Public lighting for safe and attractive pedestrian areas

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Executive summary

This report adds to the understanding of public lighting for safe and attractive pedestrian areas. It aims to direct perspectives from which to review pedestrian lighting schemes by informing on recommended practices for the safe and attractive lighting of pedestrian areas. It is based on literature review findings incorporated with information from the lighting industry.

Guidance and recommendations for pedestrian lighting coexist with the Australia/New Zealand standard *Lighting for roads and public spaces, part 3.1: pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)* and do not replace it, as their contents and purposes are different. By its nature, a standard defines *adequate* and *acceptable* practices. The pedestrian lighting standard has a neutral effect on modal change. That is, if someone wants to walk in an area during the hours of darkness, the lighting design's compliance with the standard ensures that enough light is provided to make walking safe. In contrast, guidance on pedestrian lighting belongs to a context of *encouraging* people to walk.

During daytime, natural light facilitates a safe, comfortable, efficient and enjoyable walking experience. During darkness, artificial lighting techniques should light the environment for the particular needs and preferences of pedestrians to maintain that standard of walking experience.

Effective pedestrian lighting optimises the amount of *useable visibility* that is provided.

Useable visibility relates to the pedestrian behaviours that are intended and desired for an area or route – it is the nature of those pedestrian activities and locations that should drive determination of the appropriate size, location and intensity of pedestrian lighting. Pedestrian lighting can be designed to effectively match and facilitate those needs if there is understanding of both how human vision works, and how light can be controlled.

When designing a pedestrian lighting scheme to accommodate or manipulate pedestrian behaviours, the preliminary review needs to consider what the lighting communicates to the pedestrian, and also what it provides from the pedestrian's perspective. Lighting designers and engineers can measure lighting parameters, but these techniques also have to be assessed in terms of how well the measures represent the pedestrians' experience.

The research findings highlighted the following as key elements of pedestrian lighting scheme design and review:

- The significance of shadows, or apparent three-dimensionality, within a pedestrian lighting environment needs to be considered. The extent of shadows can be managed through the angle of light incidence or the intensity and number of light sources.
- Lighting uniformity is important. It can be managed through luminaire output, apparent light size, mounting height, and spacing.
- Lighting colour can optimise colour rendering – perhaps selected to recreate natural daylight conditions, or to combine and enhance the colours of the pedestrian environment.
- The visibility field for physical safety should be related to the likely speed of pedestrian movement. Although recommendations vary and the particulars of the pedestrian situation should rule this decision, the visibility field for personal security appears to be approximately 10 metres.

- Although overall literature and industry guidance is not conclusive, it seems that pedestrian lighting can influence *perceptions* of personal security. This effect needs to be considered and managed to ensure the pedestrian lighting scheme communicates the appropriate message to pedestrians about the use of a pedestrian area during the hours of darkness.
- Throughout a pedestrian lighting scheme, the illuminance needs to be reviewed from the perspective of likely pedestrian activity types and locations, and potentially matched to desired pedestrian activity types and locations.

Abstract

The Australian/New Zealand standard *Lighting for roads and public spaces, part 3.1: pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)* sets out specifications for pedestrian lighting. The standard defines adequate and acceptable pedestrian lighting practices to make walking safe. This research project complements and extends the standard by investigating pedestrian lighting practices to make walking not only safe, but also more attractive. The project highlights issues and perspectives from which to view the effectiveness of the pedestrian lighting.

This research is partly based on the observation that most lighting in the public arena has traditionally been driven by the needs of motorists, but pedestrians' needs are different. It studies those differences and guides on lighting techniques that can appropriately and specifically cater for pedestrians. The findings are based on a review of literature incorporated with information from the lighting industry.

1 Introduction

1.1 Background and context

The benefits to society of increasing the number of people who regularly walk are many and various, and include:

- improved health
- increased transportation options and accessibility
- greater quality of life and community interaction
- reduction of the negative environmental impacts of some other transport modes
- positive economic effects for individuals and local enterprises.

While the main thrust of strategies aiming to increase the number of people walking is likely to rely on addressing a range of educational issues and social attitudes, pedestrian-friendly infrastructure and environments are also required to ensure that walking is an attractive and practical option.

A number of initiatives and frameworks are currently being implemented to encourage pedestrian activity within New Zealand's urban areas. For example, the New Zealand Transport Strategy (Ministry of Transport 2008) contains a target to 'increase walking, cycling and other active modes to 30% of total trips in urban areas by 2040'. The promotion and facilitation of walking contributes to this target. Other organisations such as SPARC (Sport and Recreation New Zealand) and the Ministry of Health are also working to increase the physical activity of New Zealanders through exercise such as walking. This includes recreational walking, incidental walking, and walking for transport.

The design and interactions of pedestrian infrastructure elements affect the quality and practicality of pedestrians' walking experiences, and there are standards and supporting guidelines that address many of these elements. Specifications for pedestrian lighting are established in the standard *Lighting for roads and public spaces, part 3.1: pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)*. Pedestrian lighting guidelines can complement the pedestrian lighting standard and provide greater understanding of the particular lighting requirements and preferences of pedestrians. This project particularly recognises that competent pedestrian lighting design requires an understanding of how people respond to lighting, as well as technical lighting knowledge.

1.2 Project and document scope

This report adds to the understanding of public lighting for safe and attractive pedestrian areas.

Guidance and recommendations for pedestrian lighting coexist with the standard *Lighting for roads and public spaces, part 3.1: pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)* and do not replace it, as their contents and purposes are different. By its nature, a standard defines *adequate* and *acceptable* practices. The pedestrian lighting standard has a neutral effect on modal change. That is, if someone wants to walk in an area during the hours of darkness, the lighting design's compliance with the standard ensures that enough light is provided to make walking safe.

This guidance on pedestrian lighting belongs to a context of *encouraging* people to walk. 'Safe and attractive' public lighting for pedestrian areas therefore covers the following issues:

- Safety – For walking to be a viable mode of transport, pedestrians must be safe. Safe public lighting ensures that pedestrians do not get injured. Pedestrians should be able to see clearly enough to negotiate possible obstacles and obstructions and the physical terrain without discomfort or physical harm. To minimise the risk of near misses or collisions, pedestrians should be easily visible to all other users of the space, such as motorists, cyclists, and other pedestrians.

  In New Zealand, lighting for pedestrian safety is comprehensively covered by lighting standards, notably:

  - *Lighting for roads and public spaces, part 1.1: lighting for roads and public spaces; part 1.1: vehicular traffic (category V) lighting – performance and design requirements (AS/NZS 1158.1.1:2005)*, which is particularly concerned with road safety
  - *Lighting for roads and public spaces, part 3.1: pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)*
  - *Lighting for roads and public spaces, part 4: lighting of pedestrian crossings (AS/NZS 1158.4:2009).*

- Personal security – Public lighting that promotes personal security may reduce the potential for harm to pedestrians and should deliver some comfort to users. Enhancing actual or perceived levels of personal security for pedestrians increases the likelihood that people will walk.

  Lighting may contribute to providing pedestrians with protection from being mugged or assaulted; and lighting may minimise the presence or likelihood of antisocial behaviour and undesirable uncivil loitering. These types of effects can be difficult to predict or measure, but there is evidence that the lighting of a facility may reduce pedestrians' *perceptions* of risk of physical harm or of encountering antisocial behaviour.

  The effects of lighting on personal security are referred to in AS/NZS 1158.3.1:2005, particularly in 'Appendix C: Selection of lighting subcategory based on risk of crime or need to enhance prestige'.

- Attractiveness – Attractive public lighting has a positive effect on pedestrians and contributes to their enjoyment of the walking environment and experience.

  Walking involves a high degree of interaction with the urban environment. Lighting can be used to create, communicate, or contribute to an area's atmosphere, and can help make walking a more positive experience and a more appealing activity and mode of transport – thus increasing the modal share of walking.

  The potential for pedestrian lighting to be so attractive as to enhance the walking experience, and thereby increase the numbers of pedestrians, is outside the coverage of AS/NZS 1158.3.1:2005.

This report aims to direct perspectives from which to review pedestrian lighting schemes by informing on recommended practices for the safe and attractive lighting of pedestrian areas. It is based on literature review findings incorporated with information from the lighting industry.

The project does not cover the infrastructure of lighting or compare lighting technologies. Light pollution is also largely outside of the scope of the project. Rather, it focuses on public lighting that pedestrians can benefit from and enjoy. The information is primarily aimed at those involved in the planning of urban pedestrian facilities, and is also to be used by lighting designers; however people should apply their own skill and judgement when using this information.

1.2.1 Note on information sources

The project's initial sources for information focused on pedestrian lighting. The results were inadequate, lacking in scope and detailed discussion. In many potential sources, the significance of pedestrian lighting was stated, but without justification or analysis. Pedestrian lighting was often considered as a general entity without recognition of the constituent parts of 'pedestrian lighting'. Therefore the search for information was broadened to encompass outdoor lighting and indoor lighting, the human sight mechanism, and photographic lighting.

The selection of information sources was guided by principles of a logical rationale for approaching any specific lighting design. Information sources contributing objective information were keenly sought, such as discussions of lighting techniques and facts about human vision. Many reviews or editorials of lighting projects inevitably contain a subjective component, and these were avoided. Prescriptive statements and limits were also minimised in order to encourage development of a rational generic *approach*, rather than a generic *treatment*.

1.3 Definitions of terms

This report references the definitions contained in the standard *Lighting for roads and public spaces, part 0: introduction (AS/NZS 1158.0:2005).* Definitions of some terms are included within the text of the report, and definitions of a sample of terms are summarised here:

Illumination	the light arriving at a surface
Illuminance	the physical measure of illumination
Colour rendering	the degree to which a light source reproduces the colours of an object as they would appear under illumination by daylight or a reference light source
Luminaire	the complete lighting unit of the light source (lamp or lamps) and the parts for fixing, protecting and directing the light source
Mounting height	the vertical height between the centre of the luminaire and the surface which is to be illuminated
Spacing	the horizontal distance between successive luminaires

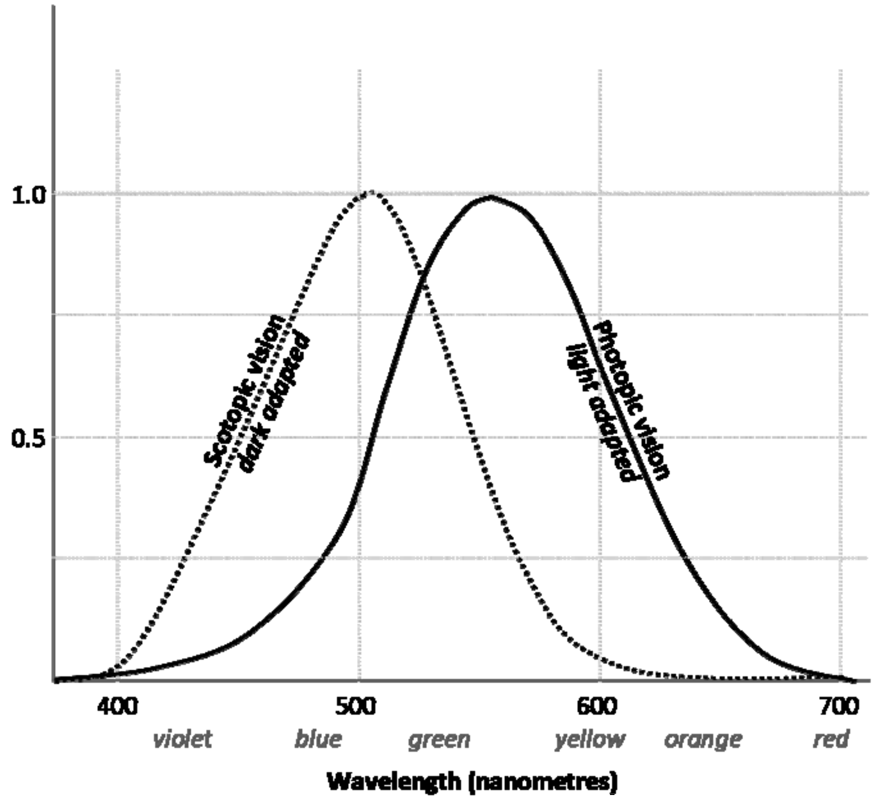
2 Introduction to human night vision

The effectiveness of public lighting for pedestrians can be better assessed, and thus provided for, through an understanding of the human body's natural vision process.

The light-sensing structures for vision are in the retina of the eye. The retina contains two types of cells – rods and cones.

- **Cones** are concentrated in the centre of the retina and provide clear, sharp central vision and detect colours and fine details. 'Photopic vision' occurs in well-lit conditions, and is dominated by the cones in the retina. Figure 2.1 shows the perception of light of different wavelengths via photopic vision, and illustrates the colour perception that cones provide.
- **Rods** are located outside the centre of the retina. They provide peripheral vision, and allow the eye to detect motion. Vision of the eye in low-light conditions is called 'scotopic vision', and is dominated by the rods in the retina. Figure 2.1 also shows the perception of light of different wavelengths via scotopic vision, which is more sensitive to light of wavelengths around the blue area of the spectrum.

Figure 2.1 Diagram of the visual sensitivity of the human eye to light of different wavelengths, for photopic vision and for scotopic vision (adapted from Wikipedia Contributors 2010)



At night, or under the levels of illumination typical of pedestrian lighting, pedestrians use 'mesopic vision', which utilises both the cones and the rods. As the light availability reduces:

- the rods, with their greater sensitivity to light, contribute more than the cones to providing vision
- the level of visual acuity decreases and the capacity to discriminate between colours declines.

The visible light spectrum runs from the long wavelengths of red colours through to the shorter wavelengths of blue and violet colours. Cones are most sensitive to the wavelengths of yellow light; rods respond best to green-blue light. The activation of different parts of the retina under different lighting conditions means that in bright sunlight, when the cones are dominant, red flowers on a plant appear bright red against dull green leaves, whereas under low levels of illumination, when the rods are dominant, the red of the flowers seems duller and the leaves seem paler (Bianco 2000, Schreuder 1998). Illuminance meters cannot register this subtlety that affects pedestrians' *experience* of lighting.

Thus, illuminance meter readings can be quite different from pedestrians' perceptions of lighting at low-lighting levels, where different colours of light are involved. Illuminance meters measure light according to the photopic frequency response curve. However at low light levels, the human eye's frequency response tends to move towards the scotopic curve (as shown in figure 2.1), where a light source containing more blue light makes it easier for people to see. Bullough (2006) found that laboratory and field studies verified that while an illuminance meter registered that a white light source and a yellowish light source provided identical levels of illumination, the light source with the greater amount of blue light resulted in people having improved peripheral (rod) vision.

People experience well-being and comfort when their interpretation of the physical world feels 'natural'. Natural (daylight) lighting gives clear spatial orientation, as the position of the sun (as the light source) provides for steady illuminated and non-illuminated areas. This means that although a person's viewing point may change, the logical pattern of light and shadows remains the same (Simenova 2004). Light-meter readings and achievement of the lighting parameters of formal standards may not reflect how well an artificial pedestrian lighting scheme delivers on these aspects.

3 Controlling public lighting of pedestrian areas

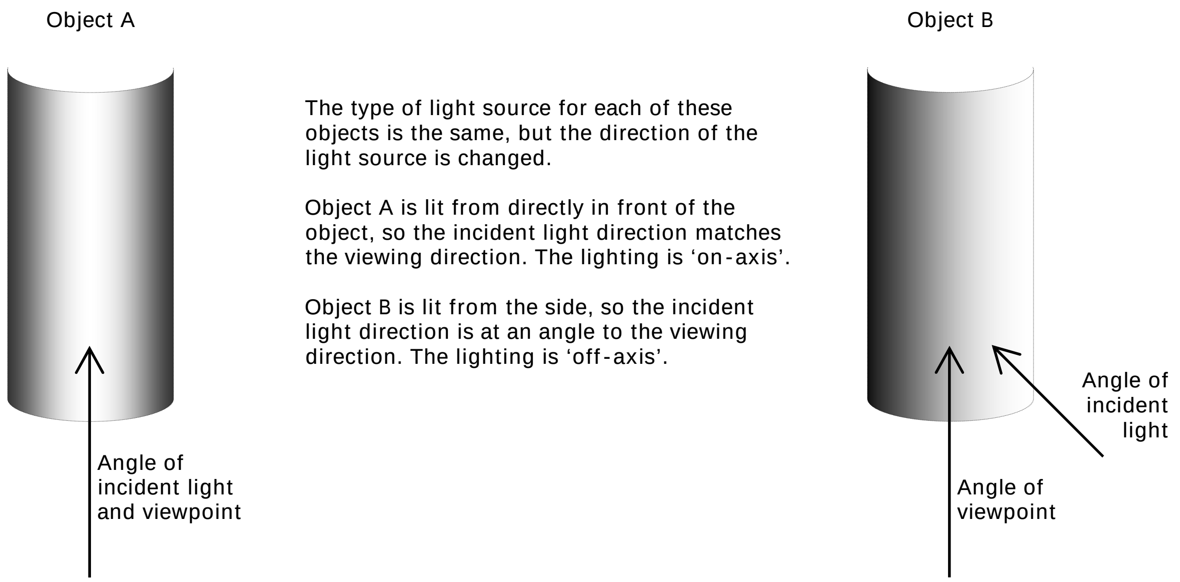
This section describes some basic lighting concepts that are relevant to the public lighting of pedestrian areas. Understanding how light can be controlled provides a way to assess and develop pedestrian lighting schemes.

3.1 The angle between the light source and the viewer

Section 2 notes the comfort that people feel when lighting feels familiar and 'natural'. From the perspective of an individual viewer, lighting is generally 'off-axis': ie the sun does not stay directly behind an individual, and interior lighting illuminates from above. This off-axis lighting, or the presence of an angle between the incident light and the viewing direction, helps the viewer define the three-dimensionality of the viewed scene. Figure 3.1 illustrates the lighting and viewing of two identical cylinders – object A looks 'flatter' than object B.

- The 'on-axis' lighting of object A illustrates that incident light along an axis similar to the viewing direction has a limited ability to reveal the three-dimensionality of the lit object. However, this on-axis lighting angle does reduce shadowing from the aligned viewing direction.
- Object B is lit with a greater angle between the incident light and the viewing direction. This can be desirable for creating a more dramatic three-dimensional appearance, but can be undesirable because of the deeper shadows that it creates.

Figure 3.1 The angle of incident light and its 'flattening' or dramatic effect



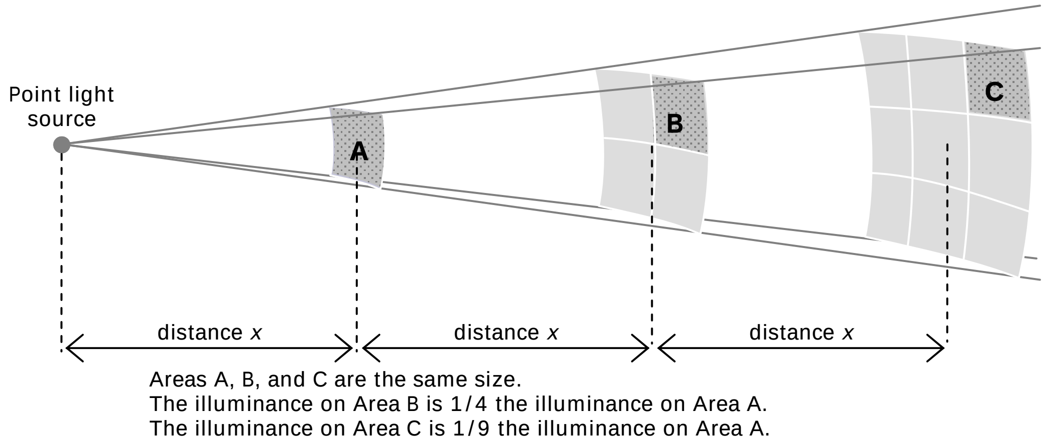
Where objects are lit from multiple directions and sources, features (particularly vertical building elements, such as columns and towers) can appear 'flat' if they are equally illuminated from multiple directions. A major incident light direction should be selected and evident. Images can also be optimised by ensuring that the greatest proportion of light arriving at a feature's surface comes from an off-axis direction, even though there may actually be many luminaires providing this light.

Overall, the extent of natural shadowing intended to be created by the pedestrian lighting scheme should be determined, and then primary incident light angles manipulated to deliver the desired effect.

3.2 The distance between the light source and the lit subject

Figure 3.2 illustrates how light from a point source follows the 'inverse square' law; thus, the light energy at twice the distance from the source is spread over four times the area, hence is one-fourth the intensity. This is relevant in the lighting of pedestrian areas, as a rapid decline of illuminance can cause an apparent lack of uniformity. The rate of decline of illuminance will be particularly marked closer to the light source. Therefore, lights can illuminate broad subjects more evenly when they are placed far from the subject; however, lighting at a greater distance from the subject may necessitate the use of a greater number of lights or a greater amount of illuminance.

Figure 3.2 Illuminance is inversely proportional to the square of the distance from the light source



Understanding this inverse square law that governs illuminance can be useful in considering public lighting for safe and attractive pedestrian areas. For example, when lighting objects against a background, if the distance from the light source to the object is about the same as the distance between the light source and the background, then the object and the background will be lit to about the same degree. If the light source is moved closer to the object, or if the object is moved closer to the light source, there will be greater relative distance from the light source to the background than from the light source to the object. Thus the background will be less lit than the object, emphasising the object and the three-dimensionality of the scene.

Lighting designers can manage combinations of luminaire mounting height, spacing and strength to give uniformity of illuminance over a pedestrian area. For example, lighting uniformity can be increased by shortening the spacing between luminaires, which means increasing the number of luminaires used, but potentially allowing a reduction in the output of each luminaire. Or, increasing the mounting height of luminaires may necessitate increasing the output of each luminaire, but can allow for greater spacing between luminaires.

Consideration and balancing of the distance between the light source and the lit area or subject is illustrated where a street is lit from luminaires on poles on only one side of the street. The footpath beneath the luminaires may have 'pools' of intense illumination but a noticeable decrease in illuminance between those pools. The footpath on the opposite site of the street could have less-intense illumination but greater uniformity of illuminance.

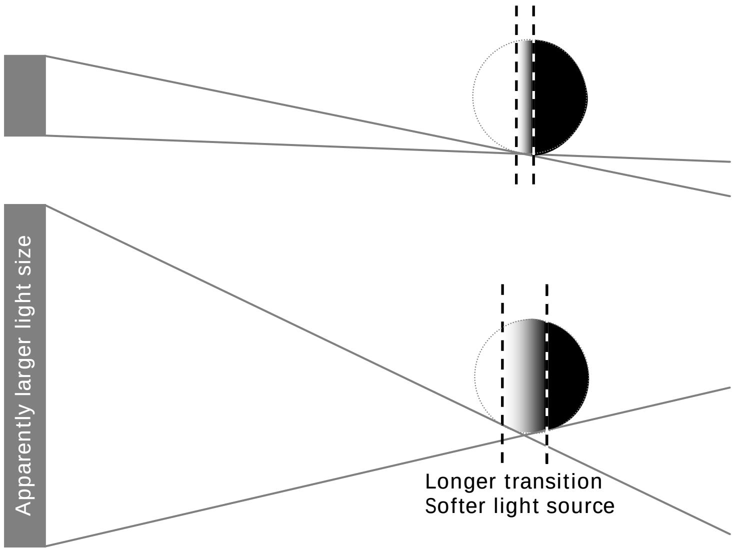
Lighting uniformity requirements are specified in the AS/NZS pedestrian lighting standards, but there may be particular circumstances where pedestrians can benefit from uniformity beyond the requirements of the standard. The significance of uniformity within a pedestrian lighting scheme should be identified and then managed, at least in part, through considering the distance between light sources.

3.3 Shadows and the ‘size’ of the light source

Creating public lighting for pedestrian areas naturally includes creating shadows in pedestrian areas. To predict some characteristics of the shadows, it is useful to consider the light source from the perspective of the lit subject. For example:

- The sun is immensely large as a light source, but from the perspective of any lit subject, it is so far away that it looks very small.
- For a subject only one metre from a regular light bulb, the light source can look quite large.
- Thus, the light source can be made to look larger by either increasing the size of the light source, or by moving the light source closer to the subject.

Figure 3.3 Demonstrating the shadowing effect of light sources of different ‘size’ – from the perspective of the lit subject, the (apparently) larger and softer the light source, the smoother and longer the transition from full illumination



The ‘size’ of the light source, as experienced by the lighted subject, affects the rate of graduation in the formation of shadows and thus affects the hardness or softness of shadows created. Figure 3.3 illustrates the three zones of lighting that are created over an object’s surface according to where the object experiences the *full* light source (the diffused highlight), *some* of the light source, and *none* of the light source (the shadow).

- A subject lit by a small light source has a narrow or abrupt transition zone, so the lighting is termed a ‘hard light source’.

- A subject lit by a large light source has a broad transition zone, so the lighting is termed a 'soft light source'.

For public lighting situations, luminaires with high mounting heights can appear small from the perspective of the lit subject, and thus hard shadows can be created. Pedestrians' general comfort can be adversely affected by the sudden transitions of hard shadows, which exacerbate the perception of lack of lighting uniformity. Strategies to counteract hard shadows include having multiple light sources from other directions providing light into the shadow areas created by the light source in question, or providing an apparently larger light source.

Pedestrian lighting schemes can be inspected for the presence of hard light sources creating hard-shadow transitions, and if this is considered to be having an adverse effect on pedestrians' experience of the lighting, the design can be altered to mitigate this problem. This may entail providing a greater number of light sources, which can mean increased costs and the potential for light spill and wastage.

3.4 Other aspects of lighting to be controlled

3.4.1 Light–surface interactions

In road safety lighting design, the reflective properties of the surface of the road play a major role in design calculations. The variety and abrupt changes of textures and grades that are characteristic of pedestrian areas mean that lighting levels within these areas should be considered independently of the reflective properties of any surfaces involved (Fördergemeinschaft Gutes Licht 1999). The standard AS/NZS 1158.3.1:2005 also requires that surface reflection properties are not taken into account in the design of pedestrian lighting.

Nevertheless, pedestrian lighting designers must be aware that the effects on visibility of any illumination will be affected by its interplay with the environmental surfaces.

To *highlight* an object with light, the illuminance required at the surface depends essentially on the object's surface reflectance and the level of background or ambient luminance.

For *general* lighting, and particularly when using lighting for certain effects:

- the lower the object's reflectance, the higher the on-object illuminance that is required
- the higher the ambient luminance, the higher the on-object illuminance that is required (Fördergemeinschaft Gutes Licht 2000).

For general lighting over a pedestrian area, the lighting designer may consider the areas where maximisation of illumination effects is appropriate, and other areas where minimisation of illumination effects is appropriate. For example:

- Where more luminance is appropriate, greater utilisation of supplied illuminance can be achieved by providing light-coloured walls and surfaces to facilitate inter-reflection of light.
- Where glare and discomfort could arise from light interacting with high-gloss finishings and surfaces, dark or matte surfaces can be used to limit obtrusive light by reducing the amount of reflected or dispersed light.

- While it may seem to be outside of a lighting designer's duties, it should be remembered that reflection of light can also arise when some smooth-textured surfaces become wet – therefore, free-draining conditions should be ensured for all surfaces.

3.4.2 Pedestrians and coloured lighting

Lighting colour affects pedestrians' experience of lighting, and can be controlled via two aspects of illumination colour: colour appearance and colour rendering.

- **Colour appearance** refers to the apparent colour of the emitted light. For example:
  - The red or green of a traffic signal can be created via the light being viewed through a coloured gel.
  - Street lighting from low-pressure sodium lamps can appear orange because of the wavelength of this light source.
  - The colour appearance of lighting may influence the amount of useable visibility provided by that lighting. This is frequently topical with respect to 'white light versus yellow light', and is discussed in section 4.3.1.
  - The colour appearance of lighting can be selected to particularly complement the scene being lit, to create prestigious and attractive effects (discussed in section 6.3.1).
- **Colour rendering** refers to the effect that lighting has on the colours of the objects that it illuminates. For example:
  - A yellow sheet of paper would appear yellow under daylight conditions, but if seen under the light of a regular house lamp or under a fluorescent tube light source, the shade of yellow could vary.
  - The accuracy of colour rendering may be particularly pertinent to pedestrians' perceptions of personal security, and this is discussed in section 4.3.2.

3.4.3 Minimising potential nuisance of light

Pedestrian lighting can sometimes be criticised for causing nuisance through misdirection of illumination creating glare or 'spill' light. It is also possible to create 'inappropriate lighting' through over-lighting a location or certain features. Each of these can represent illumination distributed at unnecessary angles or intensities. Thus, besides other potentially adverse effects, they can indicate inefficient design and usage of lighting energy.

'More illumination' does not necessarily create better pedestrian lighting. Over-lighting of spaces and objects can diminish the contrast and effect of highlighting, thus diminishing the overall aesthetic appeal. Additionally, the potential for pedestrian lighting to communicate the type of usage intended for a pedestrian area during the hours of darkness can be diminished if the entire area has a uniformly bright illuminance.

Over-lighting of particular areas or features with intense, directed illumination can create glare that may reduce pedestrians' perceptions of comfort and security.

- **Glare** occurs when light is seen as too bright, relative to the ambient brightness that the viewer has adapted to, eg when the pedestrian moves rapidly between an area of low luminance and an area of high luminance; or if a light source within the pedestrian's field of view provides illumination much more intense than the general level of ambient lighting.

  - Pedestrians may squint, or avert or shade their eyes from sources of 'discomfort glare'. This type of glare may not affect vision, but it can be irritating or produce adverse psychological effects.
  - 'Disability glare' affects, and can impair, viewing ability. The surfaces and fluids of the eye are not perfectly clear, and these can cause scattering of light entering the eye. This scattering can form a veil of light that reduces available contrasts and visibility, creating disability glare.
  - Glare can be distracting as, at night, the human eye is drawn to the most luminous element in its field of vision.

- '**Spill light'** occurs where illumination is provided outside of the target area. Illumination can also spill upwards, creating 'sky glow'.

The potential for a pedestrian lighting scheme to produce spill light should be assessed both within the lit area, and more broadly outside the subject area. Physical measures and careful consideration through the design of a pedestrian lighting scheme can restrict glare and spill light. For example:

- Luminaires should be positioned and aimed to minimise the incidence of bright light shining straight into a person's field of view.

- Luminaire mounting heights need to be carefully considered for all likely users of a lit space. For instance, some areas lit for pedestrians are also used by buses or delivery trucks. While a low luminaire mounting height may provide well for pedestrians' lighting needs or preferences, it could create glare for drivers of higher vehicles, as illustrated in figure 3.5 on the next page.

- Bright sources of light can be replaced with a larger number of weak sources, to reduce glare levels but still provide the same overall level of illumination.

- Interactions with glossy surfaces creating reflected glare should be avoided.

- Luminaire fittings can be selected to control the distribution of light. As figure 3.4 illustrates, different luminaires control the maximum angle between the central perpendicular axis of illumination (or straight down) and the extent at which no illumination from the luminaire is visible. Luminaires recommended for a pedestrian area should be assessed in terms of the angles of illumination they permit and the resultant extent of glare or unwanted spill light.

Figure 3.4 Luminaire fittings can be chosen to control the range of angles of illumination they provide

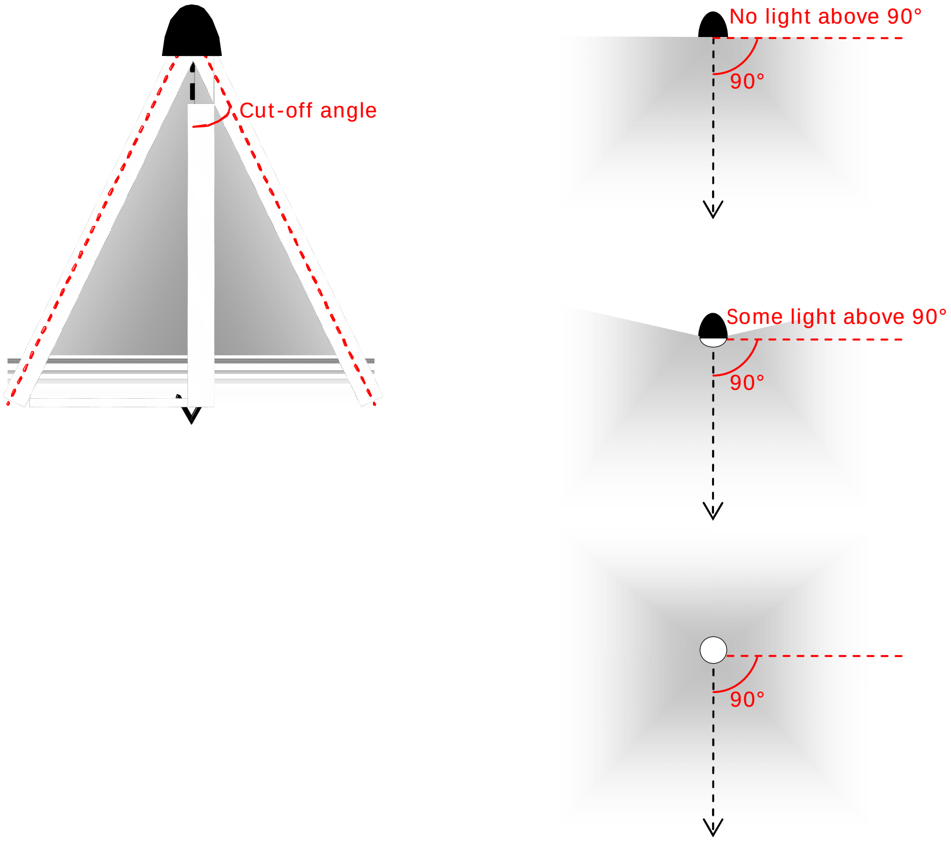
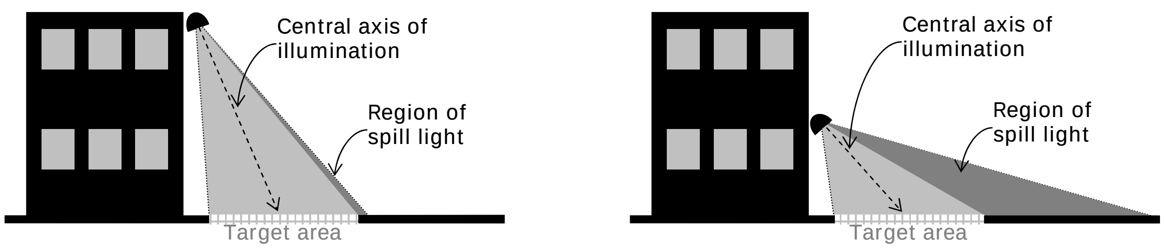


Figure 3.5 illustrates how illumination can be better managed by using narrower, controlled beams of light mounted at greater heights. This can ensure the same overall lighting coverage as wider beams of light mounted at lower heights, but the narrower beams of light can be more effectively aimed towards a confined area, thereby reducing the amount of spill light that is created (Lighting Research Center 2003).

Figure 3.5 A controlled light source at a higher mounting height provides the same amount of useful light to a target area, with less spill light than would be achieved with a luminaire with a wide-angle beam at a lower mounting height (Lighting Research Center 2003)



With the central axis of illumination on the centre of the target area, the target area can be lit from a **high mounting** height with a **narrow-angled** luminaire → there is only a **small** region of spill light.

With the central axis of illumination on the centre of the target area, the target area can be lit from a **low mounting** height with a **wide-angled** luminaire → there is a **large** region of spill light.

4 Pedestrians' experience of lighting

During daytime, natural light aids a safe, comfortable, efficient and enjoyable walking experience. During darkness, artificial lighting techniques should light the environment for the particular needs and preferences of pedestrians to maintain that standard of walking experience.

It is important to differentiate between the lighting needs and preferences of motorists and the lighting needs and preferences of pedestrians. In the following sections, where appropriate, some lighting concepts will be explained through a comparison of the pedestrian's perspective with the motorist's perspective.

Effective pedestrian lighting optimises the amount of useable visibility that is provided for pedestrians. Visibility via 'negative contrast' and visibility via 'positive contrast' have different effects on pedestrians' vision, and section 4.1 describes how these options should be considered and used in pedestrian contexts. Section 4.2 compares techniques for measuring lighting with pedestrians' experience of lighting; and section 4.3 considers how lighting colour affects the useable visibility created for pedestrians.

4.1 Pedestrians and 'negative-contrast' lighting versus 'positive-contrast' lighting

Figure 4.1 illustrates two approaches for providing visibility through lighting.

Figure 4.1 Visibility through negative contrast versus visibility through positive contrast

Negative contrast
Dark (silhouette) object on bright background – movement of the object can be detected.

Positive contrast
Bright lit object on dark background – detail of the object can also be discerned.

Lighting for road safety generally involves maintaining a level of background illumination on the road surface so that objects (and potential obstacles) are seen by drivers as dark silhouettes. This is known as 'negative contrast'. Negative contrast is effective at providing visibility of the outlines of objects and will show movement of an object, even at longer distances. Human vision is particularly sensitive to negative contrast, with acceptable visibility (for road safety purposes, for example) being created through the extent of the contrast between the dark silhouettes and the bright background.

In some pedestrian environments, pedestrians can benefit from greater quantities of illumination to see, at close range, details that are of less importance to the driving task and road safety. 'Positive contrast', where the object is lit to be brighter than the background, helps people discern the particulars of the object, such as surface patterns and textures. These aspects are valuable for pedestrian safety with regard to negotiating surfaces and obstacles, or for object identification. Visibility of these details contributes to pedestrian comfort.

To meet pedestrians' needs, it is possible to use a combination of the negative-contrast and positive-contrast approaches. The nature, purpose, and scale of the pedestrian area or regions within the pedestrian area can indicate the places where close-range visibility is required, and where visibility to enable only the detection of movement is sufficient. For example, in places where pedestrian traffic through an area is concentrated and encouraged to travel along a defined path, the following approaches are suggested:

- Within the immediate vicinity of that path, provide greater positive-contrast illuminance.
- Away from the path, where the highlighted details that are provided from positive-contrast lighting would be unnecessary, graduate to techniques of illumination for negative contrast (eg lighting the bordering surfaces to create silhouettes of any objects that are against them).

Where it is appropriate, lighting to create negative contrast can be more economical than lighting for positive contrast, and can also lessen adverse effects of light wastage or light spill. Both 'negative-contrast' lighting and 'positive-contrast' lighting should be considered when assessing a pedestrian lighting scheme, with pedestrian visibility requirements being the key factor.

4.2 Pedestrians' experience of lighting compared with lighting measurements

There are a variety of ways to measure the amount of lighting (or illuminance) provided throughout a pedestrian area. These need to be applied judiciously to ensure that the measure corresponds meaningfully to the illuminance that pedestrians can effectively use. There are specific vertical heights and lighting angles that are most useful to pedestrians, and these should be the focus of illuminance measurement and design in pedestrian contexts.

Being able to see an approaching person's face is important for a pedestrian when they are trying to judge whether that approaching person is an acquaintance, or perhaps means to do harm. AS/NZS 1158.3.1:2005 sets requirements for the illuminance on a vertical plane at a height of 1.5 metres above ground level (clause 3.4.9(b)). The vertical orientation and 1.5 metres height of the measurement plane are cognisant of the typical approximate orientation and height of a human face.

This standard is supported by the Australian/New Zealand standard *Lighting for roads and public spaces, part 2: computer procedures for the calculation of light technical parameters for category V and category P lighting (AS/NZS 1158.2:2005)*, which describes how to calculate vertical illuminance within 'public activity areas' – at each calculation point, the vertical illuminance should be calculated for a vertical plane at a height of 1.5 metres above ground level 'in any selected orientation' and 'for both sides of the vertical plane'.

> *The intention of this requirement is to ensure that, as far as is practicable, light reaching a given point will come from several divergent directions which should ensure reasonable*

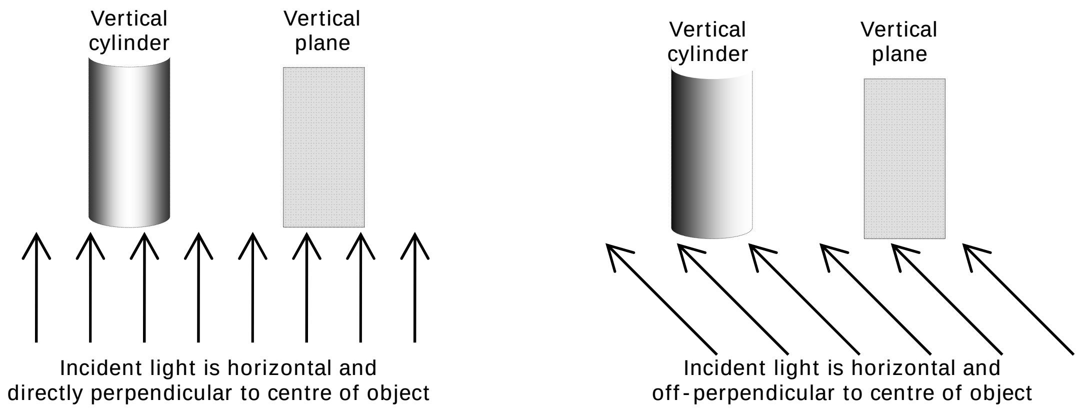
modelling[1]*, and therefore recognition, of persons viewed from any orientation* (AS/NZS 1158.2:2005, clause 3.3.6(b)).

This aspect of the vertical illuminance calculation recognises that pedestrian lighting must be considered in flexible terms to reflect how pedestrian activity in an area is also flexible and multidirectional. Features and areas should be lit with more than one light source, to increase the extent and occurrence of acceptable viewpoints. Whereas the general movements of motorised road users are typically constrained within the defined traffic lanes, so that street lighting can primarily only be experienced from a limited number of approach directions, pedestrians are more mobile and are able to observe lighting from a full range of locations within the subject area. The experience of a pedestrian lighting scheme must be considered from every possible viewpoint.

Further to this, some literature suggests that considerations of *vertical* illuminance do not effectively relate to a pedestrian's visual experience. Vertical illuminance is measured on a designated vertical flat plane. The value of illuminance received on the surface is strongly dependent on the direction of the incident light. In pedestrian areas and situations, flat and static vertical planes seldom exist. Plus, as indicated above, pedestrians and other objects within a pedestrian area are mobile, so the orientation of a subject relative to light sources is not constant. Some research proposes that *semi-cylindrical* illuminance allows greater consideration of the three-dimensionality or roundness of objects and may better represent pedestrians' visual reality.

Figure 4.2 represents the visual effects that could be created on semi-cylindrical objects and flat planes through equal quantities of illuminance but provided at different angles of incidence. When the incident light is direct and perpendicular to the objects, the difference between the illuminance effect on the objects is slight; but when the incident light is (horizontally) angled across the objects, deeper shadows are created on the face of the cylinder.

Figure 4.2 Sensitivity of vertical illuminance on the face of a vertical cylinder versus on a vertical plane



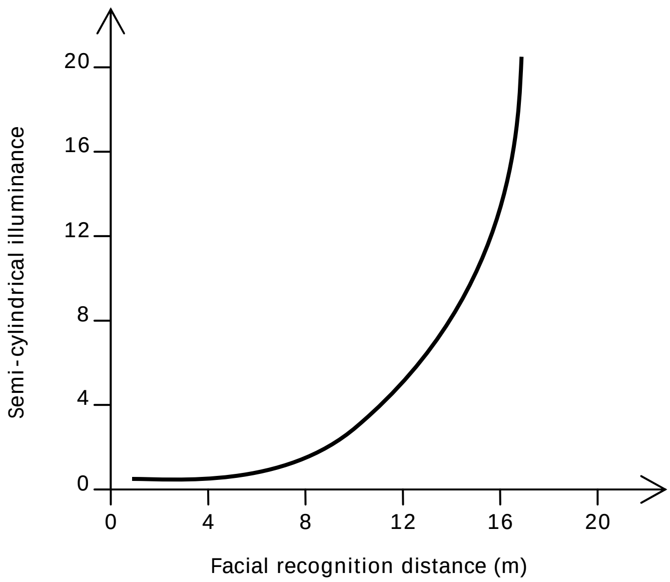
Rombauts et al (1987) propose that 'semi-cylindrical illuminance is the appropriate descriptive parameter' to describe pedestrians' facial recognition capacities based on 'experiments carried out under real outdoor

1 In this context, 'modelling' refers to the way in which a light source can be moved, relative to the subject, to control the extent of shadows created. Modelling light can be used to exaggerate the relief or contours of objects, with dramatic effect, or can be used to accurately re-create natural lighting conditions.

conditions'. The experiments showed a 'very good correlation between the facial recognition distance and the value of [semi-cylindrical illuminance]', as sketched in figure 4.3. The authors suggest that the 'vertical asymptote' for facial recognition distance, at approximately 17 metres, corresponds to a physiological limit of human vision; they therefore note that 'at levels of 20 to 25lux, increasing [semi-cylindrical illuminance] will not lead to a further increase in the [facial] recognition distance'.

The general shape and values of the relationship shown in figure 4.3 on the next page are similar to those found by Caminada and van Bommel (1980), who investigated for relationships between facial recognition distance and any of the three illuminance types – vertical illuminance, semi-cylindrical illuminance, or hemispherical illuminance[2] – measured at face height. It was found that there was no reliable correlation between vertical illuminance and facial recognition distance. Some correlation was found between hemispherical illuminance and facial recognition distance, but a good correlation was found between semi-cylindrical illuminance and facial recognition distance.

Figure 4.3 Sketch of the relationship between facial recognition distance and semi-cylindrical illuminance, found by Rombauts et al (1987)



The standard AS/NZS 1158.3.1:2005 does not refer to semi-cylindrical illuminance. Particularly during design and review of a pedestrian lighting scheme, there should be awareness of this concept and its potential for effects on visibility for pedestrians. Including semi-cylindrical illuminance criteria would promote the provision of illuminance from multiple sources at multiple angles.

The comparisons and measurements of vertical illuminance versus semi-cylindrical illuminance may all be taken in the context that Rombauts et al (1987) note: '... when people are asked to express their overall impression of an area, they seem to remain thinking in terms of light coming from above (as they are used to the sunlight by day)'. Thus, pedestrians may primarily relate assessment of lighting to the levels of horizontal illuminance present.

2 Hemispherical illuminance is calculated as the luminous flux on a small hemisphere with a horizontal base divided by the surface area of the hemisphere.

Even if it is not possible or practical to widely calculate semi-cylindrical illuminance within the assessment of a pedestrian lighting scheme, awareness of the concept still offers value as a perspective to include in the process.

4.3 Lighting colour

4.3.1 Colour appearance

The human eye's response to different colours (or wavelengths) of light varies, and the effectiveness of a particular output of illumination may be experienced as greater or lesser depending on the light colour. This is part of the basis of the 'white light versus yellow light' debate. Figure 2.1 illustrated how darkness-adapted scotopic vision is most sensitive around the blue range of the spectrum of light wavelengths. White light includes more of this blue range of wavelengths than yellow light does.

Traditionally, a lot of public lighting and road lighting has been provided by sources such as sodium vapour lamps. These lamps generally provide illumination with a yellow colour appearance. Other lamps that supply an illumination with a white colour appearance are available, such as mercury vapour lamps or metal halide lamps.

Although not all publications agree on the extent to which the colour appearance of a light source influences the visibility it provides for pedestrians, the majority (examples are detailed below) indicate that white light provides greater visibility than yellow light.

- Raynham and Saksvikronning (2003) conducted a series of laboratory-based experiments to determine the impact of a light's colour appearance on the distance at which users could discern facial features and expressions. A laboratory was set up to simulate a street with lighting columns. Experiment subjects walked towards a person (or two people) until facial recognition was achieved. Three light sources, ranging in colour appearance from white to yellow (provided by a high-pressure sodium lamp such as those regularly used in street lighting), were used. Overall, at equal illuminance levels (number of lumens), white light was determined to permit a greater facial recognition distance than yellow light.

- The City of Melbourne (2002) states that 'at low levels of illumination, such as those experienced on a city street at night, the human eye is more sensitive to white light than yellow light'. This is in line with the physiological information contained in section 2 of this report; ie the frequency of white light facilitates the peripheral vision provided by rods in the eye's retina thus broadening the size of the visibility field more so than the effects of light at the yellow frequency.

- Clause 2.6 of AS/NZS 1158.3.1:2005 discusses calculation of illuminance. It states that the illuminance values 'for [slightly yellow] high pressure sodium (HPS) lamps shall be derated to 0.75 of their quoted value and those for [more yellow] low pressure sodium (LPS) lamps shall be derated to 0.5 of their quoted value'. The standard explains that 'this requirement is included to compensate for the decreased sensitivity of the eye in yellow light at low light levels'.

The artistic and subjective effects of lighting colouring are discussed in section 6.3.1.

4.3.2 Colour rendering

Colour rendering refers to the way in which colours are perceived when illuminated by a light source. Whereas colour appearance refers to the colour of the light that a source emits, colour rendering refers to the effect that a source's light has on the colours of the surfaces that it is lighting.

The colour impression of a surface is considered 'normal' under daylight conditions, and the colour-rendering ability of a light source can be compared to this standard. The colour-rendering index of sunlight is 100, and this represents the upper limit and optimum on the index. Incandescent light sources and metal halide light sources, which create white light, typically have high colour-rendering indices, greater than 80. Sodium lamps, such as have historically been the predominant type for use in public lighting, and which create yellow light, have lower colour-rendering capabilities, typically with indices less than 25.

City of Melbourne (2002) states that 'public lighting with high colour rendering, such as white light from metal halide sources, provides viewers with a more accurate sense of natural colours, sizes and shapes of objects'.

This has two implications:

- Most people experience a feeling of well-being when in contact with nature, so pedestrian lighting that replicates or simulates natural lighting will be received well by pedestrians.
- Lighting with accurate colour rendering enables witnesses to discern the colours of clothing, vehicles and hair, and could therefore be useful in the investigation of crime and antisocial behaviour.

Figure 2.1 illustrated how photopic vision operates, with more illumination available, and over a wider range of light wavelengths (colours), when compared with scotopic vision. The required level of illumination should be assessed relative to the type of vision (photopic or scotopic) that will dominate in that situation, and with respect to the level of colour perception that is needed. Some literature suggests that at the levels of illuminance typical of public lighting, the eye's ability to judge colour is so impaired that the colour-rendering capability of the light source is not significant. Other research has found that promoting accurate colour rendering can increase users' sense of well-being and perceptions of personal security. This effect is especially noted in environments such as public urban pedestrian areas, where contacts with strangers and unfamiliar objects are common.

A pedestrian lighting scheme can be assessed in terms of the extent of colour-rendering accuracy. Light sources can be selected to deliver high colour rendering if that is considered to be significant to the effectiveness of the pedestrian lighting scheme's intentions.

5 Lighting spaces for pedestrians

Section 5.1 focuses on the topic of ‘where to light for pedestrians’ through considering typical pedestrian tasks and the size of the visibility field appropriate for those tasks. Section 5.2 expands on this by considering the visual experience of pedestrian lighting with respect to the purposes and effects over the complete area.

5.1 The visibility fields required by pedestrians

5.1.1 Visibility field and physical safety

For safety and navigation, the visibility field required by pedestrians is much smaller than that required by motorised road users.

Motorists require lighting that will make obstacles on the carriageway visible and provide advance guidance to allow route navigation. Generally, this requires a viewing field corresponding to a travelling time of 5–10 seconds.

Compared with motorists, pedestrians can be much more responsive to obstacles, and only require lighting that will give a few seconds of visibility of such objects to enable safe passage with no physical injury. The ‘few seconds’ visibility can be related to the travelling speed of the pedestrians – for example, a few seconds at a likely pedestrian walking speed of 80 metres per minute corresponds to a forward visibility range of approximately 4–6 metres.

Obstacles to safe physical pedestrian negotiation of an area are most likely to be on or near the walking surface – for example, loose material or changes in level (although other ‘higher’ obstacles, such as overhanging branches, should also be considered). Lighting of ‘physical obstacles’ and the ‘ground level’ must create the few seconds of visibility field required by pedestrians for physical safety. Where meeting obstacles is more likely, such as on a stairway, or where pedestrians are moving faster, such as on a running route, a greater quantity of ground-level illuminance is appropriate. Once the amount of ground preview time is defined, the lighting can be technically specified to provide that visibility field.

5.1.2 Visibility field and personal security

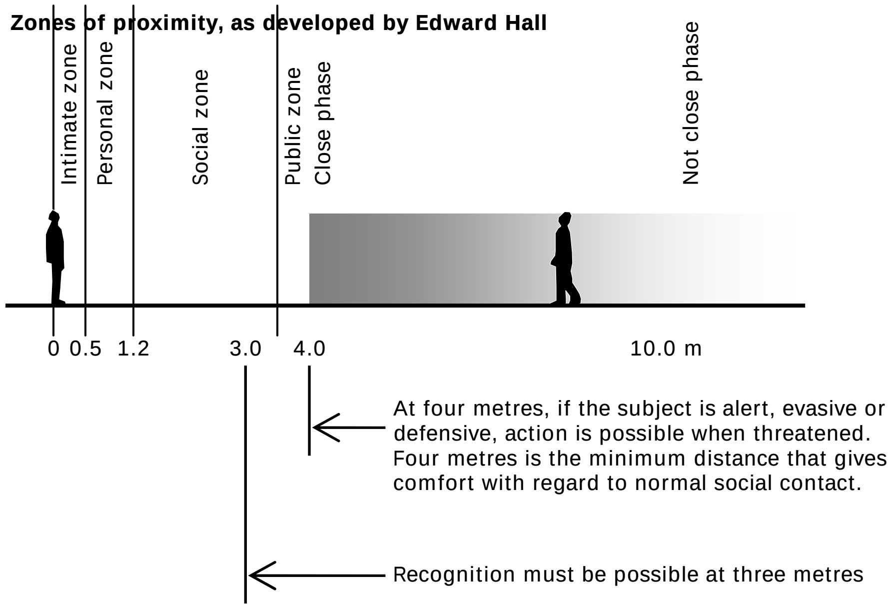
With respect to personal security, pedestrians require lighting to enable visibility of other people who are approaching, or in the vicinity, from a reasonable distance away. Pedestrians must be able to judge whether an oncoming person is friendly, indifferent, or aggressive in sufficient time and space to make any appropriate response. According to Caminada and van Bommel (1980):

> *The lighting in a street should permit of mutual recognition before coming almost face to face and provide sufficient visual information regarding a person anywhere on the street while he or she is still a reasonable distance away. This has to do with the feeling of security.*
>
> *The point is to define a ‘reasonable distance’ as well as what is meant by ‘sufficient visual information’.*

The range of visibility field required for acceptable pedestrian perceptions of personal security is greater than the range required for their physical safety. Much pedestrian lighting guidance incidentally illustrates alignment with this approach by commonly considering personal security as the critical determinant of pedestrian lighting requirements. Other sources provide more formal evidence and a range of suggestions for the size of visibility field required.

As cited in works by Raynham (2004) and Caminada and van Bommel (1980), in the 1960s Edward Hall, an anthropologist, investigated the distances between people at which they feel comfortable, and developed four 'zones of proximity' that depend on the nature of the social context, as shown in figure 5.1.

Figure 5.1 Zones of proximity, as developed by Edward Hall



- The 'intimate zone' is within approximately 0.5 metres and applies for social contacts – eg embracing, touching, or whispering.
- The 'personal zone' is 0.5–1.2 metres apart – interactions among good friends occur within this range.
- The 'social zone' is 1.2–3.5 metres apart – interactions among acquaintances occur within this range.
- The 'public zone' is outside of 3.5 metres, and divided into two phases of 'close' (3.5–10 metres) and 'not close' (starting at 10 metres).

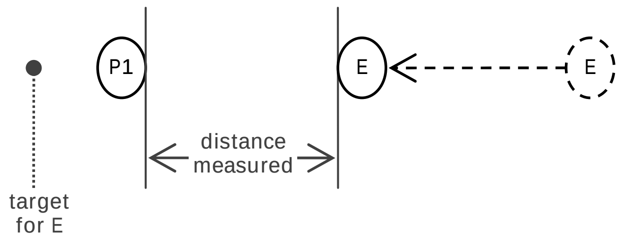
Hall added that low illumination of an environment can increase the spacing of these zones.

Based on the work of Hall and some experimental investigation, Caminada and van Bommel (1980) suggest that an ideal facial recognition distance would be 10 metres, at the point of transition between the 'not close' and 'close' phases of the public zone. A recommendation for the minimum distance for facial recognition is about 3 metres.

Research from Oc and Tiesdell (1997) indicates that facial recognition in 'day lighting conditions' normally occurs up to 22 metres away. 'Once this distance is reduced below 15 metres, the space in which [pedestrians] have time to react to avoid trouble, or simply an undesirable situation, becomes reduced beyond comfortable levels.'

Research undertaken by Fuijiyama et al (2005) included an experiment where participants stood stationary while being approached by another pedestrian, as illustrated in figure 5.2. The experimenter pedestrian continued to walk towards each participant until the participant indicated they were uncomfortable because of the close distance between them and the oncoming pedestrian. The experiment was repeated under five different lighting conditions.

Figure 5.2 Experiment setup by Fujiyama et al (2005) for establishing 'minimum comfort distance'



Minimum comfort distance
One experimenter (E) walks towards a participant (P1).

As the experimenter approaches the participant, the participant indicates the point when they feel uncomfortable because of the closeness of the approaching experimenter.

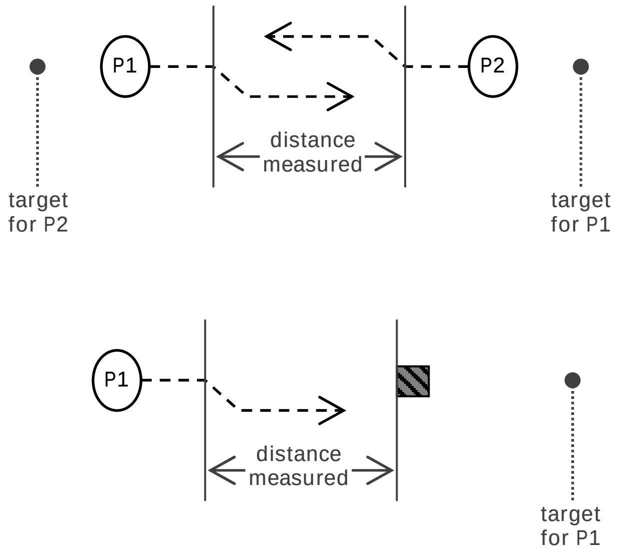
The distance between participant and experimenter at that point is recorded as the minimum comfort distance.

Under 'day lighting conditions' the 'minimum comfort distance' was found to be around 4 metres, and under 'night lighting conditions' the 'minimum comfort distance' ranged from just over 4 metres up to 5.2 metres at the lowest illumination level tested.

The 'minimum comfort distances' identified in the Fujiyama et al (2005) study, where the subject (participant) was stationary and the other person (experimenter pedestrian) was moving, are larger than the equivalent distances found in other studies where both the subject and the other person are stationary. Fujiyama et al suggested the explanation 'that the perception of pedestrians in motion is different from that of stationary people'.

Fujiyama et al also used their laboratory situation to investigate the collision-avoidance and obstacle-avoidance behaviours of pedestrians under different levels of illumination. Participant pedestrians were set walking towards a target with their path being in line with another oncoming pedestrian, or an obstacle. Experimenters recorded where participants started their avoidance manoeuvre with a deviation from their 'direct' path. The two setups are illustrated in figure 5.3.

Figure 5.3 Experiment set up by Fujiyama et al (2005) for establishing 'collision avoidance distance' and 'obstacle avoidance distance'



Collision avoidance distance
Two participants (P1 and P2) walk towards each other, each on their direct path to their target.

As the participants approach each other, at some point, a participant veers from their direct path.

The distance between the two participants at that point is recorded as the collision avoidance distance.

Obstacle avoidance distance
One participant (P1) walks towards an obstacle that lies on the participant's direct path to their target.

As the participant approaches the obstacle, at some point, the participant veers from their direct path.

The distance between the participant and the obstacle at that point is recorded as the obstacle avoidance distance

Under 'day lighting conditions' the 'collision avoidance distance' and the 'obstacle avoidance distance' was each around 5.5–6.0 metres. Under 'night lighting conditions' the 'collision avoidance distance' was 8–9 metres, and the 'obstacle avoidance distance' was 6–7 metres.

It cannot be determined whether this finding implies that pedestrians relate to 'other pedestrians-as-obstacles' differently from how they relate to 'objects-as-obstacles', or whether it is further evidence of the finding from the 'minimum comfort distance' work, that people relate to *stationary* obstacles (ie objects or other pedestrians) differently from *moving* obstacles.

Overall, factors for determining suitable visibility fields for pedestrians include the nature of movement of the pedestrians and the general level of illumination. Likely user familiarity with the area and likely user activities or interactions could also be considered.

5.1.3 Visibility for specific pedestrian tasks

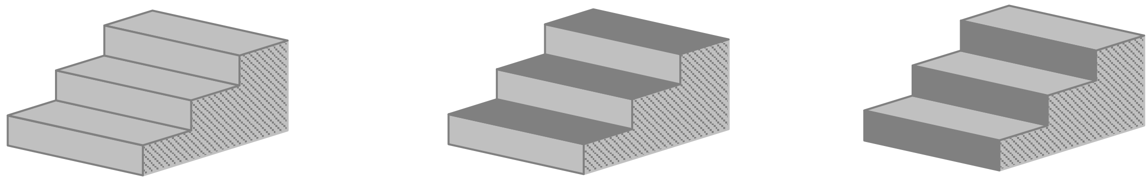
To minimise risk of trips and falls, pedestrian lighting must highlight hazardous locations such as obstacles, edges of walkways, and changes of grade. Greater ambient illumination could assist this task. Supplemental lighting at a mounting position closer to the critical surface can be considered if installed carefully to manage glare or potential for vandalism.

For stairs, the standard AS/NZS 1158.3.1:2005 sets equal values for the minimum-point horizontal illuminance and the minimum-point vertical illuminance.[3] Some literature suggests that the illumination

3 It is noted that the standard *Lighting for roads and public spaces, Part 3.1: Pedestrian area (category P) lighting – performance and design requirements (AS/NZS 1158.3.1:2005)* qualifies that 'for steps, the requirements assume that the noses of the treads are clearly delineated by a contrasting stripe or other equally effective means'.

sources for stairs could be angled (in the vertical plane) so as to maximise the contrast in illuminance values between the risers and the treads. This is illustrated in figure 5.4.

Figure 5.4 Changes in grade can be highlighted through creating contrast in illumination levels



Vertical illuminance on risers **equal to** horizontal illuminance on treads

Vertical illuminance on risers **greater than** horizontal illuminance on treads→ enhanced contrast

Vertical illuminance on risers **less than** horizontal illuminance on treads→ enhanced contrast

Pedestrian areas can include bus stops, payphones, vending machines, money machines/automatic teller machines (ATMs), and sometimes maps and information panels, or tables and seating. Around these features, pedestrians may briefly pause or may remain stationary for a time, and tasks at some of these features may involve money. These types of activities can contribute to some people feeling particularly vulnerable to crime or antisocial behaviour. Other tasks such as eating or reading, which people may conduct within pedestrian areas, may require visibility additional to that required for general walking tasks.

To overcome any associated particular feelings of risk, and to provide for extra visibility needs, special illumination could be considered for specific zones or features – but it must be designed carefully. While providing greater illumination for a certain area may aid visibility and increase users' perceptions of personal security, the use of bright lighting, relative to the ambient lighting levels, could create glare or a 'fish bowl effect', where users within the brightly lit area are made highly visible to those at a distance, yet it is difficult for the users within the brightly lit area to observe their broader surroundings (Zelinka and Brennan 2001). Where a relatively brightly lit area is to be created, visibility *within* the area, appropriate for likely tasks, and visibility *out of* the area, both need to be considered. Visibility out of the area can be facilitated by graduated transitioning between different illumination quantities.

From this contextual introduction, it is useful to define two conditions over which variation in lighting quantities occur:

- Variations in lighting quantities within a space or over an area are expressed by the uniformity of the lighting.
- Variation of lighting quantities between adjacent spaces or areas is considered in terms of a ratio of the lighting quantities.
- The ratio of lighting quantities in adjacent areas is relevant to the 'fish bowl effect'.

Table 3.2 of the Australian/New Zealand standard *Interior and workplace lighting, part 1: general principles and recommendations AS/NZS 1680.1:2006* provides a maximum recommended ratio of luminances of the task:immediate surrounds:general surrounds of 10:3:1. Table 3.2 of the standard also states that for general lighting, the illuminance ratio between adjacent spaces must not exceed 10:1, with a note to 'consider need for lower ratio if there are hazards in the space with the lower illuminance'. 'Particular attention should be given to this aspect where people may move from a well-lit space into a less well-lit space' (AS/NZS 1680.1:2006), as human eyes adapt from greater illuminance to lesser illuminance more slowly than the reverse transition.

5.2 Area-wide consideration of pedestrian lighting

The concepts of specific pedestrian visibility considerations in the preceding sections should be combined and applied throughout the design and review of a pedestrian lighting scheme. Pedestrians transition between tasks and purposes throughout a pedestrian area, and likewise, the appropriate lighting will transition, so that a completely uniform lighting provision is unlikely and is sometimes undesirable. This section considers the positive and negative effects that can be created by varying lighting between contiguous zones.

5.2.1 Variations of illuminance levels over an area

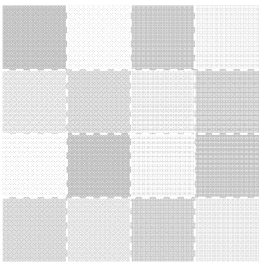
The standard AS/NZS 1158.3.1:2005 assesses lighting in terms of the following light technical parameters (as defined in category P lighting):

- Average space horizontal illuminance is the 'mean illuminance over the specified section of the applicable area'.
- Point horizontal illuminance is the illuminance arriving at a point on a horizontal plane at ground level.
- Illuminance (horizontal) uniformity, for pedestrian (category P) lighting, is the 'ratio of the maximum illuminance to the average illuminance within the specified area'.
- Point vertical illuminance is the illuminance arriving at a point on a vertical plane at a height of 1.5 metres.

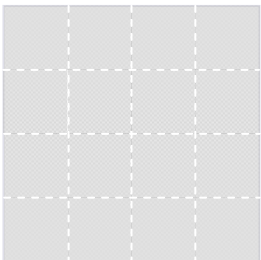
The parameters for average illuminance and illuminance uniformity are relevant to considering the light distribution over and throughout a space used by pedestrians.

Figure 5.5 represents three possible illuminance distributions. Situation A and Situation C show illuminance distributions where the range of illuminance levels present over each total area is spread evenly around the calculated average illuminance level. Situation B shows a complete area illuminated at a level equal to the calculated average illuminance.

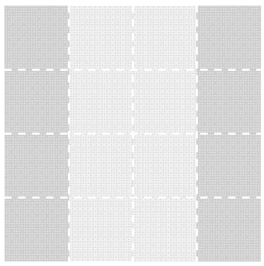
Figure 5.5 Three possible illuminance distributions giving equal average illuminance values over the total area



Situation A
Average 50%
Uniformity 90/50
1.8



Situation B
Average 50%
Uniformity 50/50
1.0



Situation C
Average 50%
Uniformity 70/50
1.4

(This figure is intended only as illustration of the concept. In reality, pedestrians would likely not be able to discern between the levels of uniformity, and AS/NZS 1158.3:2005 sets the maximum allowable illuminance uniformity at 10.)

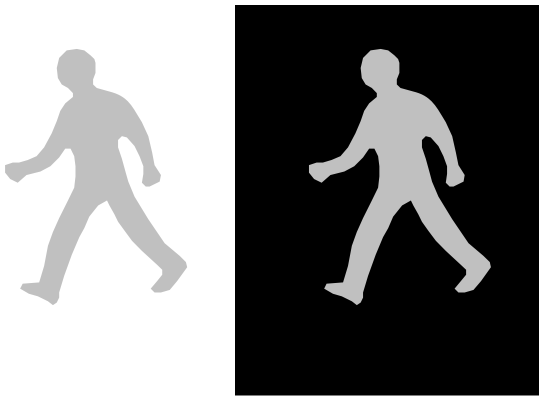
Each of the illuminance distributions illustrated in figure 5.5 give equal average illuminance values but different values of illuminance uniformity. Given that averaging calculations can mask the actual range of illuminance values within an area, as shown in figure 5.5, uniformity measurements must also be assessed when considering likely illuminance performance for users.

Schreuder (1998) presents research that user perceptions of the adequacy of lighting of areas were more influenced by the level of illuminance at the darkest locations, rather than the average illuminance overall. The distribution shown in Situation B gives the greatest uniformity, and therefore Situation B is expected to give the highest adequacy for users, relative to Situation A and Situation C.

Rombauts et al (1987) states 'uniformity of illuminances is a less important criterion [...] since observers are moving slowly'. This relates to the human eye requiring time to adapt between different lighting levels, particularly when moving from 'lighter' to 'darker' situations. This effect is called 'transient adaptation'. While Rombauts et al suggest this is not an issue for the transition speeds of typical pedestrians, other literature and advice advocates that lighting designs should minimise this potentially adverse effect on visibility. One suggestion is that the brightest area in a person's field of vision should not exceed 10 times the brightness of the average illuminance level to which the eye is adapted (International Dark Sky Association 2004). The standard AS/NZS 1158.3.1:2005 concurs, setting maximum illuminance (horizontal) uniformity at 10.

While the human eye can adjust to a wide range of light conditions, it typically can only adapt to one at a time. This is illustrated by the situations of figure 5.6, where the figure on the light background (left) is perceived as being darker than the figure on the dark background (right) (Williams et al 1998).

Figure 5.6 Demonstration of the effect of the comparative nature of assessment of lighting



The figures are the same colour (representing equal luminance).

The figure on the left, with the lighter background, appears darker.

The figure on the right, with the darker background, appears lighter.

The human eye will generally adjust to the brightest illumination present, so that everything else appears comparatively dark. For example, peripheral spaces and edges of lit pedestrian areas may seem darker if they are abutting well-lit regions. Oc and Tiesdell (1997) surmise that the proximity of such areas or shadows can concern pedestrians using the well-lit regions.

Oc and Tiesdel report on a survey of pedestrian perceptions of lighting levels on two adjacent streets. One of the streets appeared particularly light because of the installation of high-level floodlighting. Both streets were actually adequately lit, according to formal lighting standards, but surveyed pedestrians strongly identified the less-bright street as 'dimly lit and unsafe'. This perception was due to the relative difference in lighting levels between the two streets, rather than the absolute lighting levels.

Lighting design for an area or route should establish continuity or gradual transitioning with its neighbouring lighting provisions, to prevent abrupt changes in lighting levels that may affect users' perceptions or vision.

5.2.2 Using distribution of light for effect

While providing sufficient lighting for continual vision for pedestrians, the lighting scheme for a pedestrian area should also be considered for its overall holistic effect, at different scales – including its broad coverage and appearance over the complete pedestrian area, and relative to the likely pedestrian usage patterns of the area.

Motorised activity is centred upon the middle of the traffic lanes of the carriageway, and so these have commonly been the most brightly lit regions in urban areas. In contrast with motorised activity, pedestrian activity can be dispersed or around the edges of streets and areas, or where visual interest is greatest. It is the nature of pedestrian activities and locations that should drive designing the size and location of the visibility fields for pedestrians.

Lighting can be selected to complement or define the intended principal purpose of a pedestrian area, or sections within the full area. A desired atmosphere or ambience within a pedestrian area can be created through considered selection of the type and focus of lighting to be used. Lighting schemes should not necessarily attempt to light every feature of the area but rather, select the main scenes or items that hold greatest influence on reinforcing the area's desired function (Fördergemeinschaft Gutes Licht 2000). Table 5.1 on the next page expands this concept.

Table 5.1 Approaches for lighting areas according to their desired function

Area and function for lighting	Approaches and key notes
Broad and open areas – focus on *ambient lighting*	The flexibility of a space is important for some pedestrian areas – for example, those that are traversed by a variety of multidirectional or informal pedestrian routes, or areas that are frequently used for events during the hours of darkness. Uniform lighting can cater well for this type of flexibility. For example, the City of Melbourne (2002) states that 'by giving the whole of the [area] a uniform lighting treatment, the flexibility of the [area] and its receptiveness to change is maximised'. Lighting design should aim to mount light sources outside the direct field of vision of pedestrian users anywhere within the space. High-mounted and down-pointing light sources may be appropriate. A general area-wide level of illuminance with high uniformity should be provided. The attention of pedestrians will not be particularly drawn to any features within the area or surrounding facades if they are only illuminated by stray incidental light.
Zones within an area – focus on *task lighting*	Lighting can be used to create focus zones within an overall area. The lighting may direct pedestrian users to a route through an area, or concentration of lighting may be used to define areas, such as tables and seating, in which particular activities are to be encouraged. The total area should be provided with adequate background illuminance, so that the contrast between the focus zones and other zones is not stark enough to generate glare or impede vision.
Aesthetics and effects – focus on *accent lighting*	Wellington City Council (2002) states that lighting can 'accentuate significant buildings or important features within the city, and can be used to emphasise the special qualities of character areas – such as heritage or entertainment areas'. For example, where features or buildings provide the defining characteristic of an area, the pedestrian experience may be enhanced by focusing lighting to punctuate and enliven these items. Lighting should be used in a way that most favourably directs the attention of users of the space. Significant features or facades can be specifically lit to create dramatic localised shadowing effects and emphasise (or at least retain) the three-dimensionality of the objects. Facades and edges that fringe an area can be floodlit to define the space within and create an outdoor 'room'. Illuminance over the total surrounding area should be provided, so that pedestrian safety, vision, and perceptions of security are maintained throughout the entire space. (The AS/NZS pedestrian lighting standard formalises the requirements of this level of illumination.)

As introduced in the preceding sections, increased illumination may be warranted where, for example:

- pedestrians perceive greater threats to personal security
- pedestrians are moving fast
- physical obstacles are likely.

These needs could be satisfied by providing 'pockets' of increased illumination; or increased illumination of an entire area may be beneficial where pedestrian use of the area is high, widespread, or variable. Once the desired extent and type of visibility demands in a pedestrian area are defined, lighting can be engineered to satisfy those demands, using technical specifications and methods.

6 Using lighting techniques to communicate with pedestrians

6.1 Lighting and maintenance of personal security

Issues relating to personal security generally do not arise when considering lighting for motorists. However, pedestrians must feel secure while walking.

The effect of lighting on perceptions of personal security, and the effect of lighting on the incidence of criminal and antisocial behaviours, have been researched. The following discussion of references shows that the relationship between public lighting and personal security is complex.

6.1.1 ‘Crime’ and ‘personal security’

The term ‘crime’ can be used to cover an extremely wide range of behaviours that could affect pedestrians, ranging from serious offences such as muggings and assaults of pedestrians, through to antisocial or ‘public nuisance’ acts of loitering, boisterous behaviour and verbal intimidation.

Measuring crime that affects pedestrians can be difficult. Reported crime against pedestrians is more likely to be of the nature of physical attacks or confrontational robberies. Incivilities may be more common and not reported, yet still bear great influence on perceptions of personal security.

Many sources, including IDA (2002), define lighting in the context of personal security for pedestrians as ‘lighting that provides a feeling of comfort or freedom from worry for the pedestrians using the lit area’.

Quintet and Nunn (1998) researched ‘the impact of street lighting on calls for police service’. Their findings have been qualified by the idea that quantifying crime via the number of calls made to the police by pedestrian users of an area could overlook other incidents that affect pedestrians’ perceptions of personal security. Nevertheless, Quintet and Nunn found that ‘some of the effects of street lighting are crime specific’ – for example, the introduction of lighting to an area can affect burglary rates differently from, say, the incidence of assault. They said: ‘Assessments of the impact of lighting should create crime categories that are substantively meaningful to the question at hand.’

As well as issues of appropriately defining ‘personal security’ and ‘crime’, definitive information on the effect of public lighting on personal security may be further obscured by the focus on residential areas in a lot of research on the relationships between personal security and lighting. Also, some studies on the effects of pedestrian lighting on risk and fear are inconclusive because of the confounding effects of simultaneous changes to a variety of lighting aspects, or implementation of the lighting changes occurring within a package of other physical measures (Clark 2002).

6.1.2 General issues relating to lighting and personal security

Understanding the relationship between public lighting and personal security is complex, as the following sample of references shows:

- Oc and Tiesdell (1997) report that there are limits to which lighting may affect actual and perceived rates of criminal and antisocial behaviours, as these behaviours can be considered to have root social causes that cannot be addressed through interventions in the physical environment. However, the authors still consider that environmental interventions, such as lighting, may address people's levels of *fear*.

If public lighting is installed, Oc and Tiesdell caution that public lighting should not be relied upon, in isolation, to successfully prevent criminal or antisocial behaviours – to increase its chance of having any effect, it must be installed along with other complementary features. Lighting of an area may also need to be supported by other measures to ensure legitimate use of the space and light, rather than the lit area becoming vulnerable to attracting undesirable antisocial behaviour or uncivil loitering.

Oc and Tiesdell also note that public lighting does not appear to lessen crime rates over wide areas, but may have more impact when used to target small and specific areas of concern. Where newly installed or upgraded lighting reduces the incidence of crime or antisocial behaviour in a specific area, planning and instruments to cater for the possible displacement of these activities should be considered.

- From a review of studies on public lighting and crime, Clark (2002) states that artificial light at night tends to allay the fear of crime, but its effects on the actual risk of crime have not been robustly demonstrated.
- In the late 1970s, the US Department of Justice commissioned a comparative analysis of past and ongoing street lighting projects. The study concluded that 'although the paucity of reliable and uniform data and the inadequacy of available evaluation studies preclude a definitive statement regarding the relationship between street lighting and crime', it still found that 'while there is no statistically significant evidence that street lighting impacts the level of crime, especially if crime displacement is taken into account, there is a strong indication that increased lighting – perhaps lighting uniformity – decreases the fear of crime' (Tien et al 1979).
- From 'a systematic review of the effects of improved street lighting on crime', Farrington and Walsh (2002) found that 'improved street lighting led to significant reductions in recorded crime'. To explain how improved street lighting produced this change, Farrington and Welsh suggest that 'a theory of street lighting focussing on its role in increasing community pride and informal social control may be more plausible than a theory focussing on increased surveillance and increased deterrence'.
- The Australian Capital Territory Government (2000) states that lighting works to enhance feelings of personal security when there is a strong chance that someone will see any illicit activity. If this is not likely, lighting can actually make it easier to commit a crime. This concept of visibility and surveillance is also referred to by Ramsey and Newton (1991). The authors comment that pedestrian lighting can be used to complement other crime-prevention techniques, particularly through its positive effect on visibility. For example, the effectiveness of natural surveillance from members of the public and monitoring by CCTV cameras relies on adequate lighting.

6.1.3 Comments

It appears that a definitive answer to whether pedestrian lighting can decrease crime is elusive. Generally, it seems agreed that pedestrian lighting can raise *perceptions* of personal security. But the mechanisms that improve those perceptions are not well understood or even studied. Further general and concept-based studies could be conducted, but may continue to not address the knowledge gap. Pedestrian-lighting practitioners need practical advice. Progress towards providing such detailed recommendations may be better pursued through mechanism-oriented study.

6.2 Navigation and orientation by pedestrians

While travelling, a pedestrian will often be presented with a range of possible walking routes.

Regular users of an area can use their previous experiences and associated knowledge to select a route that they consider satisfactorily safe and attractive. During the night or when it is dark, lighting conditions may factor slightly in this decision, but overall familiarity with the area will have more influence. Regular users of an area are more certain of their route and the risks associated with that route, and so require lesser levels of light to consider using that route during the hours of darkness.

However, some pedestrian environments are used by people who are less familiar with the area, and here, pedestrian lighting can assist navigation and orientation needs. For users who are unfamiliar with an area, route selection is largely, perhaps most significantly, based on visual information. At night, public lighting should enable these users to assess their environment and thus successfully select an appropriate route or activity area.

Caminada and van Bommel (1980) suggest that irregular users of an area can be assisted if the pedestrian lighting serves the 'same function as general lighting in an interior: that is to say, it should enable them to roughly perceive the total space when entering it. For this purpose the lighting should light not only the horizontal surfaces within the [pedestrian] area, but also the facades'.

6.2.1 Lighting to assist navigation and orientation

Lighting type, location, and illumination quality can communicate how pedestrians can navigate their way through an urban area during the hours of darkness.

Road users may not be aware of a formalised road hierarchy, but even those unfamiliar with an area are able to distinguish between major and minor roads from the visual information provided. Major roads are typically wider and may offer more traffic lanes, but another indication of their importance is often the greater illumination of these roads relative to minor roads. Road users can then use this environmental information to more effectively travel through the roading network. Similarly, pedestrians should be able to distinguish 'through routes' from 'access routes' offered by the pedestrian network, with cues through the relative differences in the lighting levels provided to each.

For this purpose, lighting need not replicate the omnidirectional lighting conditions that are present during the day. Targeting lighting so that it highlights particular features can contribute to a sense of orientation and thereby assist people to easily find their way. Lighting well-known buildings, monuments and other significant structures can allow their use as orientation landmarks for night-time users. 'Important routes can be accentuated and objects that may aid orientation and navigation can be illuminated' (Delft University of Technology 2008).

In a large undifferentiated area, especially one that is not intended for night-time loitering, a clear thoroughfare can be encouraged and directed by providing a concentrated light passage. Physical items, such as coloured paving, could also be used to reinforce the passageway effect without compromising the daytime flexibility of the broad, open space. Outside of the light passage, lesser background illuminance can still create a pleasant ambience and provide a perception of personal security.

6.2.2 Lighting appropriate areas appropriately

Notwithstanding that many New Zealand local councils have street lighting policies referencing the *Lighting for roads and public spaces AS/NZS 1158* set of standards, there may be spaces that are beyond the scope of the street lighting policy but where provision of pedestrian lighting should be given discretionary consideration based on the nature of the desired pedestrian usage.

Where pedestrians are visually directed to use a particular route or area during the night or hours of darkness, review of the pedestrian lighting scheme should include assessing the consistency of provided lighting. Various sources of industry guidance note that improvements to lighting that create a false sense of security, or unsupported confidence about a location, are a type of 'inappropriate lighting'. Sources encourage consideration of the benefits and potential disbenefits of lighting routes and areas that are not intended for use during the hours of darkness.

- Wellington City Council (2002) states that lit pathways should be well connected to other safe well-lit links and surrounding streets. 'Lighting the first part of a path through a wilderness area which is neither policed nor frequently used may give people a false impression of safety and draw them into a dangerous area.'
- Project for Public Spaces (2006) describes a lighting hierarchy: 'The top of the hierarchy includes lighting activity areas and primary walkways so that they become the focus of pedestrian activity after dark. At the bottom of this hierarchy is the decision not to light some areas at all because their use at night would be unsafe or inappropriate.' The guidance also encourages the supply (presumably supported by lighting) of a choice of routes to and from areas. A choice of routes allows pedestrians the amenities of variety and preference, and also avoids pedestrian movements being channelled and therefore more easily predicted.
- The New Zealand Ministry of Justice (2005) states that 'it is crucial that lighting sends the right messages to the public about the safe and appropriate use of space at different times of night and day'. The guidance says 'lighting should not be provided in areas not intended for night-time use', but also notes that lighting should be considered 'for areas where safety risks have been identified'.
- Auckland City (2008) advises that 'in many cases short cuts should not be lit', but goes on to provide some questions for further assessing the characteristics of the short cut, particularly 'why should it be lit, and during what times?'
- The Australian Capital Territory Government (2000) advises 'where possible, avoid lighting areas not intended for night-time use – this avoids a false impression of use or safety. If danger spots are usually vacant at night, it may be better to avoid lighting them and close them off to pedestrians'. Further advice is to 'select and light "safe routes" so that these become the focus of legitimate pedestrian activity after dark', but notes that 'people may perceive an area where lighting has been improved as now being safe, when surrounding areas through which they must pass are still not safe'.

Overall, it appears that the industry information on whether to light, or not light, may reinforce the complexity of the issue, but the majority of sources agree that this decision is absolutely dependent on the characteristics of the subject site and its broader setting.

The proposition that lighting an area may give pedestrians false impressions of safety or security, thus leaving the people particularly vulnerable, does not seem to have been formally researched. Broader consideration of the behaviour of pedestrians suggests caution around applying the principle of deliberately ‘not lighting’ a route or area. Some literature that is not specifically focused on public lighting and pedestrians reports that people often become accustomed to routes that they generally use, and then may continue to use those routes even when other circumstances change to ostensibly make that route less attractive. Obviously not all pedestrians will do this, but it seems reasonable to assume that some will. ‘Not lighting’ provides nothing for those pedestrians who continue to use the facility during the hours of darkness, and it does not seem satisfactory to rely on this to dissuade pedestrians from an area or route. While the extent of lighting provided should reflect the actual degree of usage of the facility during darkness, there should also be some consideration of a minimum level of lighting service that will at least provide safety.

In terms of the review of the coverage and implied message of pedestrian lighting schemes, advice must be to clearly define intended and desired pedestrian behaviours, and then seek to match the lighting to the facilities and encourage those behaviours.

6.3 Lighting to enhance areas and create attractive images

6.3.1 Effects through lighting colour

Colour appearance can be described in terms of its ‘colour temperature’. The lower the light’s colour temperature, the redder the colour; and the higher the light’s colour temperature, the bluer the colour.

- Lighting with blue or green hues can introduce ‘coolness’ into an area and give a more spacious effect. Lighting with warm hues, such as red or yellow, can create a cosy and positive environment. Use of multicoloured light might be appropriate within bustling city centre areas, but could diminish the tranquillity of another area.
- The perceived colour appearance depends on both the colour temperature of the incident light and the colour characteristics of the receiving surface. The combined effect of light colour with colours of building materials and landscape elements should be harmonised within lighting designs.

Particularly effective images may be created where the colour appearance of the provided light is selected to complement the material of the illuminated object. For example, high-pressure sodium vapour lamps provide a gentle yellowish light that can attractively emphasise the colour character of red leaves or sandstone. The white light from metal halide luminaires can reinforce the gleam of metal and glass surfaces or complement foliage of various shades of green (Fördergemeinschaft Gutes Licht 1999, City of Melbourne 2002).

6.3.2 Effects through shadows and contrasts

Earlier in this document, figure 3.1 showed how the angle of incident light can be managed to create ‘flattening’ effects, or dramatic effects, via the extent and depth of shadows. Figure 3.3 showed how ‘apparent light size’ can affect the hardness/softness of shadows. Manipulation of such techniques needs to complement the purpose of the space.

- Lighting can be used to recreate the degree of shadow and contrast that exists under sun, or daytime lighting conditions. This naturalistic approach to lighting can contribute to pedestrians’ perceptions of comfort and the acceptability of the lighting installation.

- Lighting can be used to deliberately create shadows and contrasts for dramatic effects that can add to perceptions of the artistic pleasantness or prestigious impression of an area.

Establishing a strong image for a feature relies on creating suitably dark shadow zones to counter and emphasise the impact of areas of high illumination. Inadequate or excessive contrast can distort the appearance of features in the environment and create an undesirable scene. While hard-edged and high-contrast shadows can increase the visual impact of a scene, these shadows may affect users' perceptions of safety and personal security. When assessing the balance of dramatic versus naturalistic lighting, the driving consideration is prioritising the desired and appropriate pedestrian functioning of the space.

7 Guidance

Successful design of pedestrian lighting schemes both satisfies the AS/NZS pedestrian lighting standard and manages the personal perceptions of users. It is a complex and subtle area, and any guidance should not oversimplify the issues. Guidance can help by raising the profile of pedestrian-specific lighting preferences and increasing awareness of perspectives relevant to the assessment of pedestrian lighting.

The significant concepts that emerge from industry practice, literature and various publications are as follows:

1 Considering where to light:

- Define the size of the visibility field that needs to be lit based on the characteristics of likely pedestrian movements, interactions and specific task needs. For *safety*, pedestrians who are moving quickly need a larger visibility field. For *security and comfort*, pedestrians moving towards unfamiliar pedestrians or objects need a larger visibility field. For needs associated with *specific tasks and locations*, include extra illumination on steps or around areas with printed information for reading (for example, bus timetables at bus stops).
- Pedestrians can take cues from lighting schemes to direct their route selection.

2 Angles and shadows:

- Consider the angle of the incident light source relative to the pedestrians' viewpoints. Incident light on the same axis as the viewpoint can make objects look 'flat' but can minimise that viewpoint's impression of shadows. A greater angle of incidence creates deeper shadows, which may be useful for dramatic three-dimensional effects, or may be undesirable, depending on their position and the nature of the pedestrian area.
- A single illumination source will naturally and unavoidably create some shadow. The shadow can be softened, or given greater zones of transition from full light to no light, by increasing the size of the light source or decreasing the distance between the light source and the lit subject. Further, an area of shadow can be reduced through lighting by another light source.

3 Making the best use of illumination

- Luminance depends on both the illumination provided to a surface and the properties of that surface. Thus, light-coloured surfaces can be selected to optimise utilisation of supplied illumination, or matte surfaces can be selected to minimise glare from misguided reflected illumination.
- Lighting to create positive contrast provides the best visibility for pedestrians' primary needs for safety and security details. However, lighting for negative contrast can be included where appropriate to supplement the positive-contrast lighting, particularly in providing or extending the range of general awareness of the environment.
- Uniformity and illuminance need to be considered in three dimensions, recognising how the lighting will be experienced by pedestrians. Lighting legislation requires a range of lighting measurements but there may be other techniques, such as semi-cylindrical illuminance, which can be valuable in representing pedestrians' experience of lighting.

- The distance between the light source and the lit objects or area affects both the uniformity and the intensity of the lighting. Lighting effects will generally be *more uniform* further away from the light source, and *less intense* further away from the light source.

- Illumination uniformity is highly significant in pedestrian lighting schemes and can raise pedestrians' overall perceptions of the area's lighting. Changing between different levels of illumination within an area can affect the ambience and usage patterns of space(s). Note that the changes can, and must, be technically managed so that pedestrians' vision and comfort is maintained.

4 Colour

- Illumination has colour that interacts with the colours it illuminates. When selecting light colour, the intended usage of the pedestrian area should be considered in order to maximise daylight equivalency, or for aesthetic effect.

- The significance of light colour appearance and light colour rendering properties should be considered within a pedestrian lighting scheme, particularly with reference to the likely use of an area and its users.

The pedestrian must be the central focus of pedestrian lighting schemes. The likely and desired pedestrian behaviours must be identified, and then the effectiveness of the lighting can be assessed. Once the extent and type of visibility demands in a pedestrian lighting scheme have been identified, lighting can be engineered to satisfy those demands using technical specifications and methods.

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