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Supplementary artificial lighting has become a part of modern living in view of the need for maximum utilization of space. Rejecting the permanent supplementary artificial lighting system for interiors prevalent in the West as uneconomical, the authors suggest a rational basis of supplementary artificial lighting design based on experimental work, and recommend maximum utilization of daylight and switching on of supplementary artificial lights only when daylight is poor. Adoption of this proposal for artificial lighting is claimed to be economical in terms of energy consumption as also cost of installation — Ed.

Energy Economy in Day Time Lighting Design

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Permanent supplementary artificial lighting of interiors during day time has been advocated[1] in West European countries. It is well known that higher the level of daylight indoors, higher is the amount of supplementary light required to yield a visually balanced environment. This would suggest[2] restricting the entry of daylight indoors for making supplementary lighting economically feasible. In tropics, the windows can be so designed as to permit daylight indoors for most of the working hours and as such permanent supplementary lighting is not an accept able solution. The daylighting design[3 4] based on clear design sky[5] holds good for about 90 percent of the working hours. The remaining 10 percent of the working hours, when daylight is deficient, correspond to solar altitudes below 15° on clear days and to dull overcast sky conditions occurring[6] rarely. In cases where windows are heavily obstructed or where rooms are excessively deep and windows are improperly designed daylight is expected to be deficient for a much longer duration. Adequate artificial lighting is required to supplement daylight under these conditions.

So far, there has been no rational basis for the design of artificial lights for day time use in this country. For the same reason, the practice of artificial lighting design of buildings at present takes no account of the daylight availability indoors. The design is based on Lumen method assuming night conditions even if a building is to serve exclusively for day time use. The night time and day time requirements of artificial lighting are expected to be much different. The day time artificial lighting is complex because of fairly bright adaptation conditions for the eye during daylight hours and on account of variability of daylight. There is, therefore, need for investigating the requirement of artificial light for the levels of daylight which are not sufficient to provide adequate work plane illumination and acceptable visual environment.

EXPERIMENTAL WORK

Measurements of luminance and illumination were made in a two-bay room of 7·5×6·0×3·0 m size located on the top floor of a 12 m high physics laboratory building. Two symmetrically located windows, each of 1·8×1·2 m size, have been provided in this room on the north-west wall of 6×3 m size at a sill height of 1·2 m above floor level. For these investigations, four sets of twin 40 W fluorescent daylight lamps (correlated colour temperature 6 500 K) were mounted in semi-direct fixtures. The lamps could be individually switched on at will. The work plane illumination and the visual environment were subjectively assessed by six subjects in the age group 25-35 years. For deciding a suitable combination of supplementary light with daylight, a good work plane illumination for reading and writing task and a pleasant visual environment were taken as the criteria. The daylight illumination and total illumination after daylight as adequately supplemented were measured on the work plane along the centre of a bay. The luminance of different surfaces as seen from observers' positions was also recorded. Simultaneous measurements of window illumination and sky luminance as seen through the windows were also made. The following two positions of observers on three different working tables along the centre of a bay were considered:

a) Observer facing a wall normal to the window wall, and

b) Observer facing rear wall (parallel to the window wall).

The experiments were conducted with full windows open under the overcast and clear sky conditions for solar altitudes below 15°. Measurements were also taken at the time of solar noon with smaller window sizes after covering a certain portion of the actual windows. Similar experiments were conducted in a 5×3×3 m room adjacent to the above room.

Precise measurements of sky luminance distribution and vertical plane illumination and total and diffuse illumination on the horizontal plane were carried out on the terrace of the same building for solar altitudes of 15°, 10°, 5° and 0° on clear days. These data were required for calculating the daylight factor beyond design time and also for determining outdoor design conditions for the supplementary lighting.

RESULTS AND DISCUSSION

A typical distribution of daylight and the required supplementary artificial light on the work plane corresponding to a solar altitude of $7\frac{1}{2}°$ is depicted in Fig. 1. Similar distributions were observed with overcast sky conditions as well as with reduced window apertures at solar noon for clear skies. It is noticed that the need for supplementary artificial light was experienced whenever daylight level in the work areas diminished to 100 lux and below. The preferred supplementary artificial lighting requirement was such that total illumination in the work areas approached 100-150 lux.

The amount of artificial light required for different levels of daylight in the range 5-200 lux as the work plane is shown in Fig. 2. It is observed that the requirement of artificial light decreases linearly as daylight increases from about 5 to 125 lux. Between 125 and 200 lux of daylight on the work plane, the amount of artificial light that can further improve the entire visual environment increases almost linearly with increase in daylight. The trend corresponding to daylight levels above 125 lux is in broad agreement with the permanent supplementary artificial lighting basis. But the relationship of artificial lighting requirement for different levels of daylight at about 100 lux and below is more important from design utility point of view when supplementary artificial lighting becomes necessary. The following equations describe the relationship between required artificial light Ea and the level of daylight En in lux on the work plane:

$$Ea = 115 - 0{\cdot}72\,En, \quad \text{for } 5 < En < 125 \quad \ldots (1)$$

$$Ea = En - 100, \quad \text{for } 125 < En < 200 \ldots (2)$$

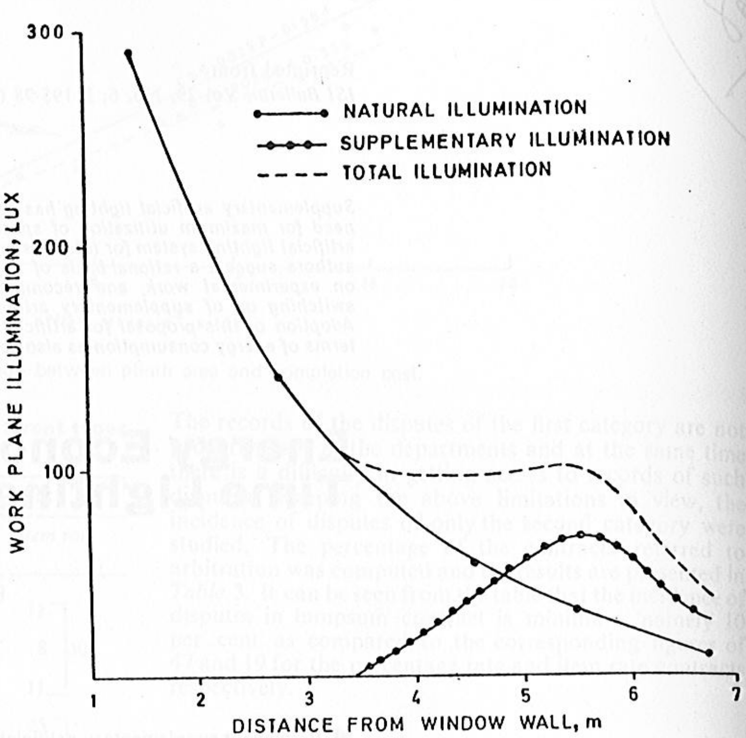

Fig. 1 Distribution of work plane illumination

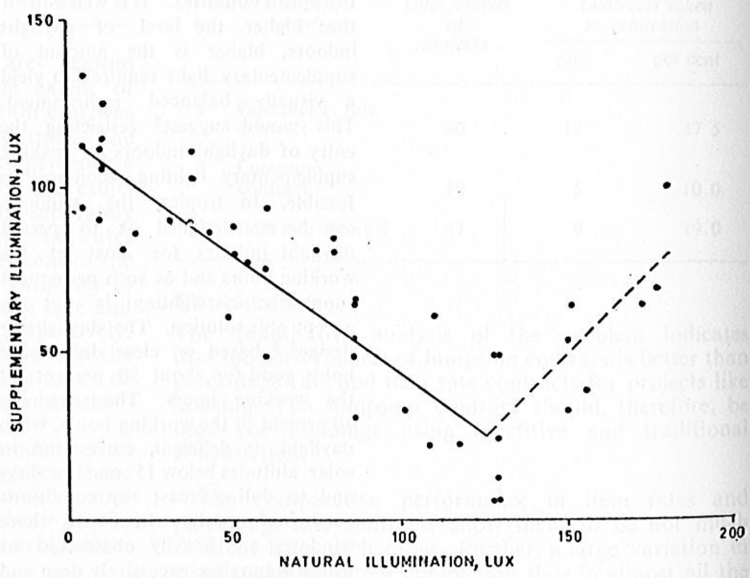

Fig. 2 Desired supplementary illumination for different levels of natural illumination on the work plane

Dependence of the desired average luminance of visual environment on the prevailing total light E_{wp} on the work plane is shown in Fig. 3. In general, as the prevailing level of light decreases preferred average luminance also decreases. Since inter-reflected illumination depends upon the average luminance of internal surfaces the desirable equivalent illumination E_r in lux due to inter-reflection can be expressed as:

$$E_r = 0{\cdot}33\,E_{wp} + 17 \qquad \ldots \; (3)$$

where

$$E_{wp} = E_a + E_n \qquad \ldots \; (4)$$

The measured vertical plane illumination opposite the sun for clear sky conditions corresponding to solar altitudes between 0° and 15° is plotted in Fig. 4. These values correspond to ground reflectance of 0·25. Brightness factors for clear sky excluding the quadrant of sky containing the sun are given in Fig. 5 for several angles subtended by the mid-point of window with the horizontal work plane as seen from an internal point. Figures 4 and 5 help estimate daylight at any internal point for clear sky between solar altitudes of 0° and 15°.

PROPOSED DESIGN BASIS

These investigations showed that the lighting conditions became critical when the daylight illumination E_n on the work plane in the work areas fell below 100 lux and supplementary artificial lighting was essential for the duration when:

$$E_n \leqslant 100 \text{ lux} \qquad \ldots \; (5)$$

Equation (1) shows that total work plane illumination for $E_n \leqslant 100$ lux should range between 115 and 143 lux when it is properly supplemented with artificial lights. Within this range of E_{wp} the desired average indirect illumination E_r should be 60 lux. This value of 60 lux of general illumination should be provided by the supplementary artificial lights and daylight together under the worst conditions.

For windows designed to provide adequate daylight between design time in the morning and evening, the worst daylight conditions occur near sunset or sunrise. However, dominance of daylight is found to be noticeably diminishing when the solar altitude falls below 5°. Therefore, the relative window illumination of value 0·1 (Fig. 4) can be taken as most suitable for design of supplementary artificial lighting. As the solar altitude approaches 0° and beyond, the brightness adaptation level diminishes and the design based on 0·1 relative window illumination will hold good. Since the

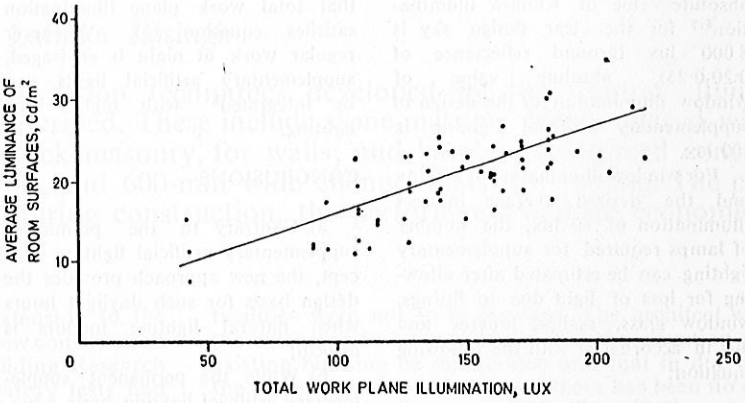

Fig. 3 Desired average luminance of room surfaces for different levels of total work plane illumination

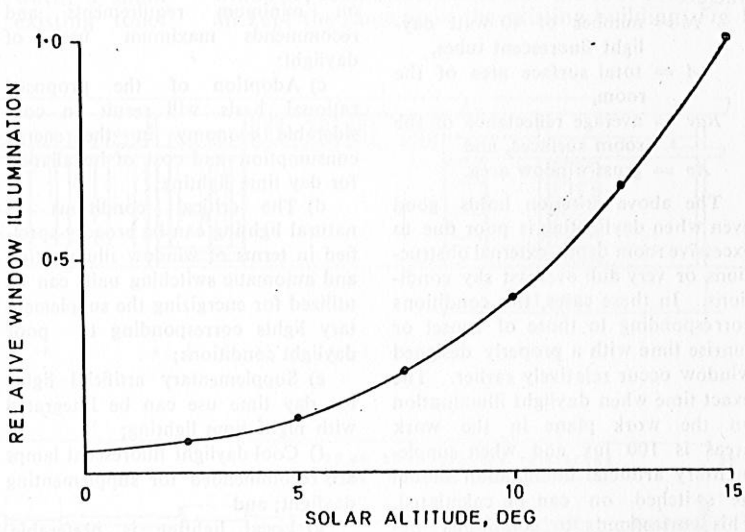

Fig. 4 Variation of daylight on a vertical plane opposite the sun with solar altitude

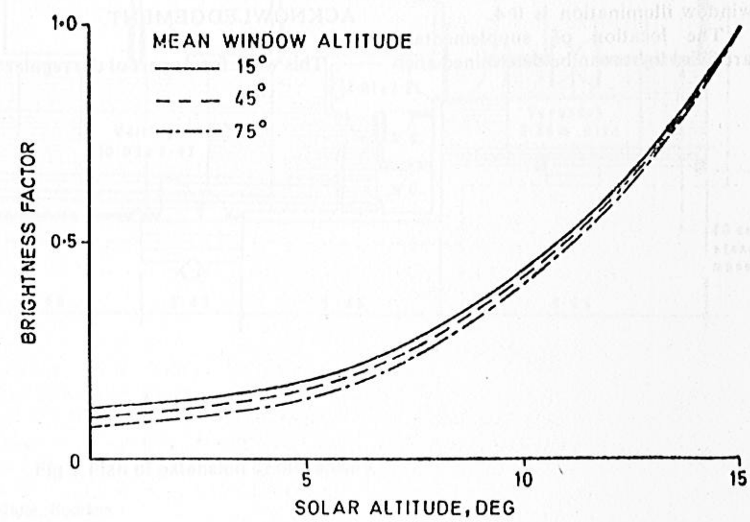

Fig. 5 Variation of sky brightness factors with solar altitude for different mean window altitudes from an internal point

absolute value of window illumination[6,7] for the clear design sky is 8 000 lux (ground reflectance of 0·20-0·25), absolute value of window illumination for the design of supplementary artificial lighting is 800 lux.

For window illumination of 800 lux and the desired average indirect illumination of 60 lux, the number of lamps required for supplementary lighting can be estimated after allowing for loss of light due to fittings, window glass, sashes, louvres and dirt in accordance with the following equation:

$$N = \frac{1}{100}\left[3A\,\frac{(1-Rav)}{Rav} - 20\,Ao\right] \quad \ldots \quad (6)$$

where

N = number of 40 watt daylight fluorescent tubes,

A = total surface area of the room,

Rav = average reflectance of the room surfaces, and

Ao = gross window area.

The above criterion holds good even when daylighting is poor due to excessive room depth, external obstructions or very dull overcast sky conditions. In these cases, the conditions corresponding to those of sunset or sunrise time with a properly designed window occur relatively earlier. The exact time when daylight illumination on the work plane in the work areas is 100 lux and when supplementary artificial illumination should be switched on can be calculated. This corresponds to conditions between 10° and 15° solar altitude for a properly designed window. Approximately, supplementary artificial lighting is required when the relative window illumination is 0·4.

The location of supplementary artificial lights can be determined such that total work plane illumination satisfies equation (1). Whenever regular work at night is envisaged, supplementary artificial lights can be integrated[8] with night time lighting.

CONCLUSIONS

a) Contrary to the permanent supplementary artificial lighting concept, the new approach provides the design basis for such daylight hours when natural lighting indoors is critical;

b) While the permanent supplementary artificial lighting basis advocates reduction of daylight indoors to make it compatible with artificial lighting, the new approach is based on minimum requirements and recommends maximum use of daylight;

c) Adoption of the proposed rational basis will result in considerable economy in the energy consumption and cost of installation for day time lighting;

d) The critical conditions of natural lighting can be broadly specified in terms of window illumination and automatic switching units can be utilized for energizing the supplementary lights corresponding to poor daylight conditions;

e) Supplementary artificial lights for day time use can be integrated with night time lighting;

f) Cool daylight fluorescent lamps are recommended for supplementing daylight; and

g) Local lighting is preferable, where it is required to supplement daylight over small areas or critical tasks.

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REFERENCES

1. HOPKINSON (R G) and LONGMORE (J). The permanent supplementary artificial lighting of interiors. *Trans Illumin Engin Soc*, London. 24; 1959; 121-48.
2. KENDRICK (J D). Daylight and supplementary artificial lighting in the design of tropical buildings. Proceedings of the Symposium 'Environmental Physics as Applied to Buildings in Tropics', 25-26 February 1969; CBRI, Roorkee; P D 15-D 31.
3. IS : 7942-1976 Code of practice for daylighting of educational buildings. Indian Standards Institution, New Delhi.
4. IS : 2440-1975 Guide for daylighting of buildings (*second revision*). Indian Standards Institution, New Delhi.
5. NARASIMHAN (V) and SAXENA (B K.) Measurement of the luminance distribution of the clear blue sky in India. *Ind J Pure & Applied Phys.* 5; 1967; 83-86.
6. NARASIMHAN (V), SAXENA (B K) and MAITREYA (V K). Measurements on luminance and illumination of cloudy skies at Roorkee. *Ind J Tech*; 8; 1970; 340-42.
7. SAXENA (B K) and NARASIMHAN (V). Precise values of sky components due to a clear blue sky for a vertical rectangular aperture. *Ind J Tech*; 5; 1967; 229-31.
8. NARASIMHAN (V) and SAXENA (B K). Supplemental artificial lighting in buildings. *Build Dig*; 120; 1976; 1-7.