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Please note

Artificial lighting in office and school buildings is a major and conspicuous consumer of electrical energy. In addition, air conditioning consumes energy and may he required to remove the heat generated by lamps. Energy consumption is measured as the product of power input (kilowatts) and the period of use (hours). To reduce it both input and hours of use must be controlled.

Power input may be reduced by lowering general illumination levels, adopting selective lighting standards, and replacing inefficient sources. Hours of use can be reduced through sensible switching arrangements and automatic light control that takes advantage of available daylight and space occupancy.

New Design Criteria

Increased knowledge of the relation between visibility and illumination has led to new methods of lighting design. Visibility is the new design tool. Not only is it a most useful measure of lighting quality, but through visual performance studies it can also be used for specifying lighting levels in numerous working environments.[1] The light-reflecting properties of an object and the direction of the incident light striking it have a greater effect on visibility than level of illuminance itself. Thus the traditional provision of a uniform illuminance level in the entire working space is being replaced by controlled illuminance concentrated at the work station. If work locations are uncertain or flexible within a space, then a general lighting scheme can be employed using luminaires with specific intensity distributions in computer-designed layouts. This can provide a uniform level of visibility but a non-uniform illuminance level across the interior space.

Task lighting integrated into office furniture has recently found wide acceptance. Here, the artificial illumination is confined to the work station. By providing good visibility where it is required, the available light is used most economically and effectively. Explanations of lighting terminology and units can be found in Reference 3.

Basic Principles of Visibility Design

Contrast

For an object to be perceived clearly there must be a difference in luminance (objective brightness) between the task detail and its immediate background. This luminance difference ratio, between detail and background, is called contrast. Size, colour and the time available to see the task may also be used to describe a visual task. Contrast, and the eye's sensitivity to it, is the most important parameter in describing visibility. All other factors may be expressed in terms of a contrast multiplier, including the degradation of seeing ability with increasing observer age.

Veiling Reflections

Veiling reflections are specular reflections superimposed upon diffuse reflections from an object that partially or totally obscure visual details by reducing luminance contrast and therefore visibility. The facets of "glossiness" inherent in almost all objects are too small to be visible to the naked eye, although they can be seen under a suitable microscope. Nevertheless, the macroscopic effect, called reflected glare, can be experienced directly by anyone who attempts to read a glossy magazine while facing a window on a bright, sunny day. The image of the sun and sky is reflected as a veil of light directly into the observer's eyes, reducing contrast and therefore also visibility.

In practice, veiling reflections may be minimized by positioning overhead luminaires (or employing ones with appropriate intensity distributions) in such a way that most of the light passes in front of and across the observer, perpendicular to the direction in which he faces, so minimizing specular reflections in the direction of view. This can also be achieved by employing multi-layer polarizing panels in luminaires that produce vertically polarized light. Veiling reflections are one of the most important factors affecting lighting quality; a non-uniform luminance distribution surrounding the visual task is another, but less significant.

Equivalent Sphere Illumination (ESI)

Equivalent sphere illumination quantifies the effects of veiling reflections and other factors that affect lighting quality and is therefore an appropriate design parameter. Expressed in units of foot-candles or lux, ESI is a measure of visibility. It is the level of illuminance under reference lighting conditions that will provide the same task visibility as the particular lighting conditions of interest. Reference lighting conditions are those produced in a photometric sphere, which gives a perfectly diffuse illuminance and in which interior luminances are equal from point to point. Sphere illumination produces very few veiling reflections, but it is not necessarily the optimum for good visibility. Rather it is a convenient and easily reproducible reference lighting condition.

ESI can be measured directly or calculated using computer programs, but its general application to lighting design is not without problems. Any single value of ESI is a function of the photometric properties of the luminaire, lighting geometry, room reflectances, viewing position and reflectance properties of the task. Computer programs to calculate ESI can be expensive for small projects and only provide useful information if the luminaire, room, viewing and task characteristics are precisely known (which is seldom the case). Direct measurement using relatively inexpensive instrumentation is now available. The values obtained, however, apply only to a standard pencil task and it is not yet clear how the values for more common visual tasks will compare. (A standard task is one for which the reflecting properties have been thoroughly investigated; in this case, those of pencil and white paper.) The ESI concept can and does help designers to produce good quality lighting and reduce lighting energy consumption, encouraging them to design for visibility and avoid unnecessary high illuminance levels in non-working areas.

Reducing Power Input and Lighting Quality

One of the most important considerations in lighting system design is the specification of the required illuminance level. The magnitude of this level and the method by which it is achieved strongly influence the electrical power input (kilowatts) needed to operate the system. Of equal importance is lighting quality, to which a number of separate factors contribute: visibility, discomfort glare, surface brightness ratios, the directional flow of light for revealing human facial features and the textured surfaces of the building interior. ESI designs to date have been more than adequate in lighting quality, and have in many cases been regarded as providing a more interesting, luminous environment than traditional monotonous, uniform illuminance schemes.

Non-Uniform Lighting

The non-uniform lighting principle advocates lighting systems that deliver to a work station the quantity and quality of lighting suitable for the task to be performed, its location, operator characteristics, and other related factors. Areas between and surrounding the work locations receive a reduced level of illumination. Illuminance level varies across the space but visibility, in terms of ESI, remains quite uniform. An often quoted disadvantage of non-uniform lighting designs for new buildings is that task location is never known precisely in advance of occupancy so that flexibility of furniture layout is lost. A good design, however, can provide a sufficient number of points meeting a criterion value of ESI to permit flexibility and good quality lighting for a large number of occupants. Desk lamps (preferably fluorescent) provide a ready-made solution to non-uniform lighting design and considerably reduce the over-all wattage per unit floor area. Because of the problems of glare, fixture durability and aesthetic considerations, the luminaire is probably best built in as an integral part of desk furniture.

Visual Performance

Figure 1 emphasizes the relative effects of changes in illuminance compared with changes in visibility (by improving contrast). Changes in relative performance, that is, each performance score divided by the maximum score attained, are plotted as a function of illuminance for visual tasks of different contrast value. Increasing illuminance for a task of low contrast can never bring about the performance level of a task of higher contrast. Up to the maximum performance that can be attained, greater percentage improvements in performance as a function of illuminance are obtained with higher contrast tasks. Visibility (or contrast), therefore, has a much greater impact on visual performance than corresponding changes in illuminance. Arbitrarily increasing illuminance levels especially for visually difficult tasks of low contrast, will not necessarily lead to significant improvement in performance. Improving the quality of the lighting by reducing veiling reflections will, however, increase contrast and result in increased visual performance.

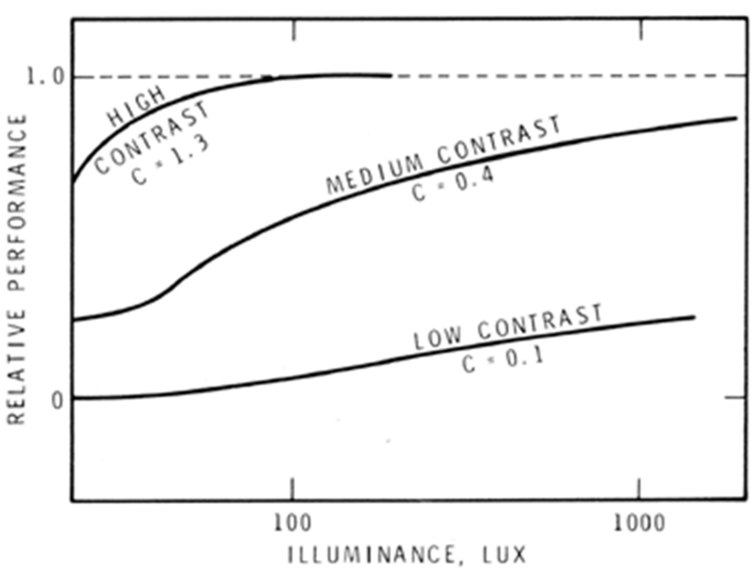

Figure 1. Relation of performance, contrast and illuminance[2]

Comparison of Lamp Characteristics

One of the most effective means of decreasing power input is to choose efficient lamps. The efficacies of common lamps are described in units of lumens per watt; typical values include incandescent 11 to 22, mercury vapour 18 to 65, fluorescent 40 to 80, metal halide 75 to 100 and high pressure sodium 85 to 130. Efficacy alone, however, does not determine the best and most economic lamp choice. For example, High Intensity Discharge (HID) lamps can require a "warm-up" period of several minutes before they reach full light output, and this may be a disadvantage if frequent switching is required.

Lamp life, lumen depreciation, colour rendering, glare, and the total light distribution from the luminaire must also be considered. There is some evidence that improved visual clarity with the better colour-rendering lamps can compensate for their lower intensity output. Reduction in the connected load can be achieved by choosing luminaires that direct most of their light below the horizontal plane in the direction of the work plane. Limiting values of Visual Comfort Probability (VCP), as given in the IES Lighting Handbook,[3] should be followed to avoid problems of discomfort glare.

Reducing Hours of Use

Artificial lighting could be employed only when needed if its use were out of the control of users, and automatic control will become more economically viable as energy costs rise. Maximum use of daylight should be sought within the environmental constraints set by the structure and the size of the building envelope. Admitting daylight through transparent walls would seem to be an ideal and simple method of achieving lighting energy conservation, but disadvantages include maintenance costs, glare, heat loss, solar gain, sound transmission through glass, and its inherent variability as a source of interior illumination.

Manual Switching

Efficient manual switching of artificial lighting is extremely important for energy conservation. Although repetitive switching of fluorescent lamps reduces their service life, off periods as short as 5 minutes can provide an over-all economic benefit. As work locations near windows always receive some daylight during most of the normal working day, luminaires near windows should always be on a separate switching circuit. The number of rows of luminaires parallel to the window on this circuit should depend on daylight penetration and the intensity distribution of the luminaires. Luminaires for the balance of the area should be switched in blocks to provide a symmetrical and logical switching pattern. The location of the control panel is of importance. It should be located so as to permit a clear view of the luminaires being controlled. Cupboards or external, gloomy corridors should be avoided. If numerous switches are on a single panel, then each switch should be individually labelled or colour keyed, or indicator lamps considered.

Alternatives to the conventional wall-mounted switch are available or under development for more flexible switching arrangements. Examples include ceiling-mounted cord switches, low voltage d-c switching with surface-mounted tape wiring and various remote control switches using sonic, ultrasonic and infrared frequencies.

Automatic Control

Where it is practical to control lighting automatically, various arrangements can be considered in terms of their cost effectiveness. Time clocks with over-ride facilities provide a relatively inexpensive method of securing some degree of control. In larger installations the use of automatic, daylight-linked lighting systems controlled by photoelectric cell can yield substantial savings; the photocells are normally mounted in the ceiling and control the power delivered to the luminaires. The cheapest system of this type is a simple on/off control. More expensive, is a continuous-dimming system that in many circumstances is more acceptable to the occupants and saves more energy. In both daylight systems the luminaires are activated when daylight illuminance in the interior falls below a preset value and de-activated when sufficient daylight becomes available. Security systems switch alarms and signals on when a space is illegally occupied. This same technology can be adapted to switch artificial lights off when a space is unoccupied for a significant period of time.

Concluding Remarks

Conservation of lighting energy can be achieved by reducing power input and hours of use jointly. Reduction in power input can be achieved through the use of the Equivalent Sphere Illumination principle, although at present the facilities for measurement and calculation of ESI are not complete. By adhering to the simple principle that lights are 'ON' when required and 'OFF' when not, significant savings in total energy consumption can be realized. Optimized switching, automatic controls and advantageous use of daylight coupled with education and propaganda, can minimize hours of use.

References

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2. International Commission on Illumination, TC 3.1. Preliminary Fifth Draft, Implementation Procedures for Evaluating Visual Performance Aspects of Lighting.
3. Illuminating Engineering Society. IES Lighting Handbook. Fifth ed., New York, 1972.