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ABSTRACT

In order to judge or design the lighting of an interior a person must be able to understand and take into account many aspects of seeing and illumination. Important areas of consideration are--(1) factors that contribute to the visibility of an object: size, brightness, contrast, and time, (2) radiant energy with regard to the visible spectrums of light, (3) visual acuity and illumination levels as they relate to dark adaptation and task performance, and (4) provisions for comfortable seeing by providing proper illumination levels and minimizing glare sources. (JD)

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PHYSICAL ASPECTS OF LIGHT--"Seeing Parameters"

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SEEING PARAMETERS

We must have light to see. Without light, no matter how good our eyes may be, we can have no vision. But light alone is not enough. The light must fall upon an object, be reflected into the eye and focused on the retina, where nerve impulses are generated and sent to the visual centers in the brain before the sensation of vision is experienced. How well we see depends upon the characteristics and functioning of all the elements from the light source to the visual centers in the brain.

The light source may be anything from natural daylight to the most modern electric sources or combinations of them. The architect must always keep in mind that whatever his design, be it for beauty or utility or a fine balance of both, it is worthless without light. A beautiful architectural detail lying in shadow is lost, and a work area without adequate lighting is nearly useless.

Adequate lighting may mean just enough light to avoid obstacles when walking outdoors at night or it may mean thousands of footcandles on the operating table in a hospital. The object of regard, that is, the thing we wish to see, its use, the effect of its surroundings, and the physical condition of the eye of the observer are all important in the determination of the quantity and quality of illumination of an area.

Four factors: size, brightness, contrast and time contribute to the visibility of an object. The size of an object as it appears to the eye, rather than its actual physical size, is important. A physically small object close by may appear considerably larger to the eye than a much larger object at a distance. The artist's pencil held at arm's length is larger to his eyes than many features of the landscape which he is transferring to paper. Handwriting on a chalkboard as seen from the back of a classroom, while it may be physically large, may appear visually smaller than the printing in a textbook at normal reading distance. The visual size of an object is usually measured in terms of minutes of angle subtended by lines of sight to the extremes of the object.

SLIDE (A) Power line poles along the roadside decrease in visual size as the distance from the observer increases. Pole No. 2 is twice the distance away as Pole No. 1 and is one-half the visual size.

SLIDE (B) The visual size of the pole is the angle subtended by the lines drawn form the eye to the top and bottom of the pole. When an architect does a site sketch, the trees near and far would have the same visual sizes as the trees on the site.

Brightness is actually what the eye sees and it is measured in footlamberts. The eye cannot see the footcandles falling on a surface, but it does see the brightness reflected (or transmitted) by the surface. The brightness of the surface depends upon its reflectance and the number of footcandles falling on it -- or by its transmittance and the light coming through it.

SLIDE (C) Three surfaces: white paper, gray cloth, and black velvet having diffuse reflectances of 80 percent, 8 percent, and 0.8 percent, respectively, have a brightness of 80 footlamberts, 8 footlamberts, and 0.8 footlamberts, respectively, with 100 footcandles of illumination on all of them. All three materials would have identical brightness (8 footlamberts) with 10 footcandles on the white paper, 100 footcandles on the gray cloth and 1000 footcandles on the black velvet. Light changes "black" to "white" ins uch a demonstration.

One hundred footcandles falling on two adjacent surfaces, one surface having a reflectance of 80 percent and the other surface having a reflectance of 40 percent, would produce a brightness of 80 footlamberts on one surface and 40 footlamberts on the other. While the footcandles, or amount of illumination, is the same for both surfaces, the brightnesses are different. The difference is 40 footlamberts.

Contrast can be defined as percent brightness difference and depends upon the relative reflectances of adjoining surfaces or an object and its background. A perfectly black object on a perfectly white background would have a contrast of 100 percent. An object reflecting 40 percent of the light, against a background reflecting 80 percent, would have a contrast of 50 percent. Objects of low contrast with their backgrounds are difficult to see. This is important in architecture, painting and sculpture.

SLIDE (D) The black threads against the black background and the white threads against the white background are difficult to see because the threads have nearly the same reflectance as their backgrounds. The black against white and white against black have high contrasts and are easy to see.

Time is also an important factor in seeing. In seeing, it is similar to the time required to take a photograph. It takes time, a matter of a few hundredths of a second for the sensation of vision to occur after the image of an object has been focused on the retina.

SLIDE (E) Objects of very high contrast can be seen fairly quickly even with comparatively low levels of illumination. With very low contrast tasks, recognition time may be three times as great as for high contrast tasks. This is a vital point in teaching -- recognition time is very important in blackboard drills.

Quick seeing makes work easier, prevents accidents, takes less nervous energy.

All four factors: size, brightness, contrast, and time are so interrelated that one cannot be varied without affecting the others. For instance, objects of large size and high contrast can be recognized more quickly than small objects of low contrast. Increasing the level of illumination will enable the eye to see objects of smaller visual size, lower in contrast and in shorter time. In the full light of day, individual bricks in a building wall can very easily be seen from some distance, but as twilight approaches, the bricks will gradually blur until only a solid wall remains.

The eye is an amazing instrument which responds to radiant energy entering it either directly from a source or reflected from an object.

SLIDE (F) Cosmic rays, gamma rays, such as emitted by radium, X-rays, ultraviolet rays that cause suntan, infrared rays produced by heat, radio waves, and electric waves range from a length of .0001 Angstroms to 3000 miles long.

In a very thin slice of the total spectrum lies the visible range -- from 4000 to 7000 Angstroms. Electrical plans may include all three components of concern to illuminating engineering -- ultraviolet, visible, and infrared, as in hospitals.

The visible portion of the electromagnetic spectrum is a very narrow band between the infrared and radio rays on one side and ultraviolet, X-rays and cosmic rays on the other side. Within this band, with wavelengths of 4000 to 7000 Angstroms, lie all the spectrum colors as seen by the human eye.

No object, which is not self luminous, can have color apart from the light which illuminates it. A red object can never appear red unless red is present in the light. Theoretically, the ideal illumination would be a white light with equal energy for all wavelengths of visible radiations. Direct light from the sun is close to being the ideal source.

SLIDE (G) The red, yellow green, and blue surfaces will appear red, yellow, green and blue to the eye since they are illuminated with light from the sun which contains all of the visible spectrum colors. If the surfaces were illuminated with a pure blue light, the blue surface would appear blue and others would appear gray or black since no red, yellow, or green wavelengths would be present with the blue light. This is a fundamental point but it is often overlooked in decorating plans.

Daylight as a whole varies over a considerable range with time of day and sky conditions. North sky light, while it has the advantage of illuminating a room without the interrerence of glaring sunlight, is decidedly a blue-white. Practically speaking, the more important points about the color of a light source are the color-rendering qualities of the light on things and the atmosphere created by it, rather than any beneficial or adverse effects to the eye itself.

SLIDE (H) The color-rendering qualities of a source can be made use of in such instances as accenting the scorch mark on white cloth. A source rich in yellow would accent the yellow of the scorch, but would also make the white cloth appear yellow and reduce the contrast. A source rich in blue and reduced in yellow would make the scorch appear darker. Incidentally, effects like these account for color problems in restaurants and night clubs where colored light often accent the wrong colors in food.

Visual acuity (the ability to see fine detail) in different colored light is not affected over a wide range of colors of light, or spectral distribution. It is only when single pure colors of light are used that significant differences can be found. It is difficult to focus on objects illuminated with pure blue light and visual acuity is better with pure yellow light, such as with sodium vapor light. But these effects do not have very much practical significance.

The eye is sensitive to brightness over a tremendous range, in the neighborhood of 10 billion to one. The lowest brightness which can be detected is approximately .000001 footlambert. The upper limit of visual tolerance is around 10,000 footlamberts. The brightness range over which the eye responds makes it possible for a person to see with starlight as well as with bright daylight. How much he can see and how easily he can see varies over this entire range of brightness.

SLIDE (1) The brightness range, of surfaces indoors, even with the highest levels of electric lighting now used, are very much less than the brightness levels of outdoor areas.

With starlight, the eye is adapted to such a low level that it responds to very low levels of brightness, but it can see no color and cannot see objects of small size. It is then in the scotopic state when the rods in the retina are most active and the cones are relatively inactive. Since there are no rods in the central part of the fovea where the retinal image is in clearest focus and the cones are inactive, only large objects can be seen by the dark adapted eye. This accounts for the fact that to see a faint star you look a little to one side of it--to see it best.

As illumination levels are gradually raised through twilight levels to daylight, the eye undergoes light adaptation until full color vision is restored and fine detail can be seen. This is the photopic state. A person's visual acuity (ability to see fine detail) continuously improves as brightness levels are raised to several hundred footlamberts.

The brightness appearance of surfaces depends upon the level of illumination and the state of adaptation of the eye. Nearly everyone has experienced the necessity for standing at the rear of a movie theater for a few minutes, after coming in from outdoors, to give his eyes time to adapt so that he can see to make his way to a seat. Architects discovered the advantage of a long foyer in a theater -- to give the eyes a chance to adapt in the time it takes to walk along it. In the daytime the lighting level at the entrance to a vehicular tunnel may be very high but gradually dropsoff to a much lower level within the tunnel. Thus the shock of sudden transition form one lighting level to another is considerably lessend. More light at tunnel entrances is often a good design answer.

Brightness patterns depend upon the distribution and brightnesses of the light sources as well as the reflecting characteristics of the surfaces being illuminated. This is true not only of the architectural features of the interior of a building but also of the objects and materials within a room.

The primary purpose of lighting in most commercial interiors is to provide for the seeing of work tasks. The secondary purpose is to create mood. In the home office of a large corporation are included typewritten material, business forms, and business machines. Drafting and artist's materials will be in Advertising, Engineering and Publicity Departments. The tasks for seeing and working with these materials are similar. In the factory are included the tasks of manufacturing and assembling of innumerable products of all sizes and shapes. It is the responsibility of the architect to design into his building (provisions for the installation of) the right kind of lighting for the work being performed.

Good lighting does not simply mean that enough light be provided to perform a specific task. It also means the distribution of that light to provide comfortable seeing. Comfortable seeing is possible only when the object of regard can be seen clearly and easily without interference from glare.

Glare can be termed any brightness in the field of view which interferes with a person's ability to perform a visual task with ease and comfort. Glare can be in the form of direct glare from bright light sources or reflected glare from shiny surfaces.

SLIDE (J) The most obvious form of direct glare is from an unshielded light source in the field of view which is so bright that it actually prevents a person from seeing to do his work. Less objectionable, but nevertheless damaging in its effects can be a bright area which is visible only out of "the corner of the eye". This glare can cause annoyance without the affected person even being aware of what is happening. Improperly shielded luminaires and window areas can both be responsible for all degrees of direct glare.

SLIDE (K) Good general lighting with properly designed supplementary lighting where needed will eliminate direct glare.

Reflected glare can cause just as much discomfort as direct glare and is often more difficult to control. Shiny architectural details, polished metal machinery, and glossy work surfaces can reflect unwanted and distrubing brightnesses into the eyes of the worker. Lighting must be so planned and surfaces so designed that reflected glare can be minimized.

SLIDE (L) Improper arrangement of lighting fixtures can cause reflected glare which is severe enough to prevent the seeing of details marked on a piece of shiny metal.

SLIDE (M) Proper lighting makes the details stand out clearly without being obscured by reflected glare.

A great deal of work is being done in the study of lighting systems to provide comfortable high-level lighting. In the early days of electric lighting, the emphasis was upon providing more light without very much concern for the quality of the lighting. As light sources were improved and higher levels of illumination became possible, it became more and more apparent that quality as well as quantity must be the goal of the lighting designer.

The use of higher brightness sources led to the classic glare studies of Holliday, a Nela Park research scientist. He determined the relationship between size and brightness for enclosing-globe fixtures which would produce varying sensations of glare. His "glare scale" ranged from "just noticeable" to "intolerable". This was the first practical attempt to provide rules to achieve comfortable lighting.

Holliday's formula proved to be practical over a limited range of size and brightnesses. Trouble arose with the extrapolation of his data to include the larger areas of fluorescent-lamp fixtures. Harrison and Meaker developed an emperical "glare rating" method which was a modification of Holliday's formula. Guth then began his studies in the laboratory and developed the BCD formula. BCD is the "Brightness between Comfort and Discomfort". It varies with the size and position of the light source in the light source in the field of view and with the general level of illumation. For instance, a luminaire whose brightness is at the borderline between comfort and discomfort when viewed near the line of sight could be increased in brightness as it is moved away from the line of sight and still have the same visual effect.

The BCD formula gives the value of the index of sensation of visual comfort, M, for a combination of field brightness, luminaire size, brightness and position in the visual field. However, an arrangement giving a specific "M" may prove to be comfortable for only a small number of persons in the room. Individuals vary greatly in their tolerance of glare. Some persons can tolerate brightnesses five times that of others, so it becomes important to know how many persons could be expected to be comfortable for each value of M over a five-to-one range.

SLIDE (N) The "Visual Comfort Index" (VCI) was derived from this information. It is simply the percentage of a large group of people who would be expected to be comfortable in a room with fixtures having brightness of a certain percentage of the BCD brightness. The VCI is now finding practical application in the design of luminaires and lighting installations.

The importance of providing ideal levels of well distributed illumination without glare is not measured only in terms of increased visual acuity of the worker and his ability to perform more quickly and more accurately. Energy is used in the process of seeing and inefficient use of that energy is manifested in numerous ways.

SLIDE (O) The convergence muscles of the eyes become less tired when reading is done with 100 footcandles than with one footcandle. The convergence muscles are those muscles attached to the outside of the eyeball which turn the eyes so that both of them can be aimed at the same spot to give single vision with the two eyes.

SLIDE (P) The nervous muscular tension created by difficult visual work can be shown by recording the pressure unconsciously exerted by the fingertips on a pressure-recording device. It was found that the average pressure exerted by the fingertips after an hour's reading was approximately 30 percent less when reading was done with 100 footcandles that with one footcandle.

The involuntary blink rate also has been used as an indicator of the relative ease of reading with different levels of illumination. One investigation showed that the rate of blinking was 35 percent slower with 100 footcandles than with one footcandle.

SLIDE (Q) In another investigation using a very difficult reading task the increase in blink rate after reading for an hour under one footcandle was 72 percent as compared with 8 percent with 100 footcandles.

The non-uniformity of brightnesses of a work area can be troublesome and annoying to a worker. The blink rate has been used to evaluate the comfort of a work area and has been found to be higher when the area surrounding the work task is considerably higher or lower in brightness than the task.

SLIDE (R) An uncomfortable situation is created when a person works alternately in areas of widely different brightnesses. It is shown that although the blink rate is higher when reading with two footcandles than with 20 footcandles, it is still higher when the reading is done for a few minutes at a time with the illumination alternating between the two levels.

The results of these investigations lead to the belief that while a person can actually see to read and perform other visual tasks with one footcandle or less, he is not doing so efficiently. Adequate illumination levels will enable him to perform with less loss of energy as indicated by muscular tension, ocular convergence, and blink rate.

SLIDE (S) A person's ability to perform a task with speed and accuracy will increase with increased illumination levels, but will reach a maximum and level off long before the less tangible, but important, benefits indicated by decreased tensions and blink rate and increased convergence reserve.

An environment for doing visual work should provide at least the illumination levels listed in standard practice schedules for different activities. Researches point to the desirability of utilizing much higher levels which can now be provided by modern lighting equipment. However, quantity of light is not enough. Quality of the illumination, proper distribution without glare, becomes increasingly important as lighting levels are raised.

With proper care in design and execution, an environment can be created in which a person can work with maximum speed and accuracy and with a minimum of energy wastefully expended. With the proper environment, a worker can be not only an efficient worker but a comfortable, and probably a cheerful one as well.

There is still much to study, much to learn, many things we wish to know more about.

SLIDE (T) As you examine an interior such as this one, you might review the parameters which we have discussed. Do its work points have acceptable brightnesses for comfortable seeing? Are its contrasts in brightness between the work spots and their background acceptable?

SLIDE (U) Could the occupants see fast enough for the inspection needed on this job?

SLIDE (V) Are the details of the work so small that the youngsters must hold them too close to their eyes? Is this in a room which is psychologically comfortable?

SLIDE (W) Are there color distortions which affect buyers eyes? Can the seller predict the color of the merchandise when the buyer gets it home?

By understanding the parameters of seeing, you should be able to judge the lighting in any interior. This is the first step in training yourself to design lighting systems that take these parameters into account in all their physical, psychological, and psycho-physiological meaning.