

Lighting Strategies for Productivity and Health

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Billions of dollars are spent each year on purchasing ergonomic chairs, keyboards, mice, and workstations. The goal is to improve performance and reduce the physical stressors that result in musculoskeletal disorders. Well-designed seating can provide postural support while promoting movement and changes in posture. Ergonomic workstations can allow for optimal monitor placement. But the benefits are limited if poor office lighting forces users to assume awkward postures or relocate monitors to avoid glare.

Office lighting should accomplish several things. Of course it must facilitate work, supporting visual tasks such as viewing VDT screens, writing, and reading hard copy – including hard copy referenced while using the computer. It must allow occupants to identify safety hazards. At the same time, lighting affects psychological well being, and it's helpful if lighting allows objects and people to look normal.

Lighting design considerations

Too often, office lighting design is based on how aesthetically pleasing is it to the designer and the building owner. The problem is that neither the designer nor the owner has to work in the space.

Support of the work performed in the office should be the primary function of lighting in the office. The lighting system should not require users to reposition their monitors or assume specific postures to avoid glare. At a minimum, the lighting should support the monitor locations required and recommended by ISO 1241 part 5 (ISO 1993), the international standard on computer ergonomics. ISO requires that the screen be located between eye level and 35° below eye level. The preferred location is with the screen centered at 35° below eye level with the monitor tipped back so the screen is at a right angle to the line of sight. Research in the fields of vision and ergonomics supports this lower screen placement (see Ankrum 1997 for a review).

However, the recommendations in RP-1 (IESNA 1993), the ANSI office lighting standard, assume that the top of the monitor will be at eye level and that the screen will be vertical. It provides little or no guidance for reducing glare with low and/or tipped back monitor locations. As a result, following the RP-1 recommendations may force users to adopt sub-optimal monitor locations that result in head/neck extension and eyestrain (Ankrum 2000).

Definitions

Lighting has its own language. Some of the following definitions have been simplified. To define them precisely is beyond the scope of this article.

Illuminance

Illuminance refers to the amount of light falling on a surface. The most common, and often only, specification for lighting is the illuminance level, which is measured in either footcandles or lux. Lux is the international unit, and the US is gradually adopting it. One footcandle equals approximately 10 lux.

Many office lighting guidelines specify an illuminance level of 200 – 500 lux for computer use and stop there. The problem with specifying illuminance only is that the visual system cannot actually *see* illuminance. The effect of illuminance is seen only after it has been reflected from (or passed through) a surface. The brightness of an object is the result of the interaction between the illuminance and the reflectance of the object. The same illuminance will appear to be quite different in an office with dark furnishings (carpet, panels, etc.) than it will in one with light furnishings. It is measured with the same type of light meter used by photographers.

Luminance

Luminance is the amount of light emitted from (or passing through) a surface. It is measured in candelas per meter squared (cd/m^2). We can see luminance. Luminance meters are specialized and expensive, costing upwards of \$800.

Glare

Many definitions exist for glare, but glare is basically unwanted light that causes discomfort or disability. It's subjective. A burglar might consider a policeman's blinding flashlight as glare, but the policeman considers the strong light desirable. Furthermore, our visual systems differ, depending on age and other factors; lighting conditions that are ideal for one person may be inappropriate for someone else.

Direct glare

Direct glare is unwanted light in the user's direct field of view. A simple test for the presence of direct glare is to shield the eyes by using a hand to mimic the brim of a baseball cap. If that gives a feeling of relief, direct glare is present. Often direct glare is brighter than the level of light to which the eyes have adapted. Adaptation is the process by which the eyes change their sensitivity to light. An example is the process the eyes go through when entering and leaving a dark theater.

Direct glare causes discomfort, but it can also be disabling. Direct glare usually results from light coming from windows or from bright luminaires in front of the workstation. Transient adaptation occurs when looking from a darker desktop to a bright window or lamp or vice versa. We may quickly adapt to bright sources of light nearby, interfering with our viewing the monitor – which requires considerably less light. As experienced when entering and exiting a theater, the eyes adapt much more quickly going from dark to light than from light to dark. Transient adaptation can result in performance losses.

One can get a rough estimate of the potential for direct glare by using the visual comfort probability (VCP) index. The VCP index estimates the percentage of people who will not experience discomfort under a given lighting condition. The IESNA (Illuminating

Engineering Society of North America) recommends a VCP of 80 or greater for offices with computers. However, a VCP of 80 means only 80 percent of viewers will find the glare conditions acceptable. The VCP index has come under criticism in recent years because the conditions under which the study was conducted do not reflect modern office environments. Despite its limitations, looking for higher VCP ratings can't hurt.

Screen washout

Excessively high ambient light levels can wash out the screen content. The light obscures screen content the way a bride's veil hides her face. Imagine trying to view a CRT monitor outside during the day; in fact, a common cause of screen washout is sunlight from skylights or uncovered windows.

Screen washout affects the entire screen and cannot usually be eliminated by repositioning the monitor. Screen washout should not be confused with veiling images. Veiling images depend on the angle of reflection and may affect only part of the screen.

For negative contrast screens (dark text with light background, similar to the printed page), Steffy (1995) recommends that ambient vertical illuminance not exceed 100 to 300 lux, depending on the task. That, however, assumes a vertical screen orientation. To support the ISO 9241 recommended monitor location – center of monitor 35 degrees below horizontal eye level – ambient illumination should be limited at the plane of the screen when the monitor is tipped back by 35 degrees.

Reflected glare

Reflected, or indirect, glare is light reflected from a surface in the field of view.

When the reflection is off a VDT screen, it is often referred to as disability glare. Disability means not just the inability to see, as in being blinded by the light, but also the inability to read the screen.

Reflected glare may be diffuse or specular. Diffuse reflections result from light reflected off an uneven, or matte, surface such as the bezel on a monitor or a muddy lake. One cannot easily determine what the image is. Specular glare is light reflected off a smooth surface such as glass or a clear mountain lake. One can usually identify the object. Reflected glare is often a combination of both diffuse and specular glare.

The key to eliminating reflected glare is eliminating glare sources and high contrast in the offending zone. The offending zone is the area behind user that the user would see if the screen were a mirror.

Convex, or curved, screens increase the offending zone for reflected glare. Flat screens reduce the offending zone and should be used whenever possible.

If a specific luminaire is causing reflected glare, it may be possible to retrofit it with small-cubed, parabolic lenses to decrease the angle at which the light is emitted. It may also be possible to reorient the entire workstation. In no case should the screen be tipped

down to avoid glare as that has been shown to increase postural and visual discomfort (Ankrum 1995).

Negative contrast screens (dark letters on a light background) substantially reduce the effect of reflections. With the monitor off, look at your reflection in the screen. Now turn the monitor on and select a Windows-type background, (black letters on a white background). Your reflection has most likely disappeared. Similarly, colored backgrounds are generally not advisable.

Contrast.

Reflections from computer screens are the most significant lighting-related problem in many offices. Reflected glare limits the options for monitor placement and often results in awkward postures. The most problematic reflections, other than exposed lamps, are caused by reflected images with high contrasts.

Luminance contrast

Luminance contrast is the relationship between the “brightness” of an object and its background. Controlling luminance contrast is a key to effective office lighting. In order to eliminate reflected glare, it is not enough to eliminate high luminance. It is also necessary to eliminate high luminance contrast.

An example of the effect of luminance contrast can be found on the dashboards of cars. If you put a light colored piece of paper on top of a dark dashboard, the reflected image on the windshield is disturbing. However, if you cover the entire dash with light colored paper, the reflected image of the paper seems to disappear. The same effect will be had with dark paper on a light colored dashboard.

Contrast threshold

To be seen, an object must differ from its background in either brightness or color. The contrast threshold is the minimum contrast that must be present to distinguish the object. While contrast depends on many factors, including size and the length of time viewing the object, Rea (1991) suggests that 2 – 5% be considered the contrast threshold values for office environments.

If the image that is reflected from the screen exceeds the contrast threshold value, it will most likely be noticed by the user.

IESNA Recommendations

In “Solving the Problem of VDT Reflections,” Rea (1991) argues that the recommendations provided by the IESNA are inadequate for addressing glare in computerized offices. See the sidebar, “Luminance contrast formulas,” for how to calculate maximum and minimum allowable luminance contrast.

Direct lighting

In order to eliminate reflections from VDT screens, the IESNA recommends that average luminances be limited to under 850 cd/m² at 55° and 65°, 350 cd/m² at 75°, and 175 cd/m² at 85°. (The angles are measured from the vertical.) However, it is not just the light from the luminaire that will be reflected off the screen. The reflected image includes both the luminaire and the adjacent ceiling.

Because it does not specify a ceiling luminance, following the IESNA guideline can still result in unacceptable reflections. With a typical screen luminance of 100 cd/m² for a negative contrast screen (light background), a luminaire with a luminance of 350 cd/m² and a (background) ceiling luminance of 15 cd/m² will have a contrast of 11.7% at 75°. That is more than double the contrast threshold of 5% and will be seen as a reflection in the screen. At 65°, luminance is limited to 850 cd/m², resulting in a luminance contrast ratio of 25%. At 85° the contrast will be 6% and may still be a problem for some users.

No limit is placed on maximum luminance below 55°. That leaves no limits for luminance in the offending zone for a monitor located at the ISO-recommended 35° below eye level monitor location with the monitor tipped back.

Note that the IES recommendation limits the *average* luminance. That means that higher luminance levels are permitted, increasing glare potential even further.

Indirect lighting

Indirect lighting is preferred for computer use in large areas containing many computers.

However, it is not enough to just follow the guidelines. For indirect lighting, the IESNA (1993) recommends a maximum luminance on the ceiling of 850 cd/m². They state that the contrast ratio between the maximum and minimum luminances on the ceiling should

Luminance contrast formulas

The basic formula for luminance contrast on a computer screen is

$$C = \frac{100[(L_{\max} + V) - (L_{\min} + V)]}{(L_{\max} + V) + (L_{\min} + V)}$$

Where C is contrast, L_{\max} and L_{\min} are the maximum and minimum luminances of the image reflected on the screen, and V is the screen luminance.

If you know the minimum luminance of the ceiling, you can find the maximum allowable illuminance by using

$$L_{\max} = \frac{100L_{\min} + L_{\min}C + 2CV}{100 - C}$$

If you know the maximum luminance of the ceiling, you can find the minimum allowable illuminance by using

$$L_{\min} = \frac{100L_{\max} - L_{\max}C - 2CV}{100 + C}$$

C, which in this case represents the acceptable contrast threshold, should be given a value between 2 and 5. Because glass, such as the front of a computer screen, reflects about 8% of the light falling on it, both L_{\max} and L_{\min} must be multiplied by .08 before calculating.

not exceed 8 to 1. The preferred ratio, according to the IESNA, is 4 to 1. At the 8 to 1 ratio, the contrast will be 21.5%. At the 4 to 1 ratio, the contrast will be 19%. In both conditions, the reflected contrast exceeds 5% and may cause unacceptable reflections in the screen. The IESNA further states that a luminance ratio of 2 to 1 is achievable. That, however, still results in an unacceptable contrast of 11%.

Because the underside of an indirect luminaire is a part of the image reflected off the screen, a dark housing will increase the contrast. The undersides of indirect luminaires should be light colors.

Most ceiling-mounted indirect lighting fixtures require a 9-foot minimum ceiling height. For lower ceilings it may be possible to use panel, desk mounted or floor standing indirect lighting fixtures.

Some manufacturers offer recessed “indirect lighting.” Technically, this lighting is indirect because the lamp directs its light upward against the recessed housing. However, the sharp contrast between the luminaire and the adjacent ceiling remains. Recessed indirect lighting has all of the disadvantages of direct lighting and none of the advantages of indirect lighting.

To satisfactorily address glare and reflections, designers must specify both the luminance of the luminaire and the luminance of the ceiling for both direct and indirect lighting (Rea 1991). For indirect lighting systems, the undersides of the luminaires should be considered as part of the ceiling.

Sharp edges in the reflected field of view

The visual system is an edge detector. When evaluating the screen quality of a monitor, sharp edges are desirable. Generally, the higher the contrast between the characters and the background, the better. When evaluating what is reflected *off* the screen, however, sharp edges are the enemy.

Abrupt changes in contrast between high and low luminances cause the reflected image to interfere with the screen image. Smooth transitions between higher and lower luminances in the reflected field of view mitigate disturbing screen reflections. The car dashboard example also illustrates the effect of sharp edges. Notice that the most troubling effect is at the edges of the piece of paper.

Sharp edges provide visual interest. Because low light levels with reduced contrast can result in a visually uninteresting, boring environment, interior designers can add interest by using color.

Color rendering

Color rendering is the effect that light has on the colors of objects. Low pressure sodium lamps, popular with used car lots, have poor color rendering. That’s why the black car you bought at night looks purple in the morning. Color rendering affects how office furnishings, clothes, and skin tones appear. Lamps with high color rendering help

compensate for lower ambient light levels because they increase the perception of brightness. Triphosphor lamps have the advantage of high color rendering and reduced operating costs when compared to standard fluorescents.

Task lamps

The lower illuminance levels desired for VDT work are often inadequate for reading and writing. Task lamps can provide higher levels of luminance without interfering with computer viewing. Task lamps with flexible arms allow them to be pointed away from the monitor and the user's eyes. Ideally, task lamps should be dimmable.

Conclusion

The final criteria for judging lighting is the most sensitive light meter available – the human eye. No matter how well a lighting design conforms to a set of quantitative criteria, if the occupants of the office cannot easily see their tasks or are uncomfortable, the design has failed.

Acknowledgement

Much of this article was inspired by Mark Rea's "Solving the Problem of VDT Reflections" (1991). It is perhaps the best article written on the subject to date.

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