ARTIFICIAL LIGHTING DESIGN TECHNIQUES – SUSTAINABILITY BY QUALITY DESIGN

Peter McLean

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- There is a disproportionate emphasis on illuminance as the yardstick of a good lighting design.
- When illuminance is the primary performance criterion the only option for improvement in lighting is to increase the illuminance with a proportional increase in energy usage and greenhouse gas emissions.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- There are four methods to reduce lighting energy consumption:
  – Minimise the quantity of lighting. This has some application where there is over-design or over-illumination however there is usually an associated reduction in visual performance.
  – Minimise the usage of lighting. This usually addresses wasted lighting when the space is unoccupied or when adequate daylight is available.
  – Use higher efficiency light sources and luminaires.
  – Improve the quality of the visual environment so that visual efficiency is improved and therefore visual performance is improved without increasing the average illuminance.
- In practice the solution is to achieve the optimal combination of all four methods.

Cutting EDGe Strategies

- By addressing the factors that dilute the efficiency of vision, namely glare, gloom and poor visual environment the quantum of light becomes less important.
- The recent identification of glare from luminaires immediately above has explained one of the anomalies of current glare theory and assisted in the reduction of fatigue in the office environment.

Synergies and References

- One factor that drives up the energy usage in lighting is the perceived need of project managers, building owners, union representatives or OH&S certifiers to have a quantitative performance criterion that an installation can be assessed against. Illuminance is the only thing that can be simply and reliably measured although it says little about the quality or visual comfort of the space.
- The competitive leasing of office space has encouraged the comparative evaluation of the facilities that various buildings offer. The inference is therefore that a higher average illuminance represents better value for money. In the mid to high end of the office market the cost of the energy consumed by lighting is almost trivial compared with the rental cost and therefore there is little incentive to control energy usage.
- Visual comfort and user satisfaction have better potential as they can relate to the efficiency of work and the retention of staff.
- Lighting: *BDP Environment Design Guide:* GEN 61, TEC 3, TEC 9, TEC 16, DES 6, DES 7, DES 62, PRO 3, PRO 32, CAS 35
- Comfort: *BDP Environment Design Guide:* GEN 15, DES 12

ENVIRONMENT DESIGN GUIDE

ARTIFICIAL LIGHTING DESIGN TECHNIQUES – SUSTAINABILITY BY QUALITY DESIGN

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1.0 INTRODUCTION

'Lighting' is good lighting when it provides adequate illuminance to enable a task to be performed efficiently, is perceived as comfortable, and people have a high level of satisfaction. Good lighting design is not simply about achieving a required illuminance on the working plane; it is about creating and controlling the lit environment.

EDG note DES 7 *Energy Efficient Artificial Lighting* sets out the basic principles for energy efficient lighting.

Energy efficient lighting is not simply the minimising of energy input through higher equipment efficiency, or reducing illuminance levels to the minimum that is tolerable. If user comfort is increased there is less likelihood for people to require increased illuminance levels to compensate for other lighting problems.

The lit environment is made up of a multitude of factors. Even with purely functional lighting installations it is not enough to simply provide adequate illuminance on the horizontal plane. If this is done there is a strong risk of creating a space with adequate illuminance to perform the task, but a visual environment that reduces the ability to see, that is unpleasant to be in and as a result, reduces the visual performance and motivation of the occupant.

Control of the visual environment can assist to maintain user satisfaction without unnecessary increases in illuminance or energy usage.

Good lighting may not necessarily be noticed, but poor lighting is a proven dissatisfier. The occupant usually cannot determine or articulate the specific problems with the lighting beyond complaints of headaches, tiredness and inability to concentrate. In work environments, complaints of insufficient or excessive lighting are often a result of gloom, glare or poor luminance distribution in the immediate field of view, rather than a significant variation from the recommended illuminance.

2.0 CONSIDERATIONS

In creating a visual environment there are many factors that must be taken into account:

- The balancing act in design between multiple requirements which are often conflicting.
- Practical limitations of the performance of the light sources and lighting equipment available.
- Issues of energy efficiency, running costs, maintenance and available funds.

2.1 Colour rendering and colour appearance

Recently it has been shown that although relatively high colour rendering may not be required for the specific task being performed, the visual environment and level of user satisfaction is significantly improved with higher colour rendering sources. Colour rendering is the ability of a light source to render the colours of surfaces accurately and is dependent on the spectral content of the light source. A colour rendering index of 100 theoretically renders all colours accurately. The colour rendering index is simply a rating factor and may not relate to specific colours. The higher the colour rendering index, however, the less chance of colour anomalies.

There is no advantage in a lower colour rendering for general illumination. The only limits are those of efficacy, life and cost that may accompany a high colour rendering source. With current lighting technology there is no justification for lighting any interior with a colour rendering index of less than 80.

With the advent of the tri-phosphor fluorescent lamps there is little relationship between colour temperature and colour rendering. The selection of colour temperature and colour rendering can therefore be made independently.

Changes in the colour appearance of lamps can be used to advantage. When highlighting an object a subtle shift in colour appearance to the cooler temperature can help draw attention, thereby requiring a smaller contrast in luminance.

2.2 The task

2.2.1 Task illuminance

The requirements of a task vary with the function of the space and the location. In industrial situations, tasks may be very specific and the lighting can be tailored to suit. In the case of commercial offices, tasks may be varied in nature and location, and in many instances the task specifications may be more general. In a museum or a retail application the task may be the effective display of an object or product.

2.2.2 Surround luminance

The task is not seen in isolation. Near peripheral and peripheral vision have an effect on the ability to see and concentrate on the task. The treatment of the immediate surround is important to maintain concentration and to reduce fatigue.

If the contrast between the task luminance and surround is too great, the eyes are continually changing their adaptation level and fatigue results. In addition, as the eye tends to be attracted to the brightest part of the field of view, over-bright tasks inhibit the ability to relax, while overbright surrounds make it difficult to concentrate on the task.

Similarly, if the background of a speaker or presenter is too bright, the audience will have difficulty concentrating on their face and will tend to close their eyes for relief – with consequential effects.

Similar distracting effects can be caused in the surround area due to high colour contrast with the task, complex patterns or moving objects in the surround area. It is then difficult to maintain concentration on the task.

The design of task oriented lighting cannot simply be confined to the selection and placement of lights.

In the traditional office work situation, the task was normally horizontal and the surround was the desk. With uniform lighting, a suitable selection of desk reflectance could generally control the surround luminance and as the eyes were directed downwards, there was less impact from bright sources, movement or complex details in the remainder of the office. It is also important that the eyes are able to relax. In the traditional office task, the person could raise their eyes to the horizontal plane and focus at infinity. This would help to relax their eye muscles and reduce fatigue.

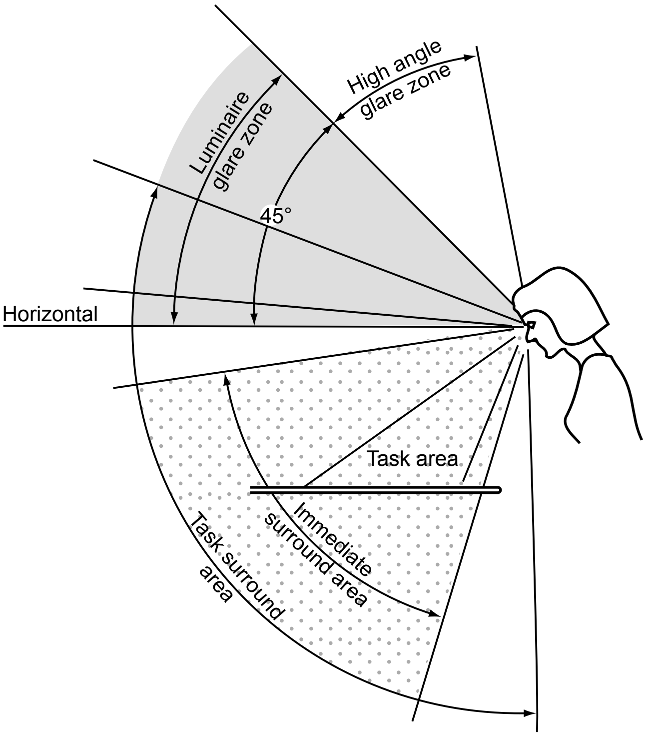

Figure 1. Office work position with a traditional paper based task: Note that the horizontal view and the luminaire glare zone do not coincide with the immediate task surround. The high angle glare zone is not a problem as it is above the top of the head.

Modern offices have largely moved to screen-based tasks. This has moved the task from a horizontal plane to a position closer to the vertical plane and has completely changed the surround environment of the task. The luminaire glare zone and the task surround zone now overlap.

The vertical task brings a whole new set of problems. Although the problems are vision related, they are not necessarily lighting related and the solution must involve the whole visual environment.

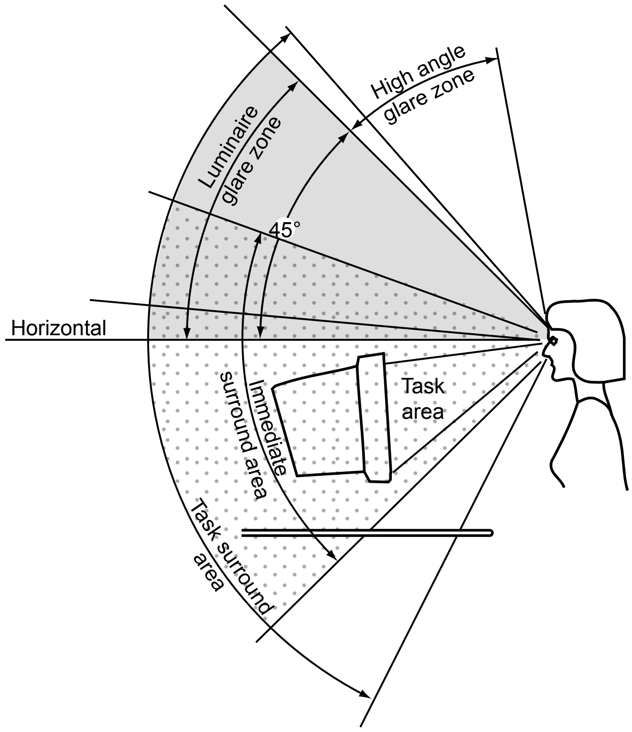

Figure 2. Screen based task: Note that due to the higher elevation of the task the immediate surround area overlaps the horizontal view and the luminaire glare zone. The high angle glare zone is also forward to the head.

With visual display units (VDUs), the surround is not in the same plane as the task and therefore has a different focus distance. It is not necessarily lit with the same lighting as the task. The task is also luminous, while the surround is generally reflective. Depending on the location of the task, the surround can be a blank wall, an outside view, or a view of a large office with people moving around.

The importance of the relationship of the surround will be greater if the VDU is the primary work task such as a word-processor, CAD operator or radar operator as the attention to the VDU is continuous. If the VDU is used for reference as with a bank teller, or a cash register, the eye gets relief with other tasks and the surround is not as important.

A VDU should not be located with an outside view as the surround. Even with low transmission glass, the outside luminance will be too high for the VDU and the variation is uncontrollable.

2.3 Work Stations

The solution to modern office tasks tends to be workstations. These are individual or group enclosures with screens that shield the view of the remainder of the office. This works well to remove the distracting background, but also removes the distant view for relaxation of the eyes. It is important in the design of workstations that the distant view is available in some direction.

The colour, reflectance and illumination of the panel behind the VDU are critical. The panel should be similar luminance to the screen, preferably slightly darker. This can be difficult to achieve because the luminance of the VDU is separately controlled to the luminance of the surround and therefore the reflectivity of the panel may not be sufficient, even if it were white. Many of the luminaires designed to control reflections in VDUs direct the light downwards and therefore restrict the light in the vertical plane. As a result, there is little light available to light the vertical panels. It is therefore difficult to achieve adequate luminance of the panels, irrespective of the reflectance of the panels.

Shelves and hamper units compound the problem by shading the panels and further reducing the luminance.

There is also often a conflicting architectural agenda that affects the selection of the panel colours. Bright colours are often chosen to give some visual interest in the space. This is a very important aspect of the interior; however the panels should not be behind the VDU. Saturated colours generally have lower reflectances than they appear and the colour contrast can be distracting.

Dark panels are sometimes selected as they show the dirt less and tend to look richer. These create an impossible work situation as no amount of supplementary light will compensate for the low reflectance.

Figure 3. The screen on the workstation is far too dark so that the luminance contrast between the screen and the VDU is excessive. Although the back wall is being lit the contrast between the bright and dark sections of wall is too great and the lighting seems to accentuate the darkness rather than making the space look lighter.

The majority of workstation situations that I have been asked to appraise due to complaints of fatigue and headaches have had dark panels behind the VDU. There is no remedy to the problem other than replacing the panels or covering them with large pieces of paper.

Under shelf lighting can be useful in increasing the luminance of the background, but only if the panels have a suitable reflectance.

Some simple guidelines for workstations are:

- The panels behind the VDU should have a reflectance > 50%.
- The panel behind the VDU should not be a strong colour.
- There should be no shelves or hampers above the panel behind the VDU.
- One or more panels should be low enough so that the occupant can look over the top to a distant object or view.
- The lighting in the space should have a reasonable horizontal component.

Figure 4. Light screens and desks on the workstation will give better luminance contrast with VDUs and the general surrounds[1].

2.4 Task and Ambient Lighting

An alternative is to provide a general ambient level which enables people to make their way around the space with supplementary lighting to perform the required tasks. In an office space the normal proposal would be to illuminate the space to 160 lux and use supplementary lighting to bring the task to 320 lux or whatever level is required. If the office lighting is to be based on a 160 lux level it is essential that the vertical surfaces of the room be lit to compensate for the gloom. In many existing offices with windows the illuminance has been installed at levels greater than 500 lux to compensate for the gloom from sky glare. It will usually be necessary to supplement the lighting of the vertical surfaces to compensate for the gloom.

Task lighting that is required for the supplementary lighting should be more than a desk lamp. It should cover the entire workspace and should maintain an appropriate luminance distribution in the surround area of the task.

Under shelf lights are generally inadequate as they do not have adequate coverage of the desk, particularly in front of the VDU, and can produce veiling reflections in the workspace.

Some form of central switching should be considered to avoid the task lighting running 24 hours a day.

2.5 The room

The room is an important part of the visual environment and cannot be isolated from the task. Irrespective of how well the task is lit, people tend to gauge the comfort and adaptation level of the eye from the room. The visual environment is controlled by several factors:

2.5.1 Luminance distribution

The luminance or brightness distribution controls how the space appears to the occupant and the level at which the eye adapts. If the vertical surfaces of the room either have a low reflectance or no light is directed onto them, the room will appear dark and under lit, irrespective of the amount of light on the horizontal plane. In contrast, if the vertical surfaces of the room are bright, the occupant will be satisfied with a lower illuminance in the horizontal plane.

2.5.2 Direction of the light

Downlights and fluorescent lights with parabolic reflectors tend to direct light in a strong downward direction, with little vertical illuminance. This creates strong shadows on the face and high contrast if the background vertical surfaces are not lit.

At the other extreme, if the space is lit with uplighting or other diffuse lighting, there are minimal shadows and the space tends to look bland or flat. In a space with side-lit daylighting, the lighting has a strong sideways direction. The direction tends to move from the horizontal to the vertical as the daylight contribution varies. This is one of the reasons why there is a higher acceptance of the automated integration of daylighting in roof lit installations, as the change from one source to the other is not obvious. With side lit installations there is a continuous shift from vertical to horizontal.

The directionality of lighting can be important in the creation of the atmosphere of the space. Strong directional light tends to make people look more severe and sinister, while diffuse light makes them look softer and more understanding. Directional light tends to add to the formality of a space. The directionality of the design should be consistent with the function of the space.

2.5.3 Visual interest

Visual interest is created in a space by variation in the luminance distribution and colour within the space. It is not achieved with simple lack of uniformity, but by using light to attract the attention of the occupant to the things that you want them to see. Highlighting can be used to reveal the architectural form of a building, to direct or lead people through a space. With visualisation programs, the calculation is simplified. It is important to draw the distinction between deciding in advance how the picture is to be painted for the observer, rather than letting the lighting program produce an image of the space and deciding that "it looks OK".

The fundamental requirement is that the designer achieves the appropriate luminance distribution on the vertical surfaces. Lighting is all about the luminance of vertical surfaces and they will not just happen as a by-product of horizontal illuminance. In the past luminaires had a more diffuse distribution and therefore over-illumination could be the solution to most lighting problems. Today, with the emphasis on the minimisation of energy consumption and better glare control, the designer must address the actual problem.

2.6 Glare

In simplistic terms, glare is any light source either direct or reflected that reduces short term or long term visual performance. It is the equivalent of noise in an audio system.

Glare results from an extremely complex set of interactions between the lighting, both electric and natural, the surroundings and the visual system of the body. Although there is a general understanding of the mechanism of glare and some algorithms for prediction of glare, the prediction of the models often, do not agree with the perception of the occupants.

The fact that glare cannot be reliably calculated does not diminish its detrimental effect on the visual environment, nor its need to be addressed in the design process.

At the same time it is not sufficient in designing a lighting installation to say that, as glare is bad, we should minimise it as much as possible. There have been many disastrous installations predicated on this philosophy. Many attempts to eliminate glare have resulted in bland spaces that lack visual interest, sparkle, and areas for visual relaxation. The end result can be uninteresting and often extremely unpleasant spaces to occupy, even for a short period.

Glare control has to be a balance between maximising visual performance and user satisfaction.

Glare is generally a combination of five things:

1. The brightness of the glare source. This can be a reflected light source as well as a direct one.
2. The brightness of the background. Note that brightness is relative. As the background luminance approaches the luminance of the glare source, the impact of the glare source is diminished.

3. Location. Generally, the closer a glare source is to the direction of view, the greater the impact.
4. The adaptation level of the eye. The eye is capable of seeing an extremely wide range of luminances, but not concurrently. The eye changes its sensitivity to adapt to the ambient luminance distribution. It is not simply the contraction of the pupil, as this is only a short-term phenomenon. The longer term adaptation is achieved by the change in the sensitivity of the receptors in the retina. The speed of adaptation depends on the incremental change in luminance and the current level of adaptation. An example of this phenomenon is driving into a covered carpark from bright sunlight. Initially, the carpark looks very dark, however once your eyes have lowered their adaptation level, vision is returned. Many glare situations arise when the luminance range in the field of view is too great for the eyes to handle concurrently.
5. The relative size of the object is also important.

There are many types of glare. The relative importance of them will depend on the requirements of the lighting task and the environment.

2.6.1 Disability glare

As the name implies, it is glare that has a disabling effect on visual performance. This is generally due to the presence of a light source that is significantly brighter than the rest of the field of view. The result is similar to the effect of the sun in a camera lens. The small amount of scatter in the lens is sufficient to wash out the contrast in the remainder of the image. The extreme case of this is the effect of an oncoming car at night on a country road. For a short period of time the whole visual field goes white, because the scattered light is well above the current adaptation level of the eye. This is followed by a period of total blackness as the eye's sensitivity has risen and is no longer appropriate for the dark environment.

A similar effect is often present in interior lighting. The effect may not be as extreme, as the background luminance is higher. In a mild form, it will scatter light in the eye, effectively reducing the contrast of the field of view and causing the eye to adapt at a higher level than the task requires.

Traditional glare theory predicts that the glare will diminish exponentially with the separation from the direction of view. Although there is general acceptance of this, there have been consistent complaints, particularly from people performing screen-based tasks, of glare from overhead luminaires that are well outside the area that should contribute to glare and often outside what would normally be considered peripheral vision. Recent studies have shown glare effects resulting from light incident on the eye almost perpendicular to the field of view (P. Ngai & P. Boyce, 2000 and P. Boyce et al, 2003). This appears to be due to flaring of the cornea or internal refracting in glasses. This has significant ramifications for much of the common practice for glare control in offices.

Figure 5. The window glare is located directly above the VDU giving a much higher surround luminance than the screen. The decorative lights are also bright small sources that act as distractions and effect the adaptation.

2.6.2 Gloom

Gloom is the phenomena where a space, although having adequate illuminance on the horizontal plane, appears to be under lit. This is generally a result of the bright light sources or areas in the field of view, with the luminance of the other vertical surfaces in the field of view being relatively low. The result is that the eye adapts to a higher level than required. There may also be some contribution from the peripheral flaring referred to above.

The effect of gloom is that people complain of insufficient light and supplement the lighting. As any additional lighting tends to diminish the effect of the glare source, there is a perceived benefit; however, this is just using additional energy to treat the symptoms rather than the cause.

The better solution is to reduce the intensity of the glare source, increase the reflectance of the other vertical surfaces or, if additional lighting is required, use it to specifically light the vertical surfaces, rather than spreading it through the whole space.

2.6.3 Sky glare

The luminance of the Australian sky, whether a clear blue sky, sunlit clouds or even general cloud cover, is generally much higher than the luminance of the surfaces in an interior situation. The relatively large area of the source adds to the glaring impact. The effect of sky glare depends on the angle of view. If you are facing the window from deep in the space then the problem will tend to be disability glare, as objects in the space will be seen in silhouette against the sky, unless illuminated to a similar luminance. If you are facing parallel to the windows, the problem will tend to be gloom, as the luminance of the interior walls will be low, compared to that of the sky. Facing with your back to the window, the room will generally look good, as there will be a high horizontal illuminance and no glare sources.

Sky glare is critical in the design of office spaces in Australia.

In the past, the solution to sky glare was to use relatively low transmission glass and to increase the illuminance in the space. The result was that a typical office might have an illuminance between 500 and 1000 lux, although the Australian Standard recommended 320 lux as adequate. Under the circumstances, 320 lux may have been extremely gloomy and therefore be inadequate for the space. It is again a solution that throws energy at the symptoms, rather than addressing the problem.

To reduce the effects of sky glare, you need to reduce the contrast between the sky and the surrounding surfaces and increase the general level of adaptation in the space.

The reduction of the contrast can be achieved by reducing the luminance of the sky, and/or increasing the luminance of the surround. It is normally not possible to get adequate reduction in contrast using one of these by itself. The sky luminance can be lessened by reducing the transmission of the glass. Low transmission glass has been used in the past to reduce the heat load of air-conditioning and also reduce sky glare. The introduction of low-e glass has meant that air-conditioning designers can reduce the thermal gain of a building with a higher light transmission of the glass.

The reduction in the contrast can be assisted by increasing the reflectance of the ceiling and the walls surrounding the windows. The geometry should also be arranged to ensure that light entering the windows falls on these surfaces. If necessary, dedicated lighting should be installed to light these surfaces. The other walls in the room are also important as these are the walls that the eye uses to select its adaptation level. These walls should either have a high reflectance, or should be specifically illuminated to increase their luminance.

Figure 6. A light shelf and sloping ceiling are used to reduce the contrast between the ceiling and the glazing thereby allowing more daylight to enter the space without creating gloom. The end wall is lit to increase the luminance of the wall. The glass below the shelf is tinted to reduce the sky glare while the upper section of glass is clear to maximise the daylight[1].

If the sky glare cannot be compensated for in this manner, then the overall illuminance may need to be increased.

If the room is to be used in daylight, it is critical that the sky glare gloom be addressed in the design. Otherwise, irrespective of the adequacy of the illuminance, people will turn lights on to compensate. It is better to isolate the lighting of the vertical surfaces from the daylight control, to minimise the gloom.

2.6.4 Veiling reflections

Veiling reflections are related to glare; however in this case, the dilution of the contrast occurs externally to the visual system. A veiling reflection occurs when a reflection of the light source can be seen in the surface of the task. This typically occurs when trying to read an object with a gloss surface. This can be much brighter than the luminance of the image to be read. The result is that the image of the light source dilutes the contrast of the image to be read.

A related effect occurs if the surrounding surfaces have a specular character. This might be a glass topped desk or a stainless steel table top. In this case, the image of the light source is seen in the area immediately adjacent to the task and acts as a glare source raising the luminance of the immediate surround to an unacceptable level.

Screen-based tasks

Veiling reflections also occur in screen based media.

The veiling reflections are a combination of the geometry of the luminaire locations with respect to the task, the viewing angle of the task, the luminance of the luminaire at the specific angle of reflection and the reflection characteristics of the task surface. The complication in designing lighting for an office, industrial or educational facility is that the screen-based task is almost perpendicular to a paper-based task and what works for one does not necessarily work for the other.

When visual display units first became part of the workplace they had highly specular screens and poor resolution, light coloured letters on a dark background. The effect was that any reflection in the screen obliterated the information at that point and operators had to move their head to see the complete story.

Much as changed since then. There have been enormous advances in screen-based tasks. The surfaces of the screens are more diffuse and the images on the screen have white backgrounds, brighter colours, higher overall brightness, higher resolution and much higher refresh rates on the image.

There have been significant work practice changes. Screen-based tasks have become part of normal workplace tools rather than process work.

In addition to the physical changes, there has been a shift in the expectations of users. People appear willing to accept some low level reflections in screens in exchange for contact with the outside environment and a visually comfortable and stimulating environment.

Unfortunately, many of the standards and guidelines for interior lighting still have hangovers from these dark ages. There are still complaints about lighting problems associated with screen-based tasks, but they tend to relate to peripheral vision glare from the luminaires directly above, poor placement of screens with respect to windows and poor design of the visual environment (see Figure 5). It seems ironic that in recent times, I have not been asked to investigate lighting problems with visual display units in a normal office space. All the problem areas have either had high-sided, dark workstations, or lighting installations that have been specifically designed for visual displays.

2.6.5 Discomfort glare

This is glare that causes discomfort and fatigue, without necessarily causing disability. Whereas disability glare has an instantaneous effect through the loss of contrast of inappropriate adaptation, discomfort glare can be less obvious and the effects can present themselves as headaches, fatigue, or the inability to concentrate on the task. There is considerable overlap between disability glare and discomfort glare.

Discomfort glare tends to be caused by bright sources or areas that are noticeable but not necessarily intense enough to be disabling. The effect of these sources is to distract the attention of the person and to cause continuous re-adaptation and refocussing of the eyes. The effect may be subliminal but the long term result is fatigue, dissatisfaction and a loss of performance. This involuntary action of the eye to continually investigate the brightest object in the field of view is called the phototropic reflex.

Discomfort glare can be caused by luminaires, the sky, back lit signs or displays or even surfaces that are too close to luminaires and therefore over illuminated.

Figure 7. Low brightness luminaires mounted too close to the wall give surface brightness that is much higher than the luminaire.

2.6.6 Glare Control

Glare control is a balance between control of the various types of glare and the need for visual interest and sparkle.

Although glare can be detrimental to visual comfort, attempts to completely eliminate a particular type of glare or to minimise all sources of glare result in uncomfortable, bland and often quite oppressive spaces. My experience is that people are willing to accept a reasonable amount of glare in exchange for a visually comfortable and stimulating space, however, when the visual stimuli are removed the occupants become less tolerant of the glare.

Glare control is not simply a function of the luminaire design – it is a function of the visual environment. It therefore cannot simply be solved by the selection of an appropriate luminaire; however the luminaire selection can have an important effect on the glare within a space.

3.0 LIGHTING CALCULATION METHODS

Lighting calculation methods fall into three broad categories:

- Manual calculation
- Computer based calculation
- Visualisation

3.1 Manual calculation methods

There are a wide range of manual computation methods for the calculation of different lighting aspects. The majority of these have now been superseded by computer programs.

The Lumen Method was the mainstay for interior lighting and has remained in use as a quick and relatively accurate method of calculating interior illuminance. The Lumen Method calculates the average illuminance at a specific level in the space, including an allowance for the light reflected from the interior surfaces of the room. The calculation method has a set of assumptions that, if followed, gives a reasonable visual environment.

The basic assumptions are:

- All the luminaires in the room are the same and the same orientation.
- The luminaires do not have a directional distribution and are aimed directly to the floor.
- The luminaires are arranged in a uniform array on the ceiling and have the same mounting height.
- The luminaires are spaced less than the maximum spacing to mounting height ratio nominated in the coefficient of utilisation tables.

3.2 Computer based calculation methods

In contrast to the Lumen Method, lighting programs now enable the lighting designer to broaden their scope:

- A mixture of luminaires can be used.
- The luminaires no longer have to be arranged in a regular array.
- Directional luminaires can be modelled.
- A large number of calculation points can be considered to give a meaningful uniformity calculation.
- Most programs can now provide some level of visualisation of the lighting solution.

Computer modelling enables the illuminance and luminance of all surfaces to be calculated, increasing the information available to the designer.

Research, experience and documentation over the past 80 years has developed the current thinking as to the adequacy of various illuminance levels for a range of tasks and functions. The usefulness of the new information is limited as there is some general understanding of the need for appropriate luminance distribution in the vertical plane, but there is little information, experience or understanding for many designers to determine:

- What the luminance of surfaces should be in varying situations?
- What is acceptable luminance uniformity?
- Whether there should there be maximum luminance uniformity?
- What is the desired graduation in luminance?
- At what point does the luminance distribution of the wall become unacceptable?

It is important in using a lighting calculation program that the output records the following information:

- The type of luminaire used
- The location of the luminaries
- The assumed lumen output of the lamp
- The light loss factor
- The aiming points.

If this is not recorded, you may have a visual image of what the installation may look like, but there is no way of making it a reality.

An output in the form shown in Figure 8 may be more useful to the designer compared with that shown in Figure 10, although Figure 10 may be more useful in communicating the lighting concept to others.

3.3 Visualisation

These are programs that create a perspective rendering of the space in levels of detail that vary from a block representation of the space, to photographic quality renderings, depending on the sophistication of the program and the level of detail of the interior to be entered. The programs fall into two basic types: flux transfer and ray tracing calculations.

Flux transfer programs assume all the surfaces are diffuse while ray tracing programs model reflective or specular surfaces as well.

A real life surface is a combination of both surfaces (semi-specular), with some materials being more reflective than others.

A flux transfer program rendering tends to appear flat with soft shadow details (Figures 9 and 10). When ray tracing is added, reflections are added in polished surfaces and shadows become sharper (Figure 11).

Visualisation programs are a useful tool in the presentation of a design: as a tool for the designer to check that the design is consistent with their own visualisation of the space; and to model specific lighting solutions. The programs are still calculation tools and not design programs. They can show the designer how a specific design will perform but they cannot reliably be used to assess the acceptability of a design for the following reasons:

- The programs cannot be used to visually assess the adequacy of illuminance, as the programs tend to use an automatic exposure correction to ensure that the image is viewable. As a result, installations with totally different illuminance levels will look the same as long as the luminance distribution is proportional. If the program provides numeric information in the form of distribution and uniformity of luminance and illuminance, then the competent designer can determine the adequacy of the design.
- The luminance range of the presentation medium is much lower than in real life. A VDU has a luminance range of approximately 100:1. For printed outputs a figure of 70:1 is probably more realistic. In a lighting installation the luminance range might exceed 15,000:1. As a result, the program either compresses the luminance range, or maintains a linear relationship through the range of the screen and displays other luminances as white or black. The result is that visualisation programs can make installations with significant glare problems, appear otherwise.

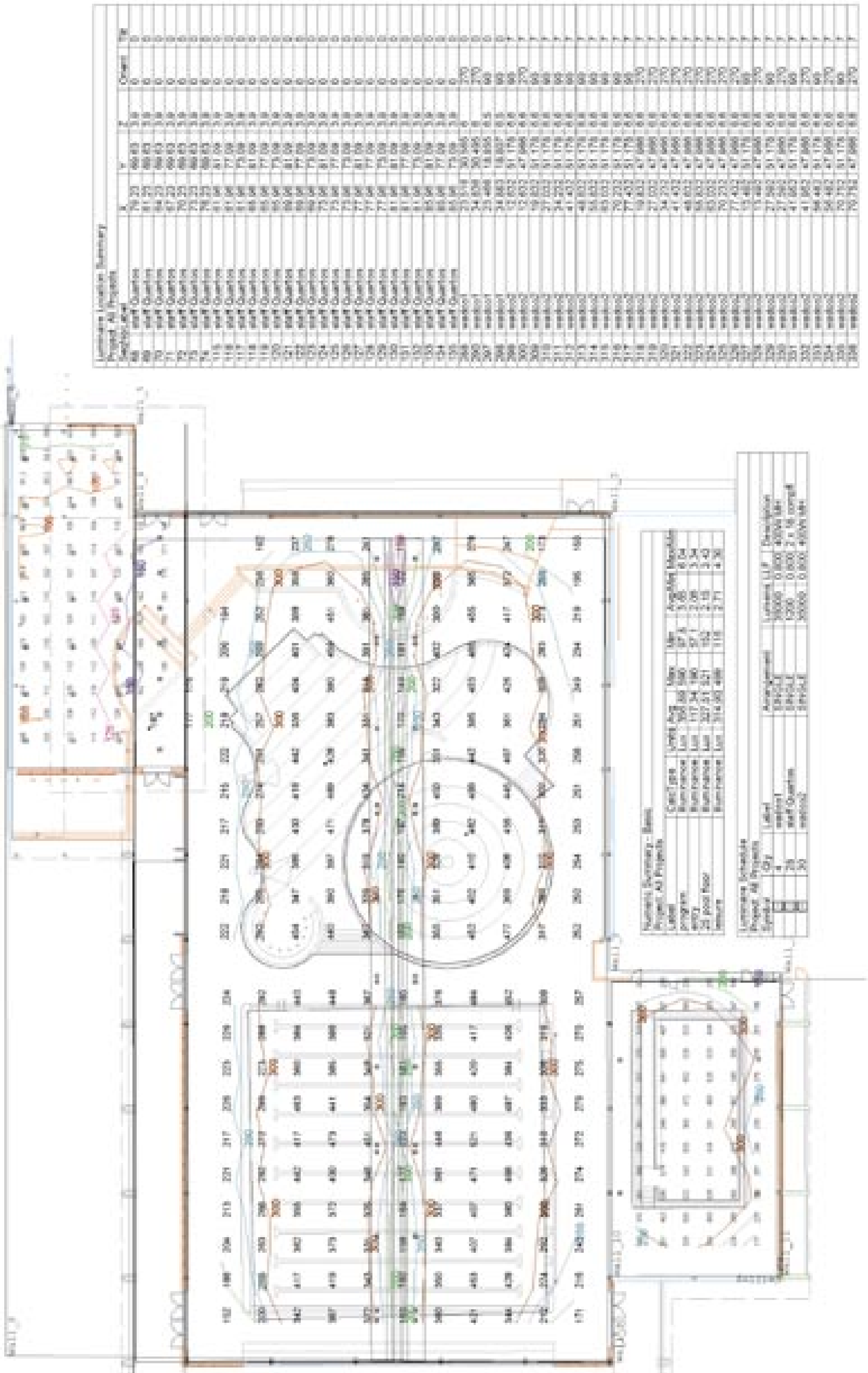

Figure 8. Good calculation programs also give a representation of the light technical parameters of the solution.

- The eye has a relatively small portion of the field of view that sees detail and has full colour perception. This is called foveal vision. When looking at an image on the screen, or as a picture, a much larger portion of the picture is in the foveal vision, than would be in the real space. The relative importance of brightness, size and position of surfaces and objects is lost.
- The phototropic reflex does not appear to apply when viewing an image so that there is no concept of discomfort glare resulting from the distraction and readaptation of the eye.

Figure 9. A detailed rendering from a flux transfer program. Note that although the view is detailed the shadows are soft and there are no reflections in the shiny surfaces[2].

4.0 TOLERANCES AND ACCURACY IN LIGHTING DESIGN

Lighting design has inherent uncertainty in its accuracy due to the uncertainty in photometric measurement, manufacturing tolerance and assumptions made in the calculation methods. AS/NZS 3827 details these sources of uncertainties. The result is that the uncertainty in a design may be greater than ±30%. If a lighting designer is therefore to guarantee a level of 320 lux, the design level must be 450 lux. As the uncertainty still applies at this design level the illuminance will be greater than 320 lux but may also be as high as 585 lux. This approach may be acceptable for a structure, but in lighting it results in over-illumination and wasted energy.

Whilst the uncertainty in lighting design is a fact of life and the ±30% may even be low in some circumstances, this should not be viewed in isolation.

AS1680.1 *Interior lighting* recommends an illuminance scale for various difficulties of task based on a preferred scale of 200% increments. This is based on 200% being close to the minimum variation that can be perceived. The perceivable level below 320 lux is 160 lux. It is therefore questionable to force the design luminance up from 320 lux to 450 lux to avoid any shortfall in the recommended illuminance of 320 lux. A reduction

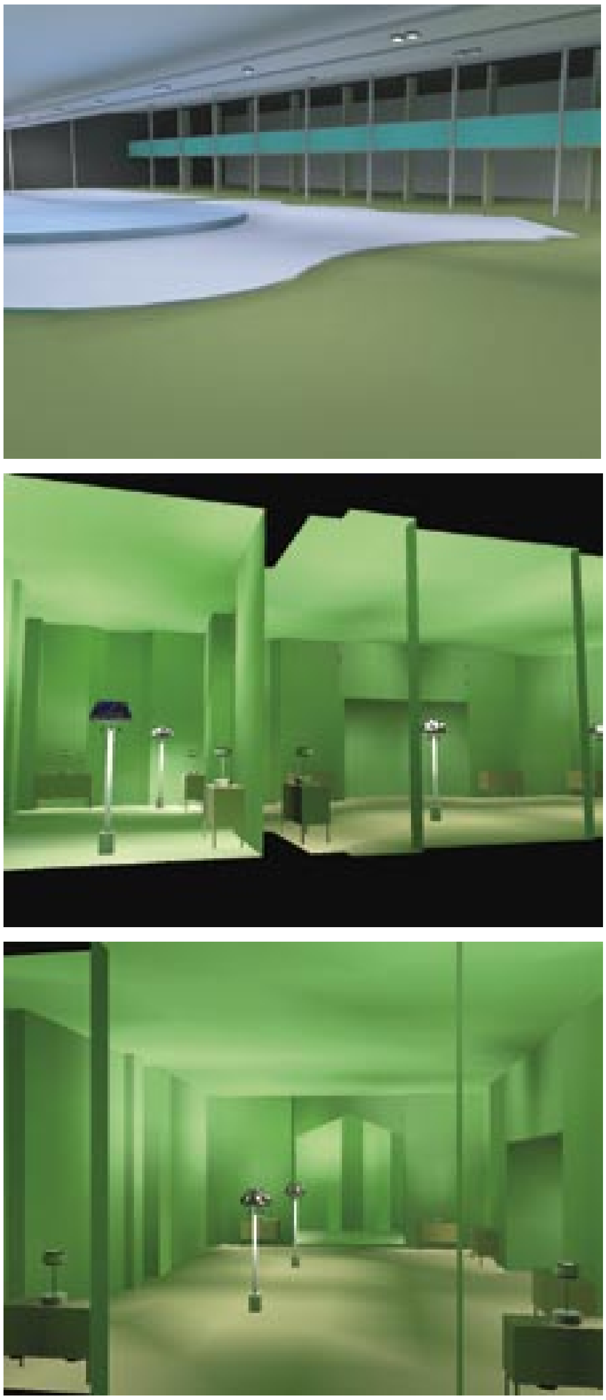

Figure 10. Normal renderings are generally only produced in sufficient detail to give the designer an understanding of what is happening in the space.

in illuminance of 10% would be imperceptible to the user and have little negligible effect on the visual performance. A shortfall in illuminance of 10, 20 or even 30% would probably have less effect on the visual performance than the creation of an unpleasant visual environment. This should be recognised in the acceptance criteria of lighting installations and the risk of the uncertainty in design shared between the designer and the client. I believe a reasonable allowance for design uncertainty should be 10% provided that the design is carried out in good faith. It would mean that there would be installations that failed to meet the recommended illuminance, but provided the quality aspects of the lighting have been addressed there would be virtually no disadvantage. On the contrary the result would avoid inherent over-illumination of installations as a safety margin with the resulting greater expense arising from more equipment and greater energy usage, unless yet more equipment is installed to dim the installation to trim back the design tolerance allowance. It must be remembered that the uncertainty of the measurement in the field will be greater than 10%.

Unfortunately because illuminance can be measured and visual comfort cannot there is a tendency to use illuminance as the acceptance criteria for a lighting design. This approach gives far too much status to the illuminance and encourages over-design at the expense of quality design.

Figure 11. Example of a rendering generated by a visualisation program. Note the sharp shadows and the reflections in the shiny surfaces[3].

5.0 CONCLUSION

Irrespective of whether you are designing a lobby or dining room for a 6-star hotel, an office, or an industrial facility, lighting design must be a holistic approach that not only provides illumination but creates a comfortable, stimulating and interesting environment.

There is far too much attention to the importance of achieving 320 lux, with the implication, and unfortunately often the reality, that 319 lux is considered a failure.

The achievement of the required illuminance will not guarantee a satisfactory lighting installation, and over-illumination will not necessarily act as a safety margin.

Although there is a requirement that there be adequate illuminance to perform a task, some variation in the level is generally not going to make a significant change to the level of visual performance. Other aspects such as glare, contrast, and user satisfaction will have greater effects than small changes in illuminance.

If the quality aspects of the space are addressed, that is:

- correct luminance distribution on the vertical surfaces;
- rational glare control;
- careful treatment of the task surround luminance;
- colour rendering; and
- visual interest,

then the relative importance of illuminance will reduce to its correct relationship.

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Biography

Peter McLean, BEng, M Bdg Sc, FIEAust, FIES Aust & NZ, is the principal of Lighting, Art + Science, a specialist lighting and electrical engineering practice in Sydney. He has 30 years experience in the design of a wide range of internal and external spaces including corporate office spaces, museums, exhibitions and urban landscapes as well as general office and workspace lighting. Recent projects include Campus MLC at North Sydney, the external lighting for Fox Family Entertainment Precinct and the Qantas First Class lounge in Singapore.