Public Lighting in Cities

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Abstract

This paper reviews a number of aspects of public lighting in cities based on a wide ranging survey of existing reliable sources of information.

The paper demonstrates a number of the key benefits of good lighting in urban areas and provides information on the best use of lighting and shows that good public lighting can more than pay for itself in terms of reduced crime fear of crime and road accidents. It then goes onto discuss the way that lighting can change the way a city looks at night. The paper then reviews some of the practical issues associated with city lighting.

Introduction

This paper is the result of study of existing publications in the field. Over 100 existing sources of information were reviewed of which over 30 are cited in this paper. A large variety of sources have been used including papers from scientific journals and conferences, reports submitted for MSc and PhD qualifications, text books, national standards and guidance published by professional bodies and web sites. The basis for selection of material for inclusion in this paper was relevance, the avoidance of duplication and scientific rigor.

The subject matter of urban lighting is highly complex and extensive, thus it is probably not possible for a short paper like this one to cover all the issues involved. Rather, it is the objective of this paper to highlight the key issues and provide some form of framework for detailed discussions of the various topics involved. In order to group the various topics involved this paper is split into three sections.
The **Human Factors** section discusses the issues associated with the needs of people using the streets at night, this includes the amount of light they require to find their way as well as issues associated with feelings of safety that can encourage people to use the streets at night. The section on **City Image** covers the way lighting impacts on the way a city appears after dark and how that relates to the way people perceive the city. The **Performance** section looks at some of the practical issues associated with the installation

of lighting and discusses such topics as energy consumption, maintenance and the impact on road traffic accidents.

Human Factors

Any street lighting must meet the needs of the people who are going to use the area being lit. In urban areas it is normal to provide lighting for pedestrians. There are a number of ways the lighting needs of pedestrians can be discussed but perhaps the best framework is due to Jones[1]. The requirements may broken down into the following headings:

- Safe movement
- Visual orientation
- Visual comfort
- Facial recognition
- A general feeling of safety

There is a certain amount of interaction between these factors and in general a lighting system designed to meet one of these needs may well go some way to meeting all of them. It is also important to note the difference in nature of these various needs, without *safe movement* and *visual orientation* it would be impossible for someone to walk along a road, however, without *a general feeling of safety* someone might chose not to walk along a road.

Safe Movement

The amount of light needed for walking along a road is relatively low. The visual tasks involved are fairly simple and associated with locating obstacles on the footpath and similar tasks. In order to judge the illuminance necessary to walk and avoid obstacles a number of authors refer to emergency lighting documents such as the current European Standard on Emergency Lighting[2] as source of guidance on how much light is needed for safe movement. The current European Standard requires 1 lx minimum on the centre of an escape route. In fact it is possible that footpaths could be lit to a lower level as a person walking along the street does not suffer from the panic that may be present when people are trying to escape from a building.

Visual Orientation

In order to walk anywhere within a city it necessary to know where you are and be able to see in which direction you need to go. In residential areas where the majority of the pedestrians are familiar with the area large objects such as houses and trees serve as landmarks and thus very little light is needed to ensure orientation. In city centres people are generally less familiar with the area and thus it is necessary to provide signage giving directions. It is thus important to provide lighting on the signage and it also helps if the key landmarks within the city are illuminated.

Visual Comfort

The concept of visual comfort contains within it two strands. Firstly, there is the concept of freedom from glare and secondly, there is the concept of pleasantness.

The current European Standard on Road Lighting[3] provides 3 methods for controlling glare; Luminous Intensity Classes, Threshold Increment and Glare Index Classes. It is the Luminous Intensity Classes that are most often used to control glare in urban lighting. The system controls glare by restricting the light output of luminaires at particular angles. Table 1 below is taken for the road lighting standard and lists the limits.

Table 1 – Luminous Intensity Classes

Class	Maximum luminous intensity in cd / klm			Other Requirements
	At 70°[a]	At 80° [a]	At 90° [a]	
G1		200	50	None
G2		150	30	None
G3		100	20	None
G4	500	100	10	Luminous intensities above 95° [a] to be zero
G5	350	100	10	Luminous intensities above 95° [a] to be zero
G6	350	100	0	Luminous intensities above 90° [a] to be zero
[a] Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.				

The class G1 imposes only a slight restriction on the glare caused by the luminaires and generally would be used where the level of illumination is high and glare is not likely to be a problem; whereas class G6 imposes very tight restrictions on the luminaires and is used where glare is potentially a big problem.

The concept of visual comfort includes a large number of other features of the visual environment ranging from the modelling of peoples' faces to the nature of the light source and the extent to which light penetrates into private houses. Hargroves[4] and others[5] developed some of these ideas into the concept of "pleasantness" and then derived recommendations for lighting systems for shopping centres to achieve pleasantness.

Facial Recognition

The basic ideas about personal spaces were developed by Edward Hall[6] and he categorised the personal spaces around a person into intimate, personal social-consultative and public.

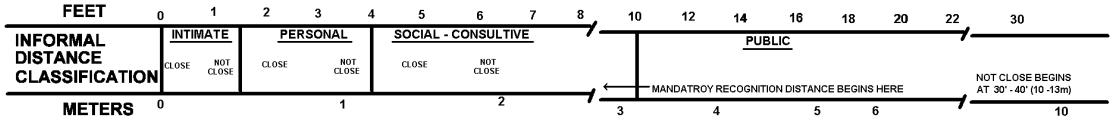

Figure 1 Hall's personal spaces

Figure 1 shows the spaces and the distances at which they occur. Hall discussed the importance of these zones to people and why they felt uncomfortable with letting strangers entering their personal spaces (at distances of less than 3m) unless they can recognise them. This basic principle was used by van Bommel and Caminada[7] as they developed their ideas about the importance of facial recognition; they then went on to show that facial recognition distance was a function of the semi cylindrical illuminance on the face that was being recognised. Further research[5] confirmed van Bommel and

Camiada's findings. Raynham and Saksvikrønning [8] used facial recognition as a tool to compare the efficacy of different light sources; Figure 2 shows some of their findings.

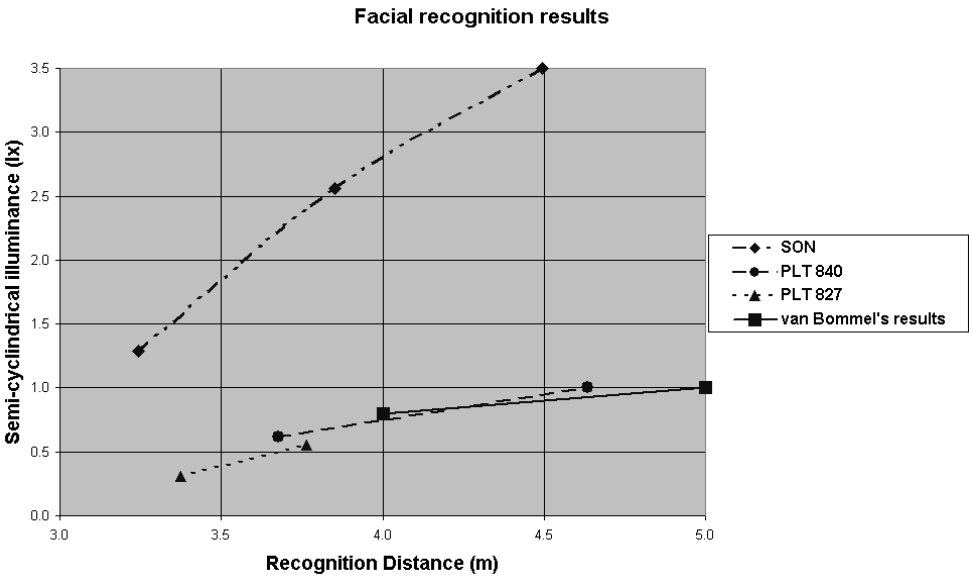

Figure 2 Facial recognition distance with different light sources (from Raynham[9])

The key finding from the work of Raynham and Saksvikrønning was that white light with a good colour rendering (Ra 80) is much better for facial recognition than light with low colour rendering from sources such as high pressure sodium lamps. On Figure 2 data is also plotted showing the results of van Bommel and Caminada, their values closely follow the data for white light sources. It was subsequently discovered that they had used white light sources with a Ra of 60.

General feeling of safety

Many researchers[1,7] have argued that lighting can promote a general feeling of safety. However, feelings of safety depend upon a lot of factors other than lighting. Boyce et al[10] conducted a study in areas of New York City and Albany that showed that in general the greater the amount of light provided by the greater the feeling of safety. Analysis of the experimental findings also revealed that in general men felt safer than women. The difference in sense of safety was also found by Mansfield and Raynham[11] who, additionally found that older people felt less safe than young people.

Boyce's study also looked at a series of car parks in Albany and compared the feeling of safety during the day and at night. In all cases he found that people felt safer during the day. Moreover, he was able to relate the change in the feeling of safety between day and night to illuminance at night, the higher the illuminance the less the change in feeling of safety. Figure 3 shows the findings of Boyce's study where subjects were asked to rate the feeling of safety that they had whilst walking in particular car parks during the day and at night, the difference in the day and night scores were then plotted against the night time illuminance.

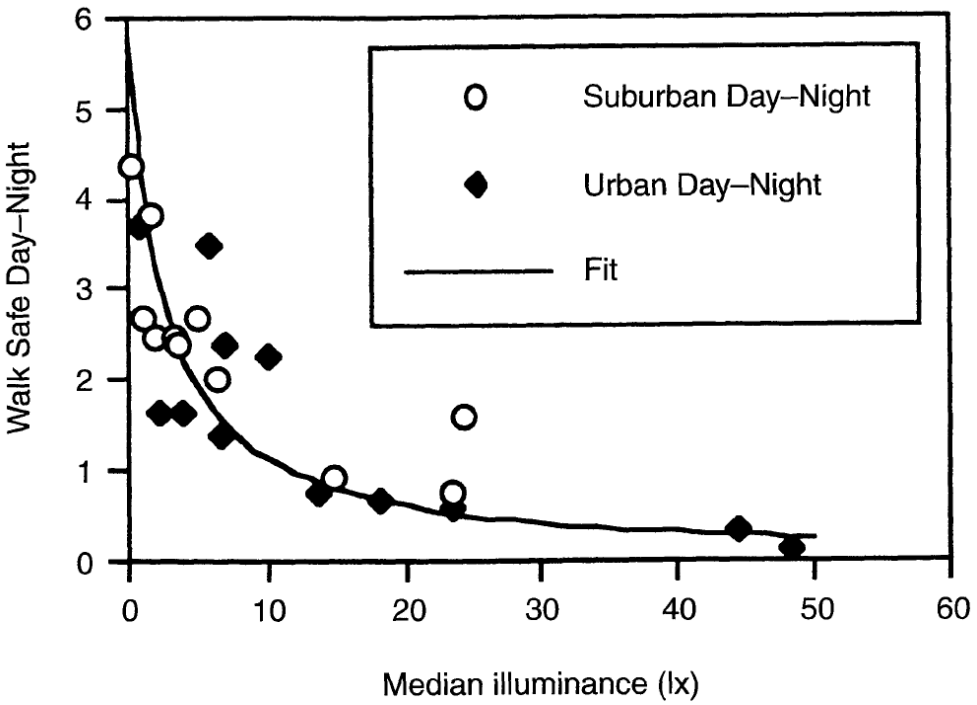

Figure 3 Difference in mean ratings of perceived safety day and night (day-night) plotted against mean illuminance

The main factor working against a feeling of safety is a fear of crime. Fear of crime is a very complex phenomenon that is only loosely related to the risk of being a victim of crime. For example Raynham and Gardner[12] found that young men were many times more likely to be victims of crime than old ladies, however, their fear of crime was much less.

In some instances fear of crime and crime are related. Painter and Farrington[13] found that good street lighting reduced the amount of crime; in fact they were able to establish that the cost saved by the community in one year from reduced crime was greater than the cost of installing the new lighting system. Whilst they did not come to a conclusion as to how this effect was created, one of the plausible explanations was that good lighting reduced the fear of crime and so more people used the streets at night, thus making it harder to commit a crime unobserved.

In general, lighting can help reduce the fear of crime, however, there are some cases where lighting alone may not have any effect on the feeling of safety. Painter and Farrington[12] reported that lighting has little effect in areas of low crime and Raynham and Gardner[11] found that in an area where there was a perceived threat from young people hanging around, extra lighting did nothing to reduce the perceived fear of crime.

City Image

The complex network of buildings, roads and open spaces that make up a modern city create a highly complex structure, thus at night it is essential that a city is appropriately lit. The lighting of the city should not only aid orientation it should be stimulating and provide a general feeling of well being and safety. Several issues need to be addressed in

order that this approach is fully satisfied with emphasis on the safety and well-being of the people: **amenity**, **planning**, **aesthetics** and **iconography**.

Amenity

Amenity is all about increasing the attractiveness of a city and thus increasing the comfort of people out and about within it. Hargroves[4] did a subjective appraisal of 13 lighting schemes, using the metrics of lightness, attractiveness and overall impression. He concluded that people ranked highest, those schemes that had a good general uniform illuminance coupled with visual accents provided by highlighting certain features within the environment, such as trees, statues, shrubs, seating, entrances, etc. Hargroves concludes for town centres that:

- There should be an overall coverage of light of not less than 20 lux average on the horizontal (E_H) with a uniformity as high as 0.3 (6 lux minimum) and not less than 0.1 (2 lux minimum)
- The average illuminance (E_V) on vertical planes 1.5m above ground, provided by the overall coverage should be greater than $0.8E_H$ average (16 lux E_V) with a uniformity of not less than 0.2 (3.2 lux min E_V)
- Accent lighting should be used to highlight particular features e.g. statues, waterfalls, seating, shrubs, entrances, etc. Such lighting should provide an illuminance on a vertical plane of 5 Lux (E_V).

He also said that in shopping precincts, the amenity value is enhanced by having shop windows lit and where decorative luminaires are to be used as accent lighting, they should aim to create sparkle whilst not causing glare.

Hargroves' research found that people preferred what one might call a layered approach to the lighting, with a general uniform base layer upon which decorative elements or accents may be applied. The study also reported that when there is no basic uniform coverage of light to start with, adding further accent lighting does not improve the appraisal ratings to the same level of those with a general uniform coverage.

Planning

In recent years, more and more city lighting master plans have been developed in order to provide a holistic approach to the city lighting strategy. In 2002 a number of cities got together to form "Lighting Urban Community International" (LUCI)[14] to provide a forum where cities can compare experiences and share skills associated with urban lighting.

A system of layering can be employed looking at the lighting and the lit pattern on a variety of levels. From the overall large scale city image, down to the macro environments of suburban areas and the micro environments of individual streets, footpaths, parks, squares, and buildings.

It is important to remember that various transport networks exist within the urban environment and the emphasis should be on lighting the environment for the most vulnerable users, the people. As Silver[15] describes, *as day turns to night the streets can*

reveal hidden secrets that can be of comfort to the pedestrian or cause a sense of insecurity in the darkness. Lighting can reveal the city at night by accentuating the urban image, or if inadequate, cause insecurity and confusion.
Urban lighting should identify the different zones of a city and how people interact with these elements. Kevin Lynch[16] in his book 'The Image of the City' identifies certain areas within the network of routes that make up the urban landscape. These are nodes, landmarks, district edges and paths. Nodes are areas where there is convergence or a change in movement, or place of physical character such as a square or street corner.

It is therefore important to identify these areas within the urban fabric and address the issue of lighting accordingly. These areas could also be broken down into their level of use, main function and level of importance. For example, a main thoroughfare could be described as HIGH, TRANSITORY and MAJOR whereas a small residential street square might be described as LOW, SOCIAL and MINOR. This grading not only aids in the provision of a suitable solution appropriate for the area and the level of use, but also ensures that amenity is appropriately provided for.

In a similar approach, Takada & Higo[17] describe a concept for the lighting of roads in and around residential areas of Tokyo with the emphasis on the pedestrian rather than the motorist. The concept is based on two points.

1. There must be no "dangerous darkness" in any part of the residential area.
2. With priority given to pedestrians' actions, a "walking space axis" of the main roads used by pedestrians must be clear.

In a similar approach to Lynch areas were divided into certain categories, main roads, and introductory roads to residential areas, pedestrian scattering roads and access roads. They also identify significant points of pedestrian movement such as bus stops or railway stations. The main routes with multiple pedestrian and vehicle junctions were illuminated to a higher level due to their higher volumes of traffic and increased level of danger. So too are major junctions and areas such as bus stops. Slowly the level of illumination is reduced until a minimum safety level is provided in the subsidiary access roads. This approach also aids the guidance of pedestrians via differences in illuminance levels. An experiment was carried out within 5 adjoining residential areas of Tokyo. First, a bright road axis was created with an illuminance of 20 lux for the main roads, with a lower level of 8 lux for scattering roads and 1.5 lux throughout the rest of the blocks. Pre-and-post experiment evaluation was carried out focusing on the subjective evaluation of brightness and facial recognition.

Other relighting evaluations have reported similar improvements in the general perception of the environment, easing the fear of crime and generally making the environment psychologically more inviting, in essence providing better amenity.

Aesthetics

Aesthetics is the branch of philosophy dealing with notions such as beauty, ugliness and the sublime. Our subjective appraisal of the city at night is directly linked to the aesthetic quality of the lighting installation.

A study of buildings in London's riverside by Babou[18] found that historic monument are illuminated to a higher level than contemporary structures, this makes them dominant and easily recognisable. Moreover these old buildings tend to be built as solid forms and their floodlighting tends to reveal their 3-dimesionality, texture and architectural detail. Some of the more modern structures tend to be more ethereal in structure, have linear elements of steel and filled in with glass. The lighting for such structures tends to depend on the form and it is common for the flood lighting to highlight certain elements of the structure, often with a multi-layered minimalist approach. Finally, the use of highly saturated colour is a common choice for the lighting of contemporary structures, it is not necessarily the main component of the lighting, but is often used for design details. It can be concluded that in areas where historic and contemporary buildings co-exist a difference in luminance is desirable. For example, in the case of St Paul's Cathedral and Millennium Bridge in London a brightness ratio of 9:1, the image is appreciated as clear and almost balanced.

This point is further supported by the work of Laksmono[19] who carried out a subjective and objective analysis of 6 bridges spanning the river Thames. It was found that overall people preferred a multi-layer integrated approach to lighting even where high contrast ratios were used to make structures stand out.

One area of considerable debate with regard to exterior lighting design is the use of colour and more recently the dynamic aspects of colour change. Derek Phillips in his book the Lit Environment[20] states *the nature of a building and its materials should be taken into account, in order for a permanent system of floodlighting to express a credible appearance*. Phillips also makes the point that for temporary installations the use of almost any saturated colour may be appropriate to make a building stand out for a particular reason.

When it comes to colour selection Lynes[21] defines *The Rational Approach to Colour* based on experimental psychology. Lynes, using the Munsell colour system suggests that lightness (or reflectance) and saturation (chroma) have more effect than hue on the impression created by surface colour.

Iconography

A city lighting strategy should enhance key features of the city by night. Often central to the city lighting plan is a river running through the city. Babou[18] found that these vistas usually dominate the night time image and create iconic views of cities; this can be seen in tourist postcards and other promotional material about the city. Babou was able to demonstrate that lighting plays a critical role in establishing the night time iconography.

The importance of lighting near rivers was underlined by Horvath[22] who claimed that *as clear reflections outlined over the calm water surfaces are stirred by a light breeze, they turned into skimmed figures that ride on the waves and change their contours continuously. The static floodlights near to the water and their expressive dynamic reflections offer a spectacle which is an important attraction of a City's nightscape.*

Performance

When installing lighting there are always a number of issues to consider relating to the impacts of the lighting system, this section looks at some of those issues.

Energy

Street lighting is a significant user of energy, for example in the UK, street lighting accounts for about 1% of all non-domestic electricity use. The energy used is 2.55TWh per year it is expected to increase by 0.7 TWh by 2020, mainly as a result of new roads in housing estates[23].

However, it must be remembered that in the UK the vehicles using the road emit 62 times as much carbon dioxide as used to generate the electricity that powers the street lighting. Thus in urban areas that are well lit, it is possible that the street lighting reduces overall CO_2 emissions by encouraging people to walk or cycle. For example, consider a residential road, illuminated to 10 lux average (horizontal) using a 70w SON lantern with a typical mounting height of 5m will achieve typical column/lantern spacing in the region of 30m. Considering a 1 kilometre stretch of road approximately 33 lanterns will be needed, each with a typical total circuit energy consumption in the region of 83 watts, thus giving a total energy consumption of 2.739 KW producing 1.7 kg of carbon dioxide emissions per hour. A typical super-mini car will produce approximately 0.13 kg of carbon dioxide emissions per kilometre. This is further increased with less efficient cars, for example a medium sized car produces approximately 0.25 kg of CO_2 per 1km, with the worst offenders, super-cars, producing in excess of 0.5kg per km[24]. Thus it only needs only a few extra people deciding not to drive for the street lighting to have the net effect of reducing CO_2 emissions.

The bulk of this energy saving is likely to be in the early part of the evening, however during the later parts of the night say between 1:00 AM and 5:00 AM pedestrian activity may be very low or non-existent. There is a case that in certain areas it may be appropriate to dim or switch off the street lights, this has the potential to save a significant amount of energy.

Maintenance

It is important to maintain a lighting system to ensure that it performs at its best. Moreover a poorly maintained one will send the message to street users that the area is run down and not cared for.
BS5489-1:2003 Lighting of Roads and public amenity areas[25] lists the following factors that should be considered when establishing a maintenance program:

- the shape of the lamp survival curve for its environment (from manufacturers' data);
- the lamp luminous flux maintenance curve for the specific lamp control gear combination (from manufacturers' data);
- system power consumption variation through life cycle;

- interference with traffic, ease of access and extent of traffic management required;
- the required frequency of night inspection monitoring;
- the frequency of need for cleaning of luminaires, related to the local environment and the IP number of the lamp enclosure;
- the overall proportion of outages that can be tolerated at any point in time without undue detriment to the level and quality of lighting;
- the grouping of outages that can be tolerated at any point in time without undue detriment to the level and quality of lighting;
- the frequency of inspection for electrical safety;
- the frequency of inspection for structural safety of lighting columns and other supporting systems.

Light Pollution

Urban lighting is not an unmitigated good and can cause problems as well as solve them. Most of the problems with lighting involve the issue of light pollution. There are a number of guidance documents[26],[27] available to provide guidance in avoiding the various forms of nuisance that lighting can cause.

To make matters more complex some countries have laws to control light pollution. For example in the UK Clause 102 Clean Neighbourhoods and Environment Act 2005[28] made it a criminal offence for *artificial light emitted from premises so as to be prejudicial to health or a nuisance*.

Road Traffic Accidents

Road accidents are a major cost to the community. The Table 2 below gives the costs for road accidents in the UK.

Table 2 –from 2005 Valuation of the Benefits of Prevention of Road Accidents and Casualties[29]

Costs of Road Traffic Accidents In UK (£ June 2005)				
Injury severity	Lost Output	Medical	Human cost	Total
Fatal	490,960	840	936,380	1,428,180
Serious	18,920	11,460	130,110	160,490
Slight	2,000	850	9,530	12,380

Typically about half of all fatal road accidents occur during the hours of darkness and given that the traffic at night is only about one third of that by day this represents a huge increase in risk at night. There are a large number of fatal and serious accidents at night, for example, in Germany in 1997[30] there were 3,834 people killed and 40,238 people seriously injured. Work by the CIE[31] studied road accident data in a number of countries and came to the conclusion that road lighting reduces accidents at night by 30%. Given

the large number and high cost of accidents the money saved by the accident reduction is significantly greater than the cost of maintaining and running the street lighting.

Conclusion

Good public lighting can transform cities at night. It can provide a sense of amenity and with careful planning boost the aesthetic qualities of a city and permit the icons of the city landscape to stand out by night as well as the day. Good well-planned lighting can make a city more legible and thus make it easier for people to use it after dark.
People out after dark have a number of needs that can be met by good lighting. These needs include safe movement, visual orientation and visual comfort; lighting provided to meet these needs will in general also provide a sense of amenity and help with legibility. However, people need to have a feeling of security when they are out after dark. To achieve this people need to recognise the faces of other people on the street at a reasonable distance, and they need to see the environment is free form dark areas where unknown threats may be.

In areas where there is a great deal of fear of crime even during the day it is unlikely that lighting alone will make the area feel safe at night. In general people are more fearful at night than they are by day; good lighting tends to minimise the difference between day and night. Lighting can make a significant reduction in the night-time crime rate of an area; the benefit to the community of this crime reduction in one year can be greater than the cost of installing and running the lighting.

Lighting is a major consumer of energy. However, it can be argued that the presence of good public lighting makes people happier to walk or use public transport at night, and so the lighting can reduce the amount of car use. If a lit road can reduce the number of car journeys along it by just a few per hour then overall the road lighting is reducing carbon dioxide emissions.

Light pollution can be a problem but there is plenty of advice on how to avoid problems that it can cause. Maintenance of any lighting scheme is also important, not only because poorly maintained lighting does not deliver as much light but also because badly maintained lighting sends a signal that an area is not considered important and can be left to become run down.

The cost of road accidents is very high and there a very large number of them at night. It is known that good lighting significantly reduces the night-time accident rate. The cost saving involved easily pays for the lighting.

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