

# BEST PRACTICES IN LIGHTING PROGRAM 2004

Publication Series

## 4. Electric Lighting – Design Techniques

*Peter McLean*

## ELECTRIC LIGHTING – DESIGN TECHNIQUES

### Peter McLean

What is the purpose of electric lighting?

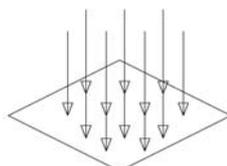
- To extend the useful hours in the day
- To assist the performance of a visual task
- To display or reveal something
- To control how something appears
- To attract attention

All of these elements are present in a good lighting design, but the relative importance of each will vary according to the nature and purpose of the space being illuminated. The selection of the lighting equipment is not the lighting design; it is simply the selection of the tools to achieve the design. Too often, selection of the luminaires is the first stage of the process and the lighting design is never done.

“Lighting” is good lighting when it provides adequate illuminance to enable the 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.

Standards often specify lighting in terms of the illumination on the horizontal plane, which is the amount of light falling onto a horizontal surface. (ref Figure 1) This is because it is easy to measure and easy to calculate. It is not a good indicator of the visual environment however, as people generally judge the adequacy of the lighting by the luminance or relative brightness of the vertical surfaces.

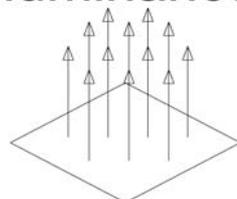
### illuminance



**Figure 1. Illuminance: a measure of the light falling on a surface**

The luminance is the amount of light that leaves a surface, either by transmission through the material or, more commonly, reflection from the surface. (ref Figure 2) In simple terms, the luminance is the product of the illuminance and the reflectance of the surface divided by  $\pi$ . The eye sees luminance rather than illuminance. Therefore with the same illumination, by changing the surface reflectance, the luminance of the surface changes proportionally.

### luminance



**Figure 2. Luminance is a measure of the light leaving a surface.**

The terms luminance and brightness have similar meanings but are not interchangeable. Luminance is a physical measurement of the amount of light that is leaving the surface. Brightness on the other hand is relative and is often closer related to the visual perception of the space. A surface with a specific luminance can look brighter depending on the relative luminance of the surrounding surfaces.

The lit environment is made up of a multitude of factors. Even with purely functional lighting installations it is not adequate to simply provide adequate illuminance on the horizontal plane. If this is done there is the 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 motivation of the occupant.

In most cases the lighting does not need to be a feature, but good lighting design can control the environment in a subtle manner, without it being obvious to the occupant that what they are seeing is being controlled. 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. In extreme cases poor control of the visual environment can even trigger aggressive behaviour.

Interior and exterior lighting are very different in nature and as a result there is little commonality in the design requirements. With external lighting, the contrast ratios are much higher, as you are generally dealing with a black background. As a result the glare from luminaires will be greater and the shadows from obstructions sharper and deeper. For this reason these comments have been confined to interior lighting. External lighting should be the subject of a separate paper

## Considerations

In creating a visual environment there are many factors that must be taken into account. The design is a balancing act between multiple requirements which are often conflicting. To this is added the practical limitations of the performance of the light sources and lighting equipment available, energy efficiency, running costs, maintenance and available funds.

At this stage, we will only consider the aspects that relate to the quality of the visual environment and not the practicalities of lighting equipment.

## Light Sources

Colour Rendering – This is the accuracy with which a light source reveals colours. The common method of measuring the colour rendering is the Colour Rendering Index (CRI). The method has some limitations, but is a reasonable indication of the performance of various light sources. It used to be considered that an average colour rendering was acceptable for normal environments and higher colour rendering was only required in areas where specific colour rendering was required. In recent times 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. This is probably due to the better rendering of skin tones and the general increase in colourfulness of the space.

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 the user comfort is increased, then there is less likelihood for people to require increased illuminance levels to compensate for other lighting problems. There is no advantage in a lower colour rendering for general illumination. Ideally all installations would have colour rendering indices of 100. The only

limits are those of efficacy, life and cost that may accompany a high colour rendering source. On that basis, with current lighting technology, I believe there is little justification for lighting any interior with a colour rendering index of less than 80.

The majority of relatively high colour rendering light sources, in common usage, are tri-phosphor fluorescent and metal halide. These do not have uniform spectral outputs. As a result, although the light produced is white, there is a significant variation in the intensity of different wavelengths. As a result if a surface is relying on a particular wavelength of light for its colour and it is not present in sufficient quantity in the light source, the colour will appear different under that light. It is always important, where colour appearance of an interior is critical, that the actual samples be viewed under the proposed light source. In particular where two different materials have the same colour such as paint and fabric or laminate, it is possible that they may appear the same colour under one light source and different under another. In an installation I evaluated some time ago it was obvious. The carpet was a large stripe of blue and purple. The rooms were lit with fluorescent and the carpet pattern was strong. In the corridor space a discharge source, that was deficient in red, was used and the stripes vanished.

Colour Appearance – This is the colour that the light source appears. It is not directly related to its colour rendering. The colour of lamps is generally specified as the Correlated Colour Temperature (CCT), which is the temperature of an equivalent black body radiator expressed in degrees Kelvin. For many years there was believed to be a relationship between user satisfaction, the colour appearance of the lamp and the average illuminance of the space. Experiments conducted by Kruithof<sub>1</sub> at Philips established a preference for lower correlated colour temperatures at lower illuminance levels and higher correlated colour temperatures at higher illuminance levels. The fluorescent lamps available at that time had relatively poor colour rendering and varied from colour to colour.

More recent studies have shown that there is a higher correlation with the colour rendering and visual interest in the space, than with the colour of the light source.

With the older, less efficient, halo-phosphor lamps the higher colour temperature, or “daylight” lamp had a higher colour rendering index than the warm white lamps. Some of the older design guides for specific tasks required daylight lamps, not due the specific colour requirement, but due to the higher colour rendering. As a result there is still some folklore related to the need for daylight lamps for specific applications. With the advent of the tri-phosphor fluorescent lamps there is little correlation between colour temperature and colour rendering. The selection of colour temperature and colour rendering can therefore be made independently.

There are several reasons for selecting a particular colour of lamp.

Atmosphere – incandescent lamps have traditionally been used in homes and hotels. As a result the warmth and reddish appearance tends to be associated with comfort and relaxation. In these types of installations and areas where people are to be encouraged to relax, a lamp with a colour temperature of 2700K to 3000K would be preferable. As low colour temperature lamps give an atmosphere of warmth, they are often preferred for cooler climates. In areas that are hot or humid and not air conditioned, moving to a cooler lamp, around 4000K or higher, can reduce the oppressive feeling.

Colour Scheme – irrespective of the colour rendering of the lamps, the correlated colour temperature needs to be co-ordinated with the colour scheme of the room. In many colour schemes it has little effect, however where warm lamps are used with a cool colour scheme or vice versa, the general feeling of space can be incongruous. It can be a particular problem where mid greys are used, as the spectral difference between a warm grey and a cool grey can be slight.

Matching with other sources – There is a general preference to match the colour of light sources throughout an installation, as significant variations in the colour appearance draws attention to the light fittings. Some people propose that spaces that have significant daylight should be

illuminated with lamps that have a colour consistent with daylight, around 5600K. My experience is that the eye and brain appear to be more tolerant of daylight related factors and can generally accept a light source as low as 3000K in daylight conditions. This is partially due to the daylight overpowering the colour of the electric lighting. In contrast however, if a very cold daylight lamp is used, the space appears cold and harsh at night.

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. Also, a reduction in colour temperature when moving from a work area to a relaxation area can increase the contrast in the atmospheres and reinforce the change in role.

In practice, care needs to be exercised when mixing lamp colours in an installation. Unless either the lamp's type or wattage is changed with the colour, or there is a stringent maintenance procedure, the effect will be lost as either the lamps will all be re-lamped with the same colour, or there will be a random assortment of lamp colours throughout the installation.

## **Flicker**

All fluorescent and high pressure discharge lamps flicker at twice the supply frequency. The intensity of the flicker depends on the rate of decay of the light output of the lamp. Most lamps flicker at 100Hz. Although the brain filters out high frequency flicker the eye still sees it and there is some evidence that the presence of flicker can cause fatigue in some people. Where there is significant daylight contribution the effect of the flicker is less. Spreading the circuits over different phases increases the flicker rate by 3 but flicker is usually a problem in the peripheral vision and as a result, if the offending flicker is due to a single fitting in the peripheral vision or the reflection of a fitting in a gloss surface, the phasing has no effect. The use of high frequency control gear increases the frequency to around 30kHz and effectively removed any perception of flicker and has been shown to increase user satisfaction.

## **The Task**

### **Task Illuminance**

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

### **Surround luminance**

The task is not seen in isolation. The 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 in maintaining concentration and the reduction of fatigue.

If the contrast between the task and the surround luminance 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.

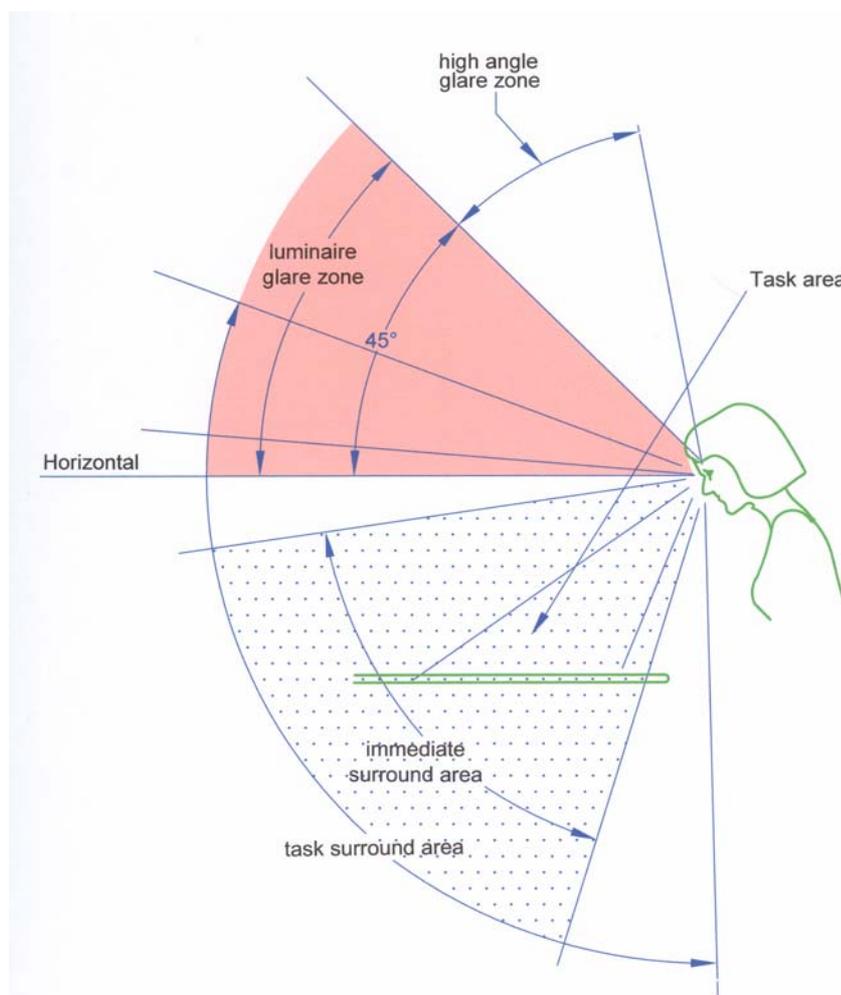
Similarly, if the background of a speaker or presenter is too bright, the audience will have difficulty concentrating on their face and will tend close their eyes to relieve their eyes - with consequential effects.

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

task. The design should also avoid moving objects in the surround area, as the eye is attracted to movement and it is difficult to concentrate 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 source, 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.



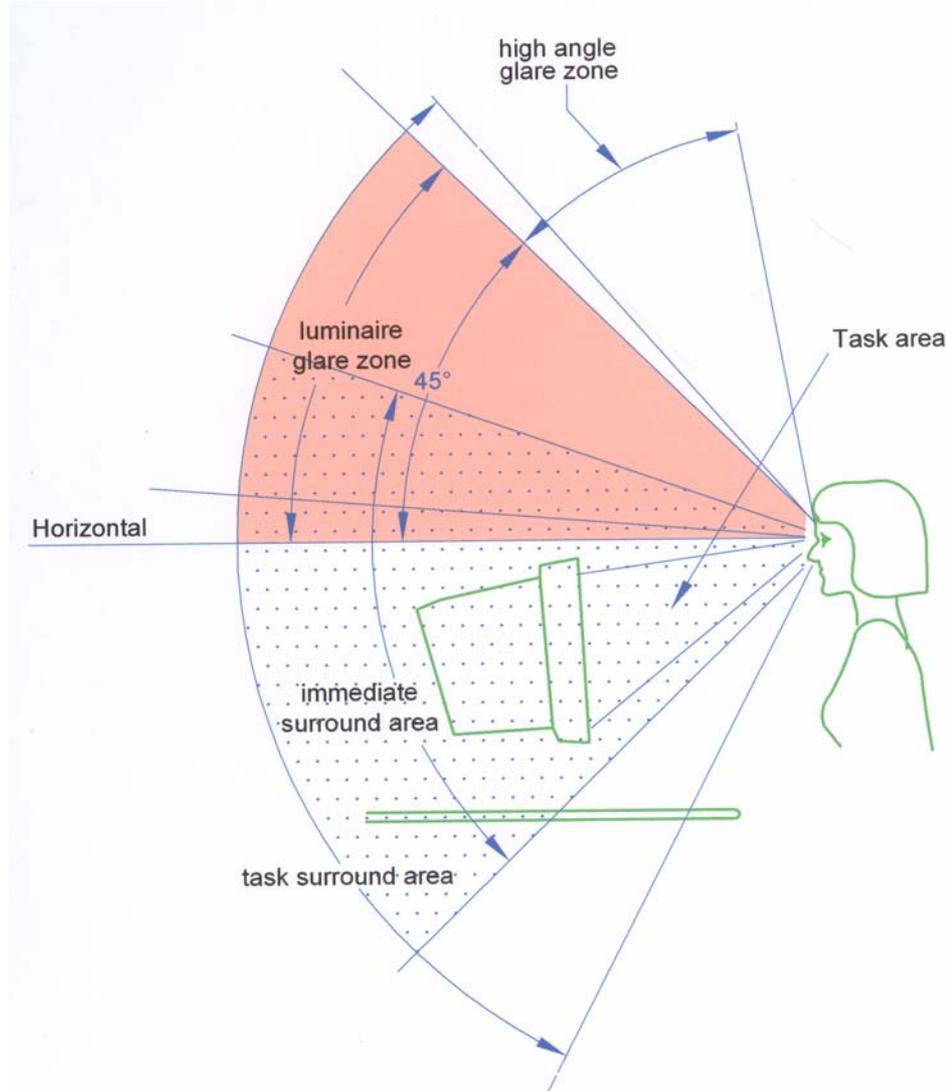
**Figure 3. Office work position with a traditional paper based task**

(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 (ref Figure 3) to a position closer to the vertical plane (ref Figure 4). This has completely changed the surround environment of the task.

Vertical tasks have always existed in industrial situations, however they are generally more likely to be fixed in their location and viewing position and can be solved by specialised lighting treatment.

In the office situation 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 4 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.

Although the eye seems to be more tolerant of changes in illuminance and brightness resulting from daylight, 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.

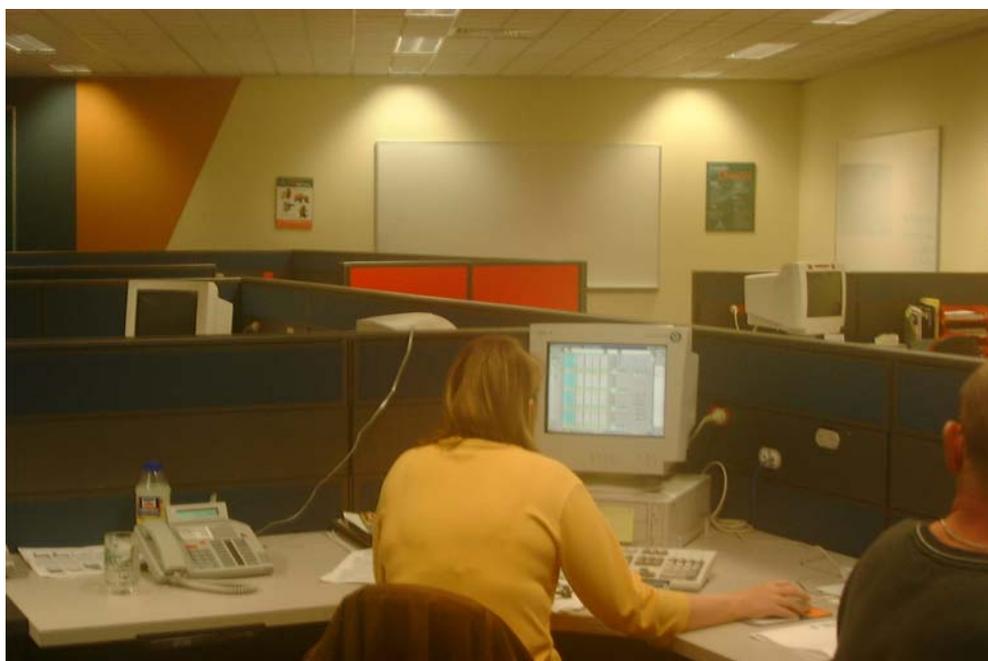
## Work Stations

The solution to modern office tasks had tended 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 directly 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, 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 (ref Figure 5).



**Figure 5. The screen on the workstation is far too dark so that the luminance contrast between the screen and the VDU is excessive.**

(Note that 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 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 6 shows a typical space that demonstrates these requirements.



**Figure 6. Light screens and desks on the workstation will give better luminance contrast with VDUs and the general surrounds<sub>2</sub>**

### **Task and Ambient Lighting**

One of the more recent approaches to energy responsible lighting 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 with 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

illumination 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. It is unlikely that this can be achieved with a single task light unless it is specially designed for the purpose and mounted at sufficient height to allow full coverage of the task and surround.

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.

## **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:

### **Luminance Distribution**

The luminance 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.

### **Direction of the light**

The direction of the light can have an important impact on the atmosphere of the space.

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.

In some instances, it can have a significant impact on the function of the space. For example, if strong directional lighting is used in a court room, the accused may tend to look sinister and more aggressive. This may effect the decision of the jury. In a board room, directional lighting may make people look more aggressive and may reduce the likelihood of agreement. In a lecture situation, a slight increase in the directionality of the lighting can increase the authority of the lecturer.

In contrast a consultation room, hospital waiting room or recovery room may have some advantage from diffuse lighting as it will be blander.

It is not necessary to provide directional lighting for the whole space. A few well-directed spotlights can produce the required directional lighting, while keeping the rest of the room softer.

## 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. The eye is naturally attracted to the brightest thing in the field of view. This is used effectively in advertising, where signage and product are excessively lit to attract attention. Similarly highlighting can be used to reveal the architectural form of a building, to direct or lead people through a space. Waldram<sup>3</sup> originally conceived the idea “Lighting by Designed Appearance”. This philosophy was used to light the interior of several British cathedrals and the exterior of the Sydney Opera House. The concept was that the designer took a picture or perspective drawings of the field of view and allocated relative luminances or brightness to each of the surfaces. The lighting was then designed to achieve those luminances. In the 1940’s, this involved a significant amount of hand calculation. Today, 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”.

Regardless of the process used to calculate the lighting design, 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. The application of design appearance does not only have to apply to prestige buildings - in more humble ways, it affects the way people react to every building. There is a function of the eye called the phototropic reflex. In simple terms, it is a tendency for the eye to seek out the brightest thing in the field of view. This is a fundamental tool in the creation of visual interest and the controlling of the occupants perception of the space by the lighting designer.

A few elementary principles:

- If you want people to move through a space into another space, light the vertical surfaces of the space or at least the entry higher than the space they are in. Their attention will be attracted to it.
- If you want people to stay in a space, highlight the walls within the space and downplay any adjacent areas.
- If you want a space to look higher, light the ceiling.
- If you want a space to look deeper, light the back wall and run the lights in rows along the length of the room
- If you want the space to look shallower light the side walls and run the lights across the room or randomly in the space them.
- If you want the space to look smaller it is better to highlight a few discrete objects whereas if you want the space to look larger it is better to uniformly light the walls.

## 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 visual comfort. By visual comfort I mean the user satisfaction, rather than a calculated criterion that models some of the glare in the space.

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.

### **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. Figure 7 shows how poor placement of tasks in relation to windows can increase the disability glare.

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<sup>4,5</sup>. This appears to be 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 7. 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**

### **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 affect 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.

### **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, particularly those with single sided, lit windows. If the space is correctly designed to utilise daylight, many of the problems will be addressed in the building design, however many buildings have the windows purely for contact with the outside environment and there is no real attempt to manage the daylight contribution to the lighting.

There is little point in using luminaires with high levels of glare control, if there is insufficient control of the sky glare.

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.



**Figure 8. A light shelf and sloping ceiling is 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 has tinted glass to reduce the sky glare while the upper section of glass is clear to maximise the daylight<sub>6</sub>**

The reduction of the contrast can be achieved by reducing the luminance of the sky, or increasing the luminance of the surround. It is normally not possible to get adequate reduction in contrast by one of these by itself. The sky luminance can be reduced by reducing the transmission of the glass. Low transmission glass has been used in the past to reduce the heat load of the air-conditioning and also reduce the sky glare. The introduction of low “E” glass has meant that the air-conditioning designer can reduce the thermal gain of the 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. A light shelf, as shown in Figure 8, can also be used to reduce the illuminance inside the windows and improve the uniformity within the space.

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 utilised 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.

## 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.

The luminance of a diffuse reflector is the product of the illuminance and the reflectance of the material divided by  $\pi$ . The contrast between the letters and the background is achieved by the differing reflectance of the text and the background. With a reflection in the gloss surface, you see a reflected image of the light source and the luminance of that image is the luminance of the source multiplied by the specular reflectance. 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 surround 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. This gave rise to a period where a primary design criterion was the exclusion of reflections in screens. The result was a series of extreme installations that excluded daylight, used sharp cutoff luminaires and had dark vertical surfaces. All the other principals of good lighting were ignored to avoid reflections. The results were extremely unpleasant work environments.

Much has 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 the normal workplace tools rather than process work.

In addition to the physical changes, 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. (Fig. 5) It seems ironical that in recent times, I have not been asked to investigate lighting problems with

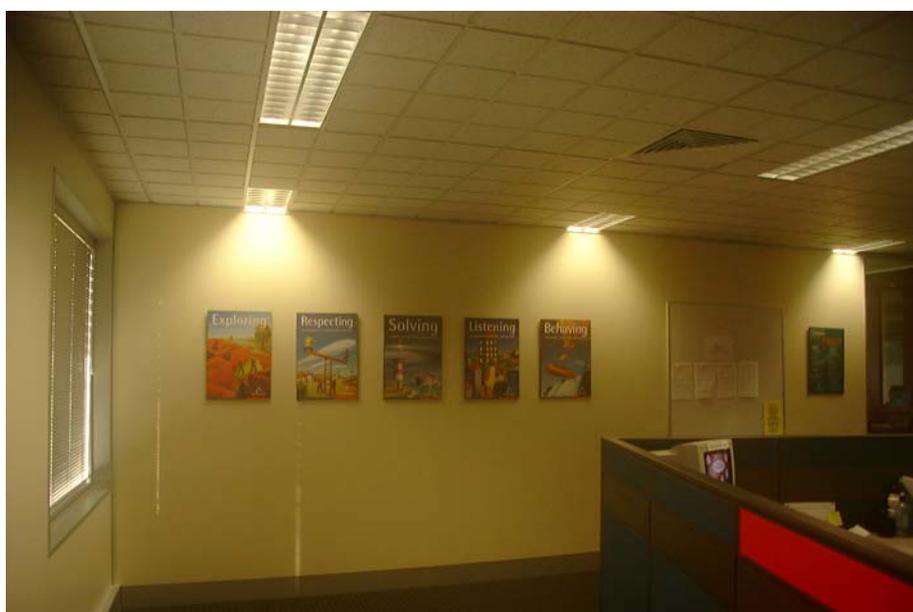
visual display units in a normal office space. All the problem areas have either had high sided, dark workstations, or lighting installations that have been specifically designed for visual displays.

### 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 glare 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.

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 (ref. Figure 9).



**Figure 9. Low brightness luminaires mounted too close to the wall give surface brightness that is much higher than the luminaire**

### Glare Control

Glare control is a balance between the 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.

Modern, high efficacy light sources such as T5 linear fluorescent, compact fluorescent and metal halide are tending towards higher lumen output in smaller source sizes. The smaller size enables higher luminaire efficiency, but a by product is an increase in the luminance of the surface. As a result, shielding of the lamp is more critical and veiling reflections are more intense.

The design of the luminaire should direct the light in a usable direction while limiting the luminance of the luminaire at angles that will contribute to the glare. The actual glare that results is a relationship between the luminaire and the background, generally the ceiling.

The selection of the luminaire type not only affects the glare but also the appearance of the space and the energy efficiency.

There are several lighting options available.

### **Uplighting –**

Provided there is an adequate ceiling height so that the fittings can be above eye level and be far enough from the ceiling to prevent bright spots, the room can be lit by light reflected off the ceiling. As a result, there is no direct vision of the luminaires. In theory, it creates a very low glare environment. In practice, it can still generate glare problems.

If the luminaires are close to the walls and the back throw is not controlled, the fitting can generate bright patches on the wall above and the wall itself becomes a glare source. Also, the lights tend to light the ceiling and the upper sections of the walls, but are not particularly effective at lighting the lower vertical surfaces. As a result the spaces can appear gloomy.

Uplighting installations are inherently inefficient. As all the light is reflected from the ceiling there is a significant loss due to the absorption of the ceiling cavity. This usually represents around a 50% loss. With the requirement to reduce energy consumption and greenhouse gases, the opportunities for uplighting should be limited.

### **Combination Uplighting/ Downlight –**

These are luminaires that provide a controlled downward distribution and a wider upward distribution. They have the advantage of providing efficient direct light onto the task, while providing an upward component to increase the background luminance. This reduces the glare and makes the space appear larger. Luminaires are available in different combinations of upward and downward components. If the upward component is too high, the problems with a full uplight installation remain. I believe that the optimum ratio for general use is around 20% upward component.

These lights still require a higher ceiling than the common 2700mm ceilings in many modern offices, as it is important that they be suspended sufficiently from the ceiling to allow a uniform ceiling luminance and to avoid hot spots. If hot spots on the ceiling are created the ceiling becomes the glare source.

### **Surface Mounted Luminaires –**

Surface mounted luminaires come in two basic families, bright sides and dark sides.

Bright sided luminaires have a prismatic lens or opal panel that diffuses the lamp image and directs the light.

Diffuse opal fittings tend to have the same luminance on the sides and the bottom and, although they reduce the lamp luminance by increasing the area of the source, they do little to control the direction of the light and should only be considered as a decorative fitting.

Prismatic lens panels control the luminance of the fitting by directing the light away from the angles of view and into the useful angles. Standard flat lens panels are designed to direct the light perpendicular to the panel. This improves the efficiency of the installation, as it directs the light onto the work surface. The side panels should direct light away from the angle of view by directing some of the light onto the ceiling and some towards the work surface. This reduces the luminance of the luminaire, when viewed from the side, and increases the luminance of the background. With this style of fitting it is only an increase in the immediate vicinity of the luminaire but it graduates the edge of the bright patch. Some of the less expensive surface mounted fittings simply bend the same panel as the base onto the sides. This then directs light horizontally from the fitting. Therefore, they do not provide adequate glare control for a work environment.

Well designed surface mounted fittings, on light ceilings, provide high efficiency and a good visual environment, however there are aesthetic, building construction and cost issues that make recessed luminaires more popular.

Surface mounted fittings with dark sides should only be used in special circumstances as the construction of the luminaire prevents light from getting to the ceiling. As a result they have the highest contrast between the fitting and the background. This makes glare control difficult.

### **Recessed Luminaires –**

Recessed luminaires come in two basic forms: fittings with prismatic panels to control the light and fittings that use reflectors to shield the lamp and control the distribution. The latter are commonly referred to as low brightness fittings.

As with the surface mounted fitting the prismatic panel is designed to direct the light in the downward direction and away from the glare angles. The panels also diffuse the lamp image thereby reducing the intensity of veiling reflections. Prismatic panels are available in a variety of options with differing glare control, efficiency and distributions. They are also available in a batwing distribution that concentrates the light to the side to provide a more uniform illuminance across the fittings distribution. This allows wider spacings.

In the 1970's in an attempt to control glare in VDUs, there were a series of different panels that attempted to control the luminance of the fittings at high viewing levels. These included black egg crate and small cell metallised parabolic plastic reflector panels. The panels tended to reduce the luminance principally by reducing the light output of the luminaire. The one version that has survived is a modified prismatic panel with a silvertint overlay. This was subjectively considered to reduce the reflections in VDUs. The actual photometric distribution of the silvertint and the standard panel are very similar except that the light output of the fitting reduces by 25% with the introduction of the silvertint. The resulting installations are extremely inefficient.

Reflector or low brightness fittings come in a wide range of configurations. The reflector is usually divided into cells to cut off the view of the lamp from the end. The luminaires work on the basis that the depth of the lamp in the fitting and the cross-blades shields the direct view of the lamp, while the reflectors are contoured to direct the light into specific angles of the distribution.

The fittings came into popularity in the late 1970's, primarily as a means of limiting glare onto VDU's. The fittings also had higher efficiencies than most fittings on the market and significantly higher efficiencies than other fittings that controlled glare into VDUs.

The initial fittings used highly polished reflectors that directed the light down and had very little scatter. The fittings produced installations where the ceilings were dark and from normal viewing angles the fittings appeared as black holes in the ceiling. These fitting produced very little vertical illuminance and were responsible for some of the most oppressive spaces created.

The design was modified to use a semi-specular aluminium reflector which gave a luminaire with a slightly lower efficiency but had sufficient scatter so that the fittings appeared as bright objects in the ceiling. The fittings were still had very low luminance at high angles and produced little vertical illuminance between the fittings. The fittings often with a batwing distribution and the layout of the fittings had very little overlap. As a result when workstations were added to the spaces some of the vertical surfaces received little light.

The fittings distribution has a sharp cut-off with the peak intensity only a few degrees below the shielding angle. As a result when partitions were added to open plan offices adjacent to the fittings very bright patches are created on the walls that themselves become glare sources. (Refer Fig 9)

Another limitation on the fittings is that as the bottom of the fitting is open the lamp is exposed from below. This means that there is no diffusion of the lamp luminance for veiling reflections. The fittings were originally designed for 38mm diameter lamps. Since then the diameter of lamps has reduced to 26mm and now 16mm diameter with an increase in light output. The luminance of the lamps has doubled.

These fittings have tended to become associated with high quality office spaces, however with the improvements in VDU technology and the improvements in high output prismatic panels, there is not the same justification for the fittings. In addition if the space has windows the justification is further limited.

These fittings are also susceptible to the high angle glare mentioned earlier as they have very high luminance directly below the luminaire.

A recent development in recessed and semi-recessed luminaires is the “soft-light” or “mellow-light” fittings. These luminaires use are based on an alternative approach to glare control. The fittings generally have a larger area than the conventional recessed fitting and use a combination of indirect light, often the fitting housing, and direct light. The theory is that the fitting becomes part of the background as well. This reduces the overall contrast with the light. Although the fittings may not meet the strict recommendations for calculation on glare, there is often a high level of user satisfaction in the spaces.

## Lighting Calculation Methods

Lighting calculation methods fall into three broad categories:

### i. Manual calculation methods

There are a wide range of manual computation methods for the calculation of different lighting aspects. These included complex methods for calculating the illuminance from a wide variety of shapes of luminous objects. <sup>7</sup> The majority of these have now been superseded by computer programs.

The Lumen Method was the main stay 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.

Unfortunately, many installations have been designed without adequate attention to the assumptions, with poor results.

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

### ii. Three dimensional modelling

Although it was possible to calculate the luminance of all the surfaces in a room, the calculations were extremely laborious and could only be justified in the most special cases. The advent of computer modelling enabled a more flexible approach to lighting design and significantly increased the information available to the designer.

In contrast to the Lumen Method, lighting programs now enabled the lighting designer to broaden the assumptions:

- 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
- The illuminance and luminance of all surfaces can be calculate

This gives the lighting designer a much greater understanding of what is happening in the room, however the new technology highlights a problem.

There has been considerable research, experience and documentation over the past 80 years that has developed the current thinking in the adequacy of various illuminance levels for various tasks and functions. Although there is some general understanding of the need for appropriate luminance distribution in the vertical plane, there is little information, experience or understanding for many designers to determine:

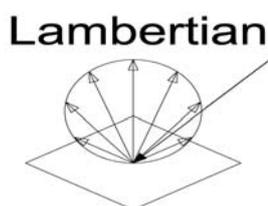
- what the luminance of surfaces should be in varying situations,
- what is an acceptable luminance uniformity,

- whether there should be a maximum luminance uniformity,
- what is the desired graduation in luminance.
- at what point is the luminance distribution of the wall unacceptable

It is important in using a lighting calculation program that the output records the type of luminaire used, the location of the luminaires, the assumed lumen output of the lamp, the light loss factor and the aiming points. If this is not recorded you have a pretty picture of the installation and no way of making it a reality.

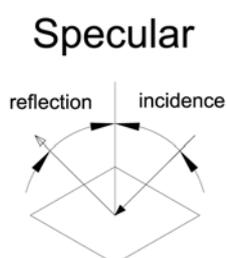
### iii. Visualisation

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 or radiosity calculations and ray tracing calculations.



**Figure 10. Lambertian or perfectly diffusing surface**

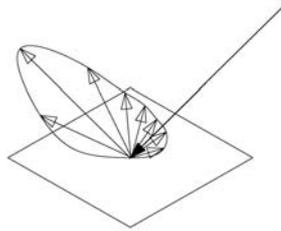
A Lambertian surface as shown in figure 10 is a perfect diffuser, where light is reflected in all directions, irrespective of the angle of incidence of the light such that irrespective of the viewing angle the surface has the same luminance. A specular surface as shown in figure 11 is a mirror like surface, where the angle of reflection of the light is the same as the angle of incidence.



**Figure 11. Specular Surface**

A real life surface is a combination of both surfaces (semi-specular), Figure 12 shows the combination of specular and diffuse characteristics. Some materials are more specular while others are more diffuse.

## Semi-specular



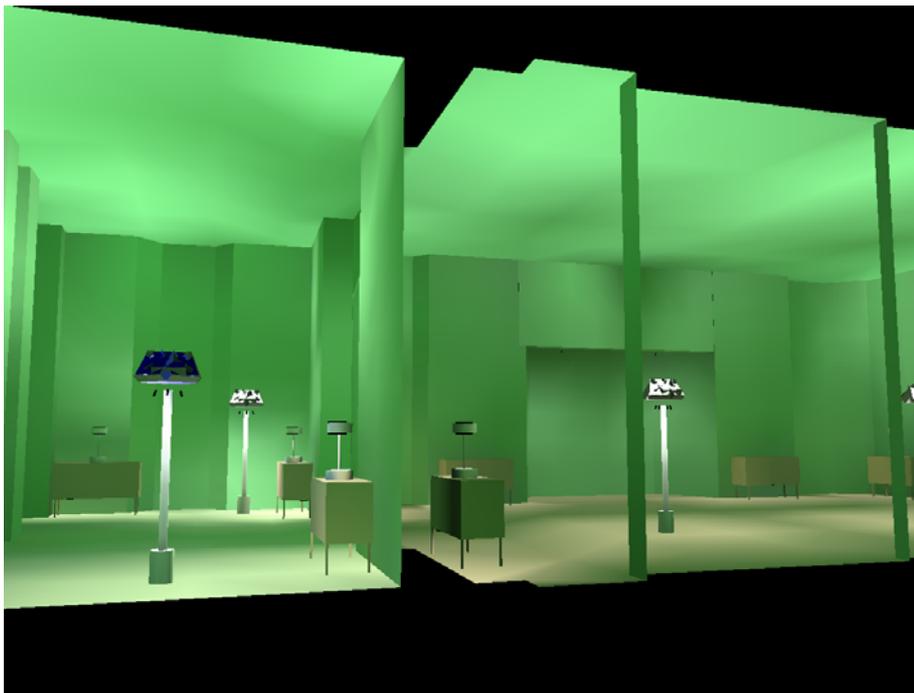
**Figure 12. Semi-specular Surface**

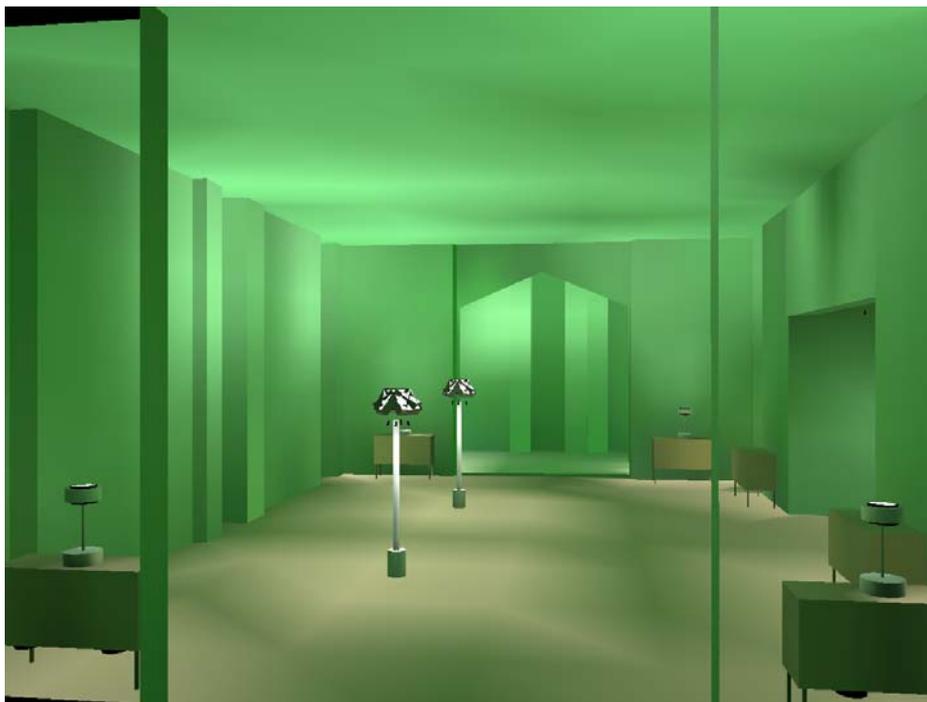
A flux transfer or radiosity program treats all surfaces as diffuse or Lambertian surfaces, as a result their rendering tends to appear flat with soft shadow details (Fig.13 & 14). It will tend to overestimate the uniformity. Ray tracing traces the individual rays of light from the source to the eye as it reflects from surface to surface around the room. As a result ray tracing can allow for the specular component of the surfaces.

Some programs calculate the entire lighting by ray tracing while others calculate the space on a flux transfer basis and have an overlay of ray tracing of specific areas to improve the quality of the rendering. When ray tracing is added, reflections are added in polished surfaces and shadows become sharper. (Fig.15)



**Figure 13. 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.**





**Figure 14. Normal renderings are generally only produced in sufficient detail to give the designer an understanding of what is happening in the space**



**Figure 15. Example of a rendering generated by a visualisation program. Note the sharp shadows and the reflections in the shiny surfaces,**

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 his own visualisation of the space, and to model specific lighting solutions. The programs are still calculation tools and not design programs. The programs can show the designer how a specific design will perform but that 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 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. With a VDU, the possible luminance range depends on the brightness and contrast settings on the screen, but under normal settings would have a range of approximately 100:1. For printed outputs the range is limited by the reflectivity of the paper and the inks. A figure of 70:1 is probably more realistic for printed outputs. In a lighting installation, particularly a poorly designed one, 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 all higher luminances as white and all lower ones as black. The result is that visualisation programs can make installations with significant glare problems, look acceptable. A similar situation exists with photographic representations of buildings.
- 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

Some of these problems may be reduced if the image were viewed in a very large wrap-around image, similar to that used in a flight simulator.

Irrespective of the form of the visualisation output it is important that the program provides adequate information to enable the construction and verification of the lighting design.

The output should include:

- Installation Information - the type and location of all luminaires and the aiming information. The lamp details should be included as well as the specific catalogue number of photometric file that has been used.
- Light technical parameters – the illuminance, uniformity and other parameters that have been calculated to achieve the design.
- Verification information – adequate details to enable the lighting calculation to be verified. This should include the luminaire type, the photometric file, surface reflectances that were assumed, light loss factors, lumen output of lamps and mounting and aiming locations.

Figure 16 shows a typical example of the technical information that a program should supply to support the visualisation.

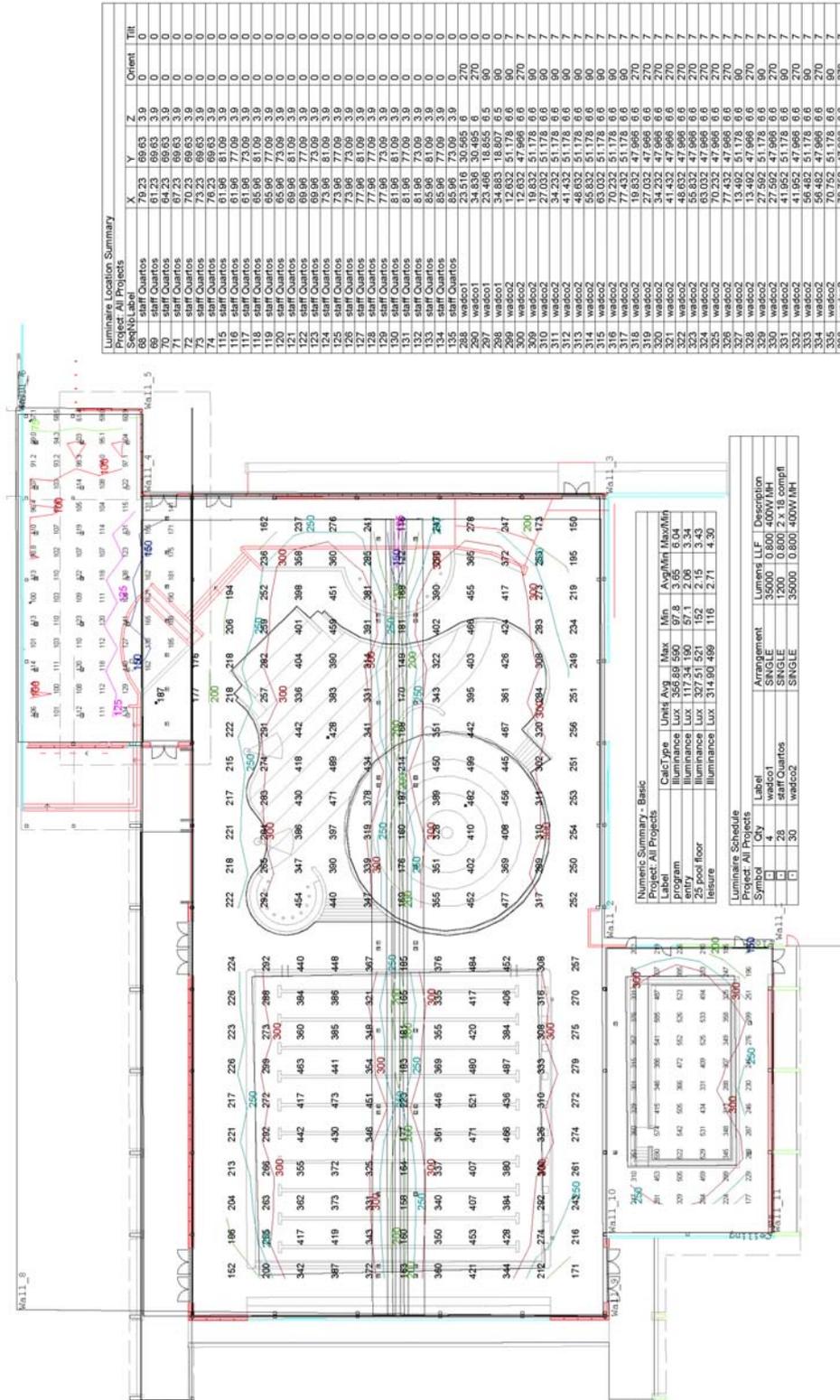


Figure 16. Good calculation programs also give a representation of the light technical parameters of the solution

#### iv. Daylight Estimation

There are some sophisticated daylight analysis programs available. All lighting programs calculate light at a specific point in time. With electric lighting, the output and the distribution of the luminaires are assumed to be static and the design is based on the actual photometric distribution of the luminaires. As a result the calculation of the illumination is not only true at a point in time but also represents the average through time.

With daylight the sky is a continuously changing light source which varies both in intensity and distribution. The calculation programs are therefore based on mathematical models of typical skies rather than the specific photometry of the sky.

The programs are extremely useful in the examination of how a space will perform under different sky conditions at different times of the year.

Daylight is weather related and there can be large variations from day to day, season to season and even year to year. With weather it may be possible to predict the average weather conditions throughout the year for specific days or months, but that does not guarantee the whether on that specific day.

There is currently not a sufficiently developed statistical database for daylight for most locations in Australia to enable an annual analysis of long term daylight availability to be calculated for a particular space.

It is therefore not possible to accurately predict the energy savings that might be achieved by the switching or dimming of electric lighting to compensate for daylight. As a result there can often be significant differences in the potential savings that people predict and the actual savings.

Daylight however has an important role to play in lighting of a space. Daylight can be considered as a potential source of light and an opportunity for energy saving, or its existence can be ignored in the calculation of the lighting. If the space is used in daytime and has windows the affect of daylight on the space cannot be ignored if a quality lit environment is to be achieved.

#### Tolerances and Accuracy in Lighting Design

Lighting is an inexact science as it is a mixture of physics and perception. It also has a wide diversity of competing criteria. Lighting, like air-conditioning, tends to be assessed on comfort of the user. The acceptable solution therefore tends to sit between two limits at which it is no longer considered comfortable. Just as there can be too little lighting, there can be too much. It is therefore not as easy to use a safety margin approach, as might be used in structural design, where the required performance might be calculated and then multiplied by a factor of 2 or 3.

It would no be acceptable having determined that 320 lux was the minimum acceptable level to install 960 lux to be certain. With air-conditioning this is overcome by variable control systems that adapt the installation to the ambient conditions. This is the equivalent to an automatic dimming system. Although automatic dimming systems are available they have not had wide spread acceptance. There are two main reasons:

- The cost of air-conditioning controls has always been seen as part of the system. With lighting the normal circumstance is to have primitive lighting control, a switch, and any improvement is seen as an extra cost that must be separately justified.
- Air conditioning has a thermal lag so that adjustments that are made to modify the temperature and humidity may not be evident in the room conditions for several minutes. Lighting is instantaneous so any rapid changes, and over or under shooting of the control system is immediately evident. The control system therefore needs to be far more sophisticated to be transparent to the occupant.

Given the narrow window of acceptance within which a designer must design, it is important to be aware of the inherent sources of uncertainty in the information and design tools available to the designer.

These are detailed in AS/NZS 3827.1:1998, “Lighting system performance – accuracies and tolerances”.<sup>10</sup>

The major sources of uncertainty are:

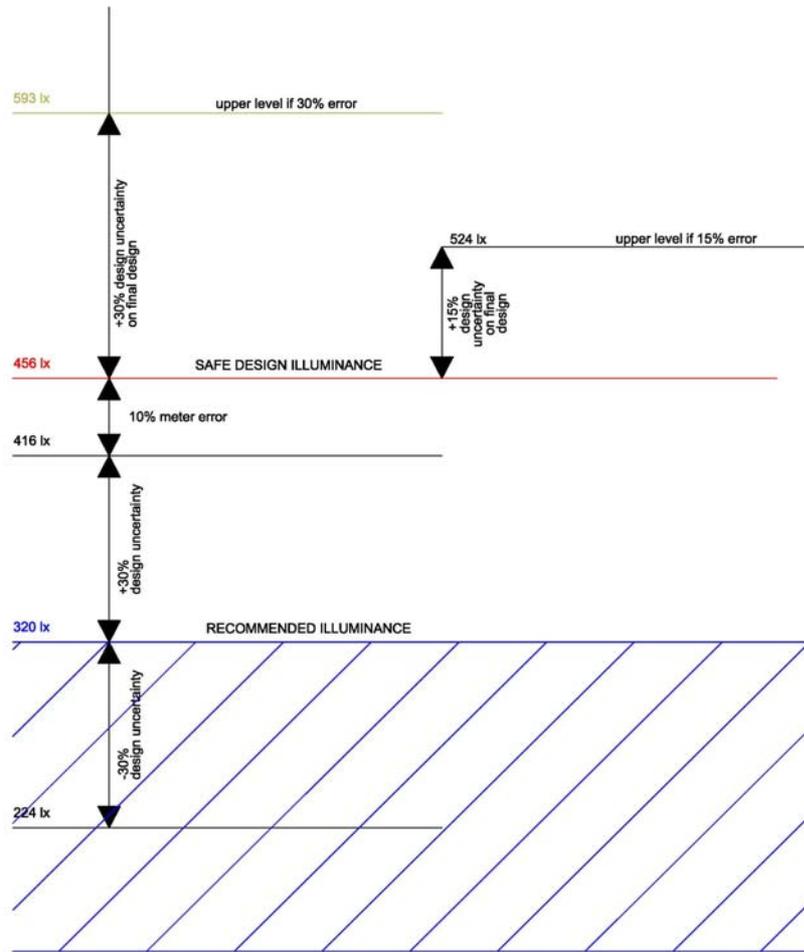
Photometric measurement - the accuracy of the photometer	±5%
Manufacture tolerance Generally only a single luminaire is photometered an often this is a pre-production model. The actual fitting produced could vary considerably	± 5%
With internal calculations the inter-reflection from the surfaces is calculated by various algorithms. The accuracy of these will vary with the room shape, relative upward and downward component of the lamp and the complexity of the model	Up to ±10%
The accuracy of the surface reflectances used in the calculation both in reflectance, area and distribution throughout the space	Up to ±30%

Based on these figures the uncertainty of a design calculation varies between 7% for a direct illuminance calculation such as a sports field, to 32%, for an internal space with indirect lighting or low brightness luminaires.

There are two approaches that can be taken to the uncertainty of design.

### Safety Factor

If the designer is forced to be certain that they meet a guaranteed average illuminance then the design illuminance has to be increased by the uniformity. Figure 17 shows that if designer has a 30% uncertainty and has to guarantee to achieve a illumination level of, say 320 lux, they must increase the design illuminance by 30% to allow for the effect of a negative error. They must then add another 10% to allow for the uncertainty in the site measurement. This means that the design illuminance has to be 456lux to guarantee a 320 lux average illuminance. If the actual error level in the calculation is 30% the actual illuminance could be as high as 593 lux.



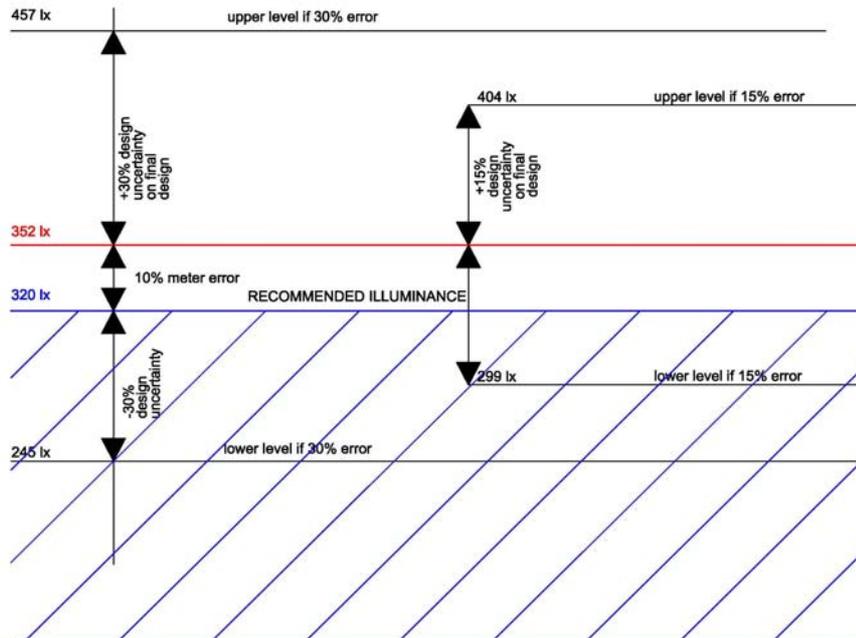
**Figure 17. Safe design**

This is in addition to light loss allowances for the lumen depreciation of the lamps and the build up of dirt in the system. This can result in significant over-illumination of the space and the associated increase in capital cost of equipment and energy usage. A lighting control system can be added to reduce the illuminance and energy consumption, but at additional initial cost.

AS/NZS 1680<sub>11</sub> is the interior lighting code. It makes recommendations for average “maintained illuminance”. These are recommended on a scale of 100% increments. This is because this is the smallest increment in illuminance that the eye can differentiate. The shaded area at the bottom of Figure 17 represents the 100% increment. As can be seen a small variation in illuminance below the recommended level is imperceptible and would have minimal effect on visual performance.

### Shared Risk

If it is accepted that there is a level of uncertainty in the design of the lighting, and that the effect of some installations being under the recommended design level is less important than the preservation of a quality design interior then the installations can be designed to a more realistic level. Figure 18 shows how a 10% safety margin in the design means that the average illuminance of the installations will only be 10% above the recommended level. If the actual error in the design is less than 30%, say 15% then the illuminance will be between 299 and 405 lux compared with 388 and 524 if we seek to guarantee the 320 lux level.



**Figure 18. Shared Risk**

There are also some further sources of difference between the design level and the actual illuminance that may be beyond the designer’s control. They are the substitution of alternative luminaires, relocation of luminaires due to co-ordination clashes on site, misinterpretation of the documents and poor aiming of the lights. These are the result of intervention in the design process rather than uncertainty.

It should be noted that the levels that are recommended in AS1680 are the recommended maintained illuminance levels or the minimum average level that is recommended for that task throughout the life of the installation. This is the illuminance at which the lighting installation requires intervention. This normally means that lamps need to be replaced or the luminaires, cleaned. There are circumstances where the lighting designer may identify a need for a higher illuminance level. In this situation the same uncertainty would be required except that the installation should be maintained should be the elevated level rather than minimum level in the standard.

## The Lighting Design Process

It is important that a design process be followed to avoid the tendency of rushing straight into a luminaire selection before determining what is required.

- i. Identify the requirements**
  - Task Requirements
    - Illuminance
    - Glare
  - Mood of the space
  - Relation to shape of space
  - Things to be emphasised
  - Things to hide
  - Direction of light
  - Interaction of Daylight
- ii. Determine the method of lighting**
  - Recessed / surface mounted / direct-indirect / uplighting
  - Prismatic / Low brightness / mellowlight
- iii. Select the lighting equipment**
- iv. Calculate the lighting parameters and adjust the design as required**
- v. Determine the control system.**
- vi. Check that the fittings to be installed are those that the design was based on**
- vii. MOST IMPORTANT**

**Inspect the installation upon completion and, if possible, a few months after occupation, to determine what worked and what didn't. This is the only way to build up experience to apply to future designs.**

## 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.

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, user satisfaction will have greater effects than small changes in illuminance

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

- i. correct luminance distribution on the vertical surfaces
- ii. rational glare control
- iii. careful treatment of the task surround luminance
- iv. colour rendering
- v. visual interest,

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

## References

1. A. A. Kruithof “Tubular Luminescence Lamps for General Illumination” Philips technical Review. Vol 6 PP65-73 (1941)
2. Photograph – Australian Government Survey Organisation –  
Photographer - [Ben Wrigley](#)  
Architect – [Eggleston MacDonald](#)
3. Waldram, J.M. 1978. Design Appearance Lighting. In: Developments in Lighting-1 Chapter 5. J. A. Lynes (editor) London: Applied Science Publishers.
4. P. Ngai and P. Boyce “The Effect of Overhead Glare on Visual Discomfort” Journal of the Illuminating Engineering Society Volume 29 Number 2 Summer 2000
5. P Boyce, C.M. Hunter and C Inclan “Overhead Glare and Visual Discomfort” Journal of the Illuminating Engineering Society Volume 32 Number 1 Winter 2003
6. Photograph – Australian Government Survey Organisation –  
Photographer - [Ben Wrigley](#)  
Architect – [Eggleston MacDonald](#)
7. Moon, Parry. The Scientific Basis of Illuminating Engineering. Dover Publications. Revised Edition 1961
8. Rendering from Lighting Technologies web site  
<http://www.lighting-technologies.com/Services/Renderings.htm>
9. Rendering by Michael Fowler , Deo A Daly (Washington DC)  
<http://usa.autodesk.com/adsk/servlet/item?siteID=123112&id=2157763>
10. AS/NZS 3827.1.1998 Lighting system performance- Accuracies and tolerances. Part 1: Overview and general recommendations
11. AS1680.1-1990 Interior Lighting Part 1 General Principles and recommendations. Standards Australia

## Further Reading

AS1680.1-1990 Interior Lighting Part 1 General Principles and recommendations. Standards Australia

Christopher Cuttle, “Lighting by Design”, ISBN 0 7506 5130X. Architectural Press, Oxford, 2003 (In Australia from Elsevier Australia)

Peter R Boyce, “Human Factors in Lighting”, 2<sup>nd</sup> Edition ISBN 0-7484-0950-5 (paperback), ISBN 0-7484-0949-1 (hardback). Taylor & Francis, London, 2003.

Warren Julian, “Lighting – Basic Concepts”, 6<sup>th</sup> Edition ISBN 1 86487 033 8, Faculty of Architecture, University of Sydney, 2003 (available from publisher)

## Lighting Design Software

There are many lighting software packages available. Some are more flexible than others, while others are quite specific in their purpose. The following list includes some of the software available. The list is not exhaustive, nor should it be taken as a recommendation or endorsement of a package. It is included to give an indication of the extent of the software available.

- AGI32: a commercial flux transfer program with limited ray-tracing functions based on North American IES photometric file format. The program models interior and external lighting and models daylight contribution in spaces.
- Dialux, Relux: a commercial flux transfer programs based on European Lumdat photometric file format. The program models interior and external lighting.
- Lightscape: a commercial flux transfer program with limited ray-tracing functions based on North American IES photometric file format. The program models interior and external lighting and models daylight contribution in spaces.
- Lumen Designer: a commercial flux transfer program based on North American IES photometric file format. The program models interior and external lighting and models daylight contribution in spaces.
- Radiance: a public domain raytracing engine that produces high accuracy modelling of daylight and interior lighting.
- Adeline: a commercial front end for Radiance