, prepared by the research workers at Southern Methodist University[5], contains a series of charts and tables which can be used to determine the interior illumination at points in simple rectangular side-lit rooms. The values obtained are restricted to three points in the room in order to simplify the calculations. The points are 5 feet from the centre of the window wall, 5 feet from the rear wall, and in the centre of the room. This is a little more restrictive than the daylight factor method which permits calculations at any point in a room. Its principal disadvantage for Canada appears to be the scarcity of reliable records of sky brightness for Canadian conditions. It is possible to use the figures for sky brightness contained in the booklet, and which are appropriate to United States conditions, to compare the relative efficiency of different building designs without being too concerned about absolute values. The lumen method can be used to obtain information on natural lighting from both overcast and clear skies.

Interior Illumination Levels

Selection of a suitable level of interior illumination is dependent on the specific task to be performed in the room. Recommended minimum values of illumination for a variety of tasks are listed in the *Lighting Handbook*, published by the *Illuminating Engineering Society*[6]. In most instances these are considerably higher than the older recommended values and are the result of a study of lighting, related to seeing efficiency, by H. R. Blackwell[7]. It is desirable that the light in a room should not fall below recommended levels, but there may be occasions when the minimum may not provide adequate conditions for seeing. For example, if the contrast between a task and its surroundings is too great, as may occur when a window is in the field of view, the eye adapts itself to the prevailing brightness and objects of lesser brightness may be difficult to see. By using one of the methods of davlight analysis it is possible to estimate the relative brightness of varions surfaces in a room and to make the necessary corrections. The *Lighting Handbook* of the *Illuminating Engineering Society* contains recommendations on the maximum ratio between task brightness and brightness of surrounding areas for comfortable conditions. The following figures relate to schools and offices where good seeing conditions are essential:

- Between task and adjacent surroundings: 1 to 1/3
- Between task and more remote darker surfaces: 1 to 1/10
- Between tasks and more remote lighter surfaces: 1 to 10
- Between fenestration and adjacent surfaces: 20 to 1
- Anywhere within the normal field of view: 40 to 1

These ratios are recommended as maximum; reductions are generally beneficial.

The principal source of glare is direct sunlight and this should be controlled by one of the many shading devices now in common use. A clear sky without direct sunlight is seldom so bright as to cause discomfort, but sunlight reflected from adjacent walls and ground surfaces can frequently be troublesome. Light coloured interior surfaces help to create more uniform distribution of illumination in a room, since the contribution of reflected light is greater at points farthest removed from a window. Reflection from the floor also contributes to illumination at the rear of a room, because the direct light falling on the floor is reflected to the ceiling and other interior surfaces. Increase in window area below the working plane does not affect the direct component but may make a significant contribution to reflected light.

The techniques used in daylighting design are not dissimilar to those found in related fields of building design. They can be valuable tools in relating the design of windows to regional climates and in making more efficient use of one of our natural resources. The methods described are helpful in solving the simpler problems of daylighting design and more advanced techniques are available. A comprehensive bibliography of daylighting studies is included in *Recommended Practice of Daylighting*[3].

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