

CSS Street Lighting Project SL3/2007

Review of luminaire maintenance factors

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Review of Luminaire Maintenance Factors Report

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Foreword

In pursuing its goals of providing advice and guidance to lighting practitioners, the CSS Lighting Group, in partnership with the Highways Agency, SCOTS, Transport Scotland, ILE, and TfL has commissioned five research projects to advance some major lighting issues.

Light output from any installation will depreciate over time primarily due to lamp degradation and grime on the luminaire. The maintenance 'factor' is assigned at the design stage which will compensate for this loss of performance depending on local circumstances and will increase the initial light output to exceed the design class requirement. This is intended to ensure that the design class is achieved even at the end of the maintenance cycle. Any error in the maintenance factor may lead to schemes being over designed or unfit for purpose, and in view of the number of streetlights in the UK, there was growing concern that the maintenance factors currently recommended should be challenged and verified by 'site' testing.

This research project is the third in the series, Mott Macdonald were commissioned to undertake the work which was managed on behalf of CSS-LG by Glyn Williams of Cornwall CC.

The help and support of numerous individuals from lighting authorities contractors, manufacturers and others in the supply chain throughout the UK, listed at 12-1 must be acknowledged for providing invaluable support to this project.

A summary of the recommendations can be found on page S-3.

CSS-LG do hope that the document proves to be valuable in assisting lighting engineers with their decisions.

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Executive Summary

This research project forms part of a programme of research funded by a number of key stakeholders including the County Surveyors Society Lighting Group (CSSLG), the United Kingdom Lighting Board (UKLB), the Society of Chief Officer of Transportation in Scotland (SCOTS), the Highways Agency (HA), Transport for London (TfL) and the Institution of Lighting Engineers (ILE).

This report is the culmination of a research project to review the use of Luminaire Maintenance Factors (LMF), which together with the Lamp Luminous Flux Maintenance Factor (LLFMF) produces the Maintenance Factor (MF) to be applied within street lighting designs.

The review comprised desktop research, questionnaires to Local Authorities on their current practice and the testing of luminaires removed from site to measure the actual light reduction over a period of time. Luminaires were taken from different locations with different environmental zones, pollution levels, traffic usage, bowl types and mounting heights.

The desktop study looked at the numerous publications and standards which incorporate a method for calculating luminaire maintenance factors and concluded that the majority of different methods were based upon early research done in the 1970's when pollution levels and traffic flows were likely to be different to current conditions. The majority of the documents referred to the MF calculation in BS5489.

The questionnaire results revealed that in general Local Authorities did not adopt a scientific approach to calculating maintenance factors, instead many opted for a medium pollution category more as a rule of thumb. It could be seen that Local Authorities also replaced 4-year lamps every 3 years.

The site measurements revealed that the luminaire output in general did not conform to the BS5489 (Table D.1) MF predictions, but in fact there was always less degradation than predicted.

The conclusion therefore is that an alternative method of calculating maintenance factors should be derived and that it should produce Luminaire Maintenance Factor values which are generally higher than are currently found in the British Standard.

The suggested curves are found at section 8.6 and show that for an E1/E2 environmental zone, the Mounting Height does not influence the LMF, whilst for an E3/E4 Environmental zone, the lower LMF's would be required for the lower mounting heights.

The benefit of this will extend to the whole life cost of installations with the potential to increase column and luminaire spacing's or to use reduced wattage lamps, or a combination of both.

The key strategies which should be incorporated into a design to minimise energy consumption are:

- Use as high a Maintenance Factor as practicable
- Use lamps with a high efficacy, long life and low lumen depreciation
- Use competent designers to optimise the lighting solution
- Vary the lighting levels according to traffic at different times of the night

Summary of Recommendations

The recommendations from this report are as follows:

1. The existing method of determining Luminaire Maintenance Factors (LMF's) is amended to take account of the different conditions prevalent in the UK highways currently.
2. The Maintenance Factor (MF) values generally to be increased.
3. A new method for calculating the LMF's could include more than one factor to calculate the depreciation. This research suggests that the best option is to calculate the LMF based upon Mounting Height and Environmental Zone.
4. Further testing should ideally be carried out to create, a larger and wider cross section of results, sampling luminaires from each of the factors that may affect the results (environmental zone, pollution category and column height) to analyse for any trends. This should enable the production of a specific table of LMF's.

The basis of a potential table is shown below, where environmental zone and mounting height are related to a new LMF by cleaning cycle intervals. Given that the results curves have been drawn beneath the worst performing luminaires, these can safely assume that the 'worst case' values are provided. Additional testing is recommended in order to provide more accurate LMF's.

Cleaning Cycle	12 months	24 months	36 months	48 months
E Zone Mounting Height	LMF	LMF	LMF	LMF
E1/E2 6m or less	0.98	0.96	0.95	0.94
E1/E2 >7m	0.98	0.96	0.95	0.94
E3/E4 6m or less	0.94	0.92	0.90	0.89
E3/E4 >7m	0.97	0.96	0.95	0.94

1 Introduction

This report is the culmination of a research project to review Luminaire Maintenance Factors (LMF). The objective of the review is to provide street lighting engineers within Local Authorities and elsewhere with relevant information and practical advice on the determination and application of Luminaire Maintenance Factors (LMF's). The review will assist in determining the effectiveness of maintenance strategies and their use in different locations and situations, thus minimising the over provision of lighting, reducing capital, energy and maintenance costs.

The project forms part of a programme of research funded by a number of key stakeholders, The County Surveyors Society Lighting Group (CSSLG), The United Kingdom Lighting Board (UKLB), The Society of Chief Officer of Transportation in Scotland (SCOTS), the Highways Agency (HA), Transport for London (TfL) and the Institution of Lighting Engineers (ILE). The results of the commission may be jointly published by one or more of the above organisations to promulgate information and promote best practice within Local Authorities. The commission was awarded by Transport for London, on behalf of the stakeholders, but relates to the whole of the United Kingdom.

Project Brief

The brief for the project is summarised in the following list of requirements:

- To investigate and determine the accuracy of current LMF's taking account of practical operational and maintenance requirements.
- To investigate the impact of varying maintenance strategies and frequency of lamp and luminaire replacement.
- To coordinate the measurement programme, compile and interpret the resulting data and produce the document in its entirety.
- To prepare a final report, to be supplied ready for publication in an agreed format, broadly in line with that used for Well Lit Highways, the Code of Practice for Highway Lighting Management, UKLB 2004.
- To prepare and present a technical paper on the subject, the findings, conclusions and recommendations at a relevant national seminar to be agreed.

One aspect of the LMF review is to look at current practice. The current method of calculating LMF is not adequate for a number of reasons including:

- The IP rating of luminaires, which has generally increased in recent years
- The cleaning cycle of luminaires which is being extended
- The pollution across the UK, which is generally reducing with less manufacturing and the introduction of a numbers of Acts such as Pollution Act (1974) and the Clean Neighbourhoods and Environment Act (2005)
- Optical protectors, which are tending to become more shallow

The desktop research phase of the LMF's project involves two areas of research which are designed to provide a backdrop to the testing of luminaires in service to obtain actual depreciation values.

- Existing Methodology

Research into existing methods of calculating, deriving and utilising LMF's in street lighting with a comment on the benefits and disadvantages of such methods. This research has identified existing and obsolete lighting standards, codes of practice and guidance notes.

- Local Authority Practice

Research into the custom and practice in Local Authorities with regard to their use of '. This research has been conducted via questionnaire.

Background

The below text is extracted and where necessary, reworded from the project brief.

One of the main inputs into the design of a street lighting system is the establishment of the Maintenance Factor (MF) for the lighting system. This factor is the product of two separate factors, the Luminaire Maintenance Factor (LMF) and the Lamp Luminous Flux Maintenance Factor (LLFMF), and is applied during the design process to ensure that the level of illumination never falls below that recommended for the type of road in BS EN 13201. Lamp luminous flux depreciation varies with the type, wattage and manufacture of the lamps used, and can normally be obtained from the lamp manufacturers. However, caution needs to be taken in the application of this data as it has generally been obtained under laboratory conditions.

The LMF is usually determined by use of Table D.1 in BS 5489-1: 2003. The majority of the data used in this table has been determined from site and laboratory measurements carried out in the 1980's (for further details see ILE Technical Report No. 19). However, as there were very few IP6x luminaires (now considered as general standard for the sealing of luminaires) available during the 1980's the data for these was mainly extrapolated from the measured data of other luminaires sealed to IP4x or IP5x. The design and materials used for glazing of luminaires (the introduction of self-cleaning films on luminaires may have a further effect on this issue) has significantly improved over the last 20-25 years and this together with reductions in air pollution may have a significant effect on the LMF now needed in street lighting design.

The MFs generally used vary between 0.7 and 0.9 dependent upon lamp type, wattage, luminaire sealing, location and maintenance frequency, however, it may fall as low as 0.6 in extreme conditions with certain lamp types. In principle at the commissioning of a new installation, the system could be providing 20 to 40 percent more light than is actually needed. If the LMF could be increased then the quantity of new luminaires in a new lighting scheme may be reduced leading to a reduction in energy consumed, cost and street scene clutter. In order to reduce routine planned maintenance costs, it is becoming common practice to maintain luminaires at the same time as the group replacement of lamps (3 or 4 years dependent upon lamp type and wattage, although some PFI schemes are looking towards 5 years for SON-T lamps). This reduces the LMF, but can be offset against overall maintenance costs.

The effect of maintenance policies on the consumption and cost of electrical energy, especially with recent and potentially substantial increases in energy costs, needs to be carefully considered. One leading luminaire manufacturer is considering carrying out laboratory measurement to determine the degradation of luminaires that have been out on site for a number of years. They propose to remove luminaires from PFI systems (the period of use on the street is easily determined due to the quality of the records) and have them photometrically tested to determine the level of deterioration due to dirt and depreciation in the glazing materials. The lamp will also be tested to determine the level of depreciation in its lumen output.

2 Objectives and status of this Guidance

2.1 Objectives

- The objective of this report is to encourage the adoption of a consistent approach for the derivation of Luminaire Maintenance Factors (LMF) to be used in lighting design.
- To encourage designers to adopt a risk based approach to the derivation of Luminaire Maintenance Factors (LMF) based on site-specific conditions, location and environment.

2.2 Status of Guidance

The guidance within this document is not intended to be a mandatory requirement upon authorities. It is intended to provide lighting designers with the tools to derive the most suitable LMF for a project to ensure that the scheme design uses minimum energy consumption.

2.3 Definitions

Local Authority means the local highway authority having a responsibility for public lighting maintenance. Note: It is expected that the guidance may also be distributed beyond the Local Authorities.

Ingress Protection (IP) rating classifies the degree of protection provided by an enclosure against water and is expressed as a two-digit number, e.g. IP66 The first digit denotes the protection against solids and the second digit denotes the protection against liquids. A full specification of IP rating is given in BS EN 60529:1992.

Lamp Luminous Flux means the light output from the lamp measured in lumens.

Initial Lamp Luminous Flux means the initial maximum output from a new lamp measured in lumens.

Lamp Luminous Flux Maintenance Factor (LLFMF) is a number (positive and less than 1) used to multiply the initial lamp flux to correct for the depreciation in lumen output due to the amount of time spent burning. It can be expressed as the ratio of the luminous flux of a lamp at a given time in its life to the initial luminous flux.

Luminaire Maintenance Factor (LMF) is a number (positive and less than 1) to correct for the depreciation in light output from a luminaire due to the build-up of dirt in the periods between cleaning. It can be expressed as the ratio of the light output ratio of a luminaire at a given time in its life to the initial light output ratio.

Maintenance Factor (MF) is the product of LLFMF and LMF and is used in calculations to account for the overall total reduction in light output from a luminaire over time.

Light Output Ratio (of a luminaire) is the ratio of the total flux of the luminaire measured under specific practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions.

Street Lighting is the lighting provided with the purpose of illuminating all types of road.

3 Historical Review

Desktop research of published or otherwise available information, relating to the use of maintenance factors has been collated and examined. This included gathering documentation relating to maintenance factors from British and European Standards as well as guidance from ILE technical reports and the Outdoor Lighting Guide, SLL reports and CIE standards. In addition current guidance in DfT Technical Advice notes has been examined. Contact has been made with the British Standards Institute's committee CPL 34/08 Road Lighting which has the task of investigating the update to BS 5489 and BS EN 13201 after 2008.

Documents consulted include the following:

- ILE Outdoor Lighting Guide
- BS5489 (1987 & 2003) Code of Practice for design of road lighting
- BS EN 13201 2003 Road Lighting
- EN 12464-2:2007 Outdoor Work Places
- TD34
- TD23
- ILE TR19 "The Effectiveness of Lantern Cleaning" 1989
- CIE 154 "Maintenance of Outdoor Lighting" 2003
- CIE 33.1-1996 "Depreciation of Installations and their Maintenance"
- CSS/UK Lighting Board "Well Lit Highways"
- TRRL Lab report 367 "Marshall Committee recommendations".
- Galvanisers Association Map

Topics researched include:

- Existing criteria for calculating maintenance factors;
- Impact of various maintenance factors being used;
- Review of published journal articles on maintenance factors.

Maintenance factors are referred to in many Standards, Codes of Practice and guidance documents. This chapter is identifying those references and putting emphasis on those documents in current usage. The most important document with guidance on Maintenance Factors is BS5489-1:2003. This standard contains a table of LMF's based upon pollution categories, cleaning cycles and ingress protection of the luminaire and provides guidance on the use of Maintenance Factors.

3.1 BS5489 (1987 & 2003) Code of Practice for design of road lighting

BS5489 is the standard which defines current usage of Maintenance Factors within the UK Road Lighting sector.

The section which contains the textual guidance is:

“6.4.4 Maintenance factor”

“The luminance or illuminance levels should not in service fall below the values specified for the lighting class selected from BS EN 13201-2, as these are maintained levels. The calculation method in BS EN 13201-3 should be used to determine luminance and illuminance levels and quality criteria.”

“NOTE 1 This method incorporates a maintenance factor (MF), which is a product of the lamp maintenance factor and the luminaire maintenance factor.”

“The lamp luminous flux maintenance factor should be obtained from the lamp manufacturer’s data, taking account of lamp type, operating environment and lamp change policy.”

“NOTE 2 The luminaire maintenance factor is influenced by the quality of sealing of the lamp compartment (represented by the IP number), the local environmental pollution, and the frequency of cleaning. Typical values of luminaire maintenance factors that take into account these aspects are given in Annex D; alternatively, luminaire maintenance factors established by local testing may be used.”

The relevant table is found in Annex D of the standard

Annex D (informative)

Typical luminaire maintenance factors

Table D.1 shows typical luminaire maintenance factors, which may be used in design calculations. It takes into account luminaire IP rating, pollution category and cleaning interval.

Table D.1 — Luminaire maintenance factors

Cleaning interval months	Luminaire maintenance factor								
	IP2X minimum ^a			IP5X minimum ^a			IP6X minimum ^a		
	High pollution ^b	Medium pollution ^c	Low pollution ^d	High pollution ^b	Medium pollution ^c	Low pollution ^d	High pollution ^b	Medium pollution ^c	Low pollution ^d
12	0.53	0.62	0.82	0.89	0.90	0.92	0.91	0.92	0.93
18	0.48	0.58	0.80	0.87	0.88	0.91	0.90	0.91	0.92
24	0.45	0.56	0.79	0.84	0.86	0.90	0.88	0.89	0.91
36	0.42	0.53	0.78	0.76	0.82	0.88	0.83	0.87	0.90

^a Ingress protection code number of lamp housing; see BS EN 60529.
^b High pollution generally occurs in the centre of large urban areas and heavy industrial areas.
^c Medium pollution generally occurs in semi-urban, residential and light industrial areas.
^d Low pollution generally occurs in rural areas.

3.2 BS EN 13201:2003 Road Lighting

BS 5489:2003 is a guidance document which in effect supports the European Norm EN 13201:2003

BS EN 13201-3:2003 Road Lighting Calculation of Performance mentions Maintenance Factors (MF) defined as the product of the lamp flux maintenance factor and the luminaire maintenance factor. This is found in Para 3.2; Table 1 – Symbols and abbreviations. This definition is then used throughout the document where MF is used in formulae to calculate average and point luminance and illuminance levels. The Standard does not make any specific recommendations with regards Maintenance Factors.

3.3 EN 12464-2:2007 Outdoor Work Places

This standard has also been published as an ISO document ISO 8995-2:2005 and a CIE document. Section 4.9 discusses Maintenance Factors but importantly refers to CIE 154:2003 for further reference.

The text is:

“4.9 *Maintenance Factor (MF)*”

“The lighting scheme should be designed with a maintenance factor calculated for the selected lighting equipment, space environment and specified maintenance schedule, as defined in CIE 154:2003. The recommended illuminance for each task is given as maintained illuminance. The maintenance factor depends on the maintenance characteristics of the lamp and control gear, the luminaire, the environment and the maintenance programme.”

The designer shall:

- *state the maintenance factor and list all assumptions made in the derivation of the value;*
- *specify lighting equipment suitable for the application environment;*
- *prepare a comprehensive maintenance schedule to include frequency of lamp replacement, luminaire cleaning intervals and cleaning method.”*

3.4 CIE 154:2003 The Maintenance of Outdoor Lighting Systems

CIE 154 is a comprehensive report into maintenance of outdoor lighting systems. In the introduction it takes the definition of “Maintenance Factor” from the International Lighting Vocabulary (CIE 17.4-1987) as “*Ratio of the average luminance / illuminance on the working plane after a certain period of use of a lighting installation to the average luminance / illuminance obtained under the same conditions for the installation considered conventionally as new.*”

Chapter 2 discusses the need for maintenance and states that:

“All lighting schemes will deteriorate progressively from the moment they are put into use. The losses are due to an accumulation of dust and dirt on all exposed surfaces of lamps and luminaires – reducing the transparency or reflecting power – and to the decay in lamp-lumen output and failing lamps”

The influencing factors for the reduction in light output can be classed as non-recoverable due to ageing (e.g. of protector) or recoverable factors such as lamp lumen maintenance and luminaire maintenance which can be recovered through the process of re-lamping or luminaire cleaning.

Chapter 3 attempts to analyse the depreciation

“3. Analysis of Depreciation”

“Several factors contribute to light losses and the effect and magnitude vary with the type of lamp, luminaire, its installation geometry and the environment. For example, areas vary as to the amount and type of dirt in the air; the amount of dirt in the centre of an industrial city is greater than that found in a rural village. But the type of dirt is also important. The dry dust from a stone quarry is very different from the crop spray and insects on a rural traffic route. It is important to be able to recognise these variations when assessing luminaire types and cleaning requirements.”

“3.1 Lamp lumen maintenance”

“The output of all lamps decreases during use. The exact rate, however, depends on the lamp type and ballasting system. The losses due to this effect can be reduced by more frequent lamp replacement, perhaps by group replacement. Table 3.1 shows typical examples. It is therefore very important to obtain up-to-date data from the manufacturers for estimating the maintenance factor and the maintenance programme, particularly when using a new type of lamp.”

Table 3.1 Lamp Lumen Maintenance Factors (LLMF).

Lamp type	Operating time (thousands of hours)				
	4	6	8	10	12
S	0,98	0,97	0,94	0,91	0,90
M	0,82	0,78	0,76	0,74	0,73
Q	0,87	0,83	0,80	0,78	0,76
L	0,98	0,96	0,93	0,90	0,87
FD* (Tph)	0,95	0,94	0,93	0,92	0,91
(Hph)	0,82	0,78	0,74	0,72	0,71
FS*	0,91	0,88	0,86	0,85	0,84

Note. The lamp abbreviations given in the table relate to the following lamps:

- | | | | |
|-----|-----------------------|-----|---------------------|
| S | High Pressure Sodium | FD | Tubular fluorescent |
| M | Metal Halide | FS | Compact fluorescent |
| Q | High Pressure Mercury | L | Low Pressure Sodium |
| Tph | Triphosphor | Hph | Halophosphate |

* Relates to value at an ambient temperature of 25°C, therefore check location.

For specific lamp data always consult the manufacturers.

“3.2 Lamp survival”

Lamp survival is the probability of lamps continuing to operate for a given time. The survival rate depends on lamp type and particularly, in the case of discharge lamps, the wattage, frequency of switching and the ballasting system. Failed lamps cause reduction in illuminance and uniformity, but the effect can be minimised by spot replacement of lamps. “

The below table shows typical examples:

Table 3.2 Lamp Survival Factors (LSF).

Lamp type	Operating time (thousands of hours)				
	4	6	8	10	12
S	0,98	0,96	0,94	0,92	0,89
M	0,98	0,97	0,94	0,92	0,88
Q	0,93	0,91	0,87	0,82	0,76
L	0,92	0,86	0,80	0,74	0,62
FD (Tph)	0,99	0,99	0,99	0,98	0,96
(Hph)	0,99	0,98	0,93	0,86	0,70
FS	0,98	0,94	0,90	0,78	0,50

Note. The lamp abbreviations given in the table relate to the following lamps:

S	High Pressure Sodium	FD	Tubular fluorescent
M	Metal Halide	FS	Compact fluorescent
Q	High Pressure Mercury	L	Low Pressure Sodium
Tph	Triphosphor	Hph	Halophosphate

For specific lamp data consult the manufacturers.

“3.3 Dirt on lamps and luminaires”

“Dirt on lamps and luminaires will generally cause the greatest loss of light. The amount of light loss depends on the nature and density of airborne dirt, luminaire design and lamp type.

Dirt accumulation on reflecting surfaces can be minimised by sealing the lamp compartment against entry of dust and moisture. Significant benefits can be obtained with the luminaire optical compartment sealed to at least IP5 - protection.”

The below table shows typical data for a range of luminaires.

Table 3.3 Luminaire Maintenance Factors (LMF).

Optical compartment IP Rating	Pollution Category	Exposure time (years)				
		1,0	1,5	2,0	2,5	3,0
IP2X	High	0,53	0,48	0,45	0,43	0,42
	Medium	0,62	0,58	0,56	0,54	0,53
	Low	0,82	0,80	0,79	0,78	0,78
IP5X	High	0,89	0,87	0,84	0,80	0,76
	Medium	0,90	0,88	0,86	0,84	0,82
	Low	0,92	0,91	0,90	0,89	0,88
IP6X	High	0,91	0,90	0,88	0,85	0,83
	Medium	0,92	0,91	0,89	0,88	0,87
	Low	0,93	0,92	0,91	0,90	0,90

3.5 Outdoor Lighting Guide

The ILE produced the Outdoor Lighting Guide in 2005 as a comprehensive reference for outdoor lighting design and maintenance. Maintenance Factors are referenced throughout the document, but essentially the guidance is taken from BS5489. Table 3.17 on p142 of the Outdoor Lighting Guide is a reproduced table from BS5489-1.

Section 4.6.2.2 recommends the use of high IP rated luminaires in order to utilise a higher Maintenance Factor and potentially reduce luminaire quantities whilst maintaining the lighting levels.

3.6 TD34 Design of Road Lighting for the Strategic Motorway and All Purpose Trunk Road Network

TD34 is part of the Design Manual for Roads and Bridges (DMRB) published by the Department for Transport. It was updated in 2007 to incorporate changes arising from the European Standard EN13201 and BS5489.

Previously TD34/91 prescribed a single value of Maintenance Factor for all motorways of 0.81. The update to TD34 requires the designer to calculate Maintenance Factors in accordance with the BS5489-1 method described above.

3.9 Maintenance factors shall be determined in accordance with Sub-Clause 6.4.4 of BS 5489-1. Luminaire maintenance factors shall be selected from Table D.1 of BS 5489-1.

3.10 The requirements for lamp changing and luminaire cleaning are set out in TD 23 Trunk Roads and Trunk Road Motorways Inspection and Maintenance of Road Lighting.

Thus TD34 is now also aligned with BS5489. This has the benefit of favouring higher IP rated luminaires which can now utilise higher Maintenance Factors and potentially achieve increased spacing's.

3.7 TD23/99 Trunk Roads and Trunk Road Motorways Inspection and Maintenance of Road Lighting

This document which is part of the DMRB does not specifically mention Road Lighting Maintenance Factors, but it does define cleaning cycles in Annex A. The values used are for bulk lamp change and clean as follows:

Low Pressure Sodium	SOX	24 months
Low Pressure Sodium	SOX-E	36 months
High Pressure Sodium	SON	36 months
Fluorescent	PL-L	24 months

These values would require updating in line with improvements in lamp life and lamp technology as well as changing lamp types being prevalent within the industry. It is understood that a revised TD23 is expected to be published in 2008.

There is also reference to luminaire cleaning in Chapter 5 – Maintenance. Clause 5.10 states that “the external surfaces of luminaires shall be cleaned during bulk lamp change” Clause 5.11 refers to the internal surfaces of luminaires which would generally relate to luminaires of a lower IP rating than IP65. It states that the “internal surfaces of luminaires shall only be cleaned, during bulk lamp change, where significant deposits are observed and reasonable access to the surface is available”.

3.8 ILE TR19 “The Effectiveness of Lantern Cleaning” 1989

This ILE report was the result of a study panel which was formed in 1984, and was a follow-on from the earlier ILE Technical Report No 8 “Maintenance of Public Lighting: Lantern Output Depreciation” published in 1977.

The report identifies lighting as a significant cost item in lighting maintenance budgets.

The report states that the IP related Maintenance Factors in BS 5489 (1987) was based on data from the studies which formed the basis of the 1977 Technical Report. On this basis the Maintenance Factors we are using in 2008 are based on studies which are over 30 years old.

Four factors were identified as causing luminaire output depreciation;

- a) Lamp Output Depreciation
- b) Internal build-up of dirt
- c) External build-up of dirt
- d) Permanent degradation of luminaire materials

Of these, the lamp output depreciation was outside the scope of the report (as it is for this report). In terms of currency of this research the fundamental difference is that modern luminaires are generally better Ingress Protection ratings (IP6x is common) so item b) is assumed to be of insignificant influence.

It states that cleaning frequencies and practices have often been historically based (and modified by financial constraints) and not related to the primary objective of maintaining the designed performances of lighting installations.

Conclusions and Recommendations

The conclusions from this report and study which relate to Maintenance Factors are reproduced below. It should be re-iterated that the conclusions are based upon studies with IP23 and IP54 luminaires which were prevalent at the time. It is now the case that the vast majority of designs will be done using IP6X luminaires, which is certainly a trend unlikely to be reversed in the near future.

6.3(i) A non-recoverable depreciation element is shown to be present in both IP23 and IP54 installations in Low, Medium and High pollution categories.

(ii) In the maintenance factor selection process the choice of pollution category, as defined in Table 4 of BS 5489 Part 2, is not as straightforward as is often supposed and a major source of error in the design calculations is introduced when the wrong choice is made.

Recommendations

(i) The findings of this report in regard to luminaire light output depreciation rates should be taken into account in any future revision of Table 4 of BS 5489 Part 2. Any such revision should include consideration of the definitions of the three pollution categories currently specified.

(ii) The development of test equipment and procedures to establish local ambient pollution categories and lantern output depreciation rates would greatly assist lighting design engineer in the selection of appropriate maintenance factors.

3.9 CIE 33.1-1996 “Depreciation of Installations and their Maintenance”

1.1 Maintained installation output

This output is clearly equal to the initial output multiplied by the product of all the depreciation factors: that is to say, in the absence of any replacements or cleaning, the output of a public lighting installation tends rapidly towards zero. This is reflected in the capital interest which such operations present from the twin points of view of economy and safety.

Even in the case of systematic maintenance, the integrated mean practical values of illumination (and thus of luminance) of an installation appear to be 20 to 30% lower than the initial calculated values. For this reason in many countries, the standard specifications or codes of practice recommend that the installation is designed to give at least the levels of illuminance E and luminance L multiplied by:

$$1/(1-20\%) = 1.25$$

NB: The American document which covers the first seven years after bringing into service can be compared, on the one hand, with the graph (fig 2) taken from the Belgian code which covers the first 10 years; and, on the other hand, with the Australian and the new Canadian Code of Practice for Traffic Route Lighting (presently being prepared), which gives the following approximate figures:

a) for the depreciation of the luminaire itself (lamp excluded):

In clean environment	5% per annum
In industrial environment	10% per annum

b) and for the total depreciation (luminaire and lamp) of the lower hemisphere flux of luminaires utilising high pressure mercury vapour lamps, situated in an industrial environment. 32% of the initial flux after 2 years: the last figure lines up rather closely with the Belgian code.

3.10 CSS/UK Lighting Board “Well Lit Highways”

3.54 Maintenance Factors (Page 18)

The Well Lit Highways document has a section on Maintenance Factors in Chapter 5 “Design for Maintenance”. This document follows the recommendation of BS5489-1

“The frequency of luminaire maintenance and the group replacement of lamps have a direct relationship on the performance of the lighting installation. BS 5489-1: 2003 recommends that the lighting installations be designed to provide a minimum maintained level of luminance or illuminance throughout the life of the installation. This is realised in the design process by the use of maintenance factor (MF) which takes account of the lamp flux maintenance factor and luminaire maintenance factor. The use of a maintenance factor provides a logical basis for the design process and helps to achieve the minimum maintained lighting level throughout the life of the installation.

Where lamps are burnt to extinction, luminaires may be maintained at the time of lamp replacement. In such circumstances it is impossible to determine an overall maintenance factor for use in design.”

3.11 TRRL Lab report 367 “Marshall Committee recommendations

The Transport and Road Research Laboratory published a report in 1970. The TRRL Laboratory Report 367 was a wide-ranging report on the findings of the Marshall Committee entitled “the Marshall Committee’s recommendations for standards of highway maintenance and for a maintenance rating system”

The section related to road lighting maintenance is shown below

14. Maintenance of Road Lighting

14.1 The object is to maintain the designed standard of illumination with a reasonable degree of certainty.

14.2 Suggested Standards

ii Lamp Changing bulk changing at nominal life and individually on failure (though replacement not to be undertaken more frequently than the scouting frequency).

iii Luminaire internal inspection and cleaning at least once a year

iv Luminaire external cleaning at least twice a year

4 Current practice in 2008

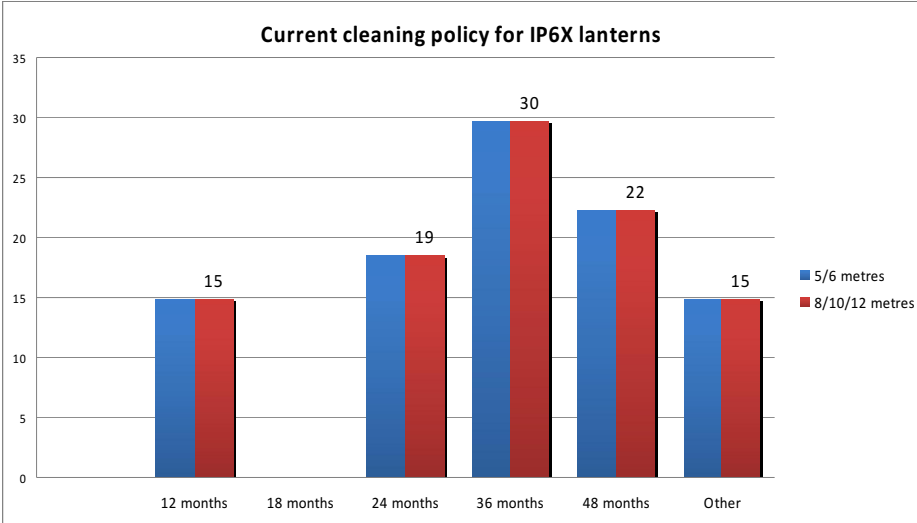
In order to make recommendations for future practice with reference to the use of Maintenance Factors, it was essential to investigate current custom and practice for designers of street lighting within Local Authorities.

In order to achieve this, a questionnaire was created with the objective of obtaining information from local authorities on current practice for calculating Maintenance Factors. The questionnaire also asked for opinions and views regarding the accuracy of the current method. Ideas were obtained on how this subject should develop in the future.

The questionnaire was sent to a sample of County Councils, Unitary Authorities, Metropolitan Boroughs, London Boroughs, Scottish Local Authorities and a good response of 30 replies was received out of approximately 75 requests.

4.1 Results of Local Authority Questionnaire

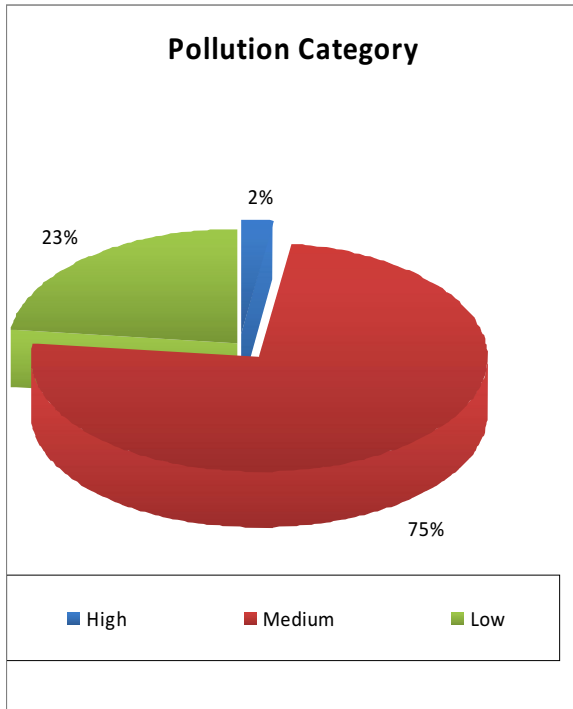
Question 1 - What is your current luminaire cleaning policy for IP 6X luminaires?



The most common cleaning policy was a 3 year clean, but a significant number are extending cleaning cycles to four years which is not currently covered by the Maintenance Factor table in BS5489-1

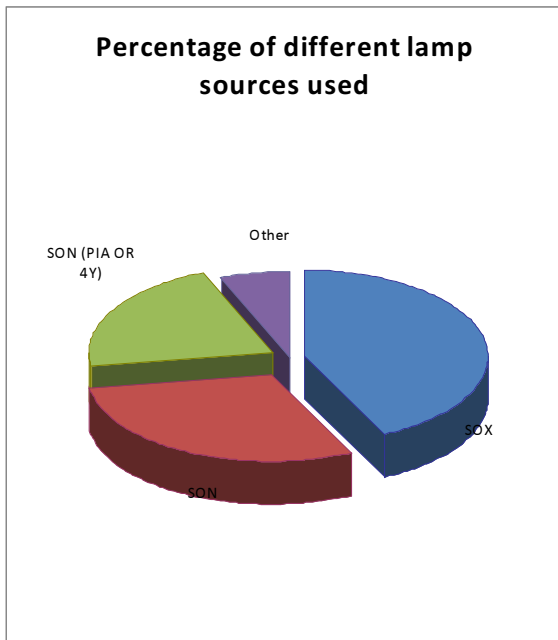
A significant number of authorities are also tied into annual cleans which would seem to be too often.

2 What pollution category do you use predominantly?

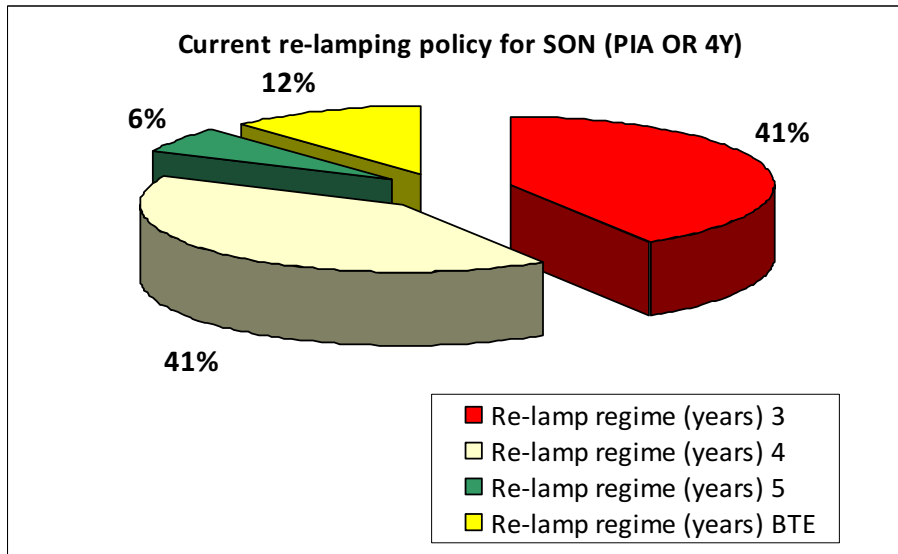


The key point from the question regarding pollution category is that very few authorities use a high pollution category, so it is clear that this method of using pollution categories is not being used in the way in which it was originally intended. The vast majority of Local Authorities use a 'Medium' pollution category.

3 a) What lamps are most prevalent in your inventory?

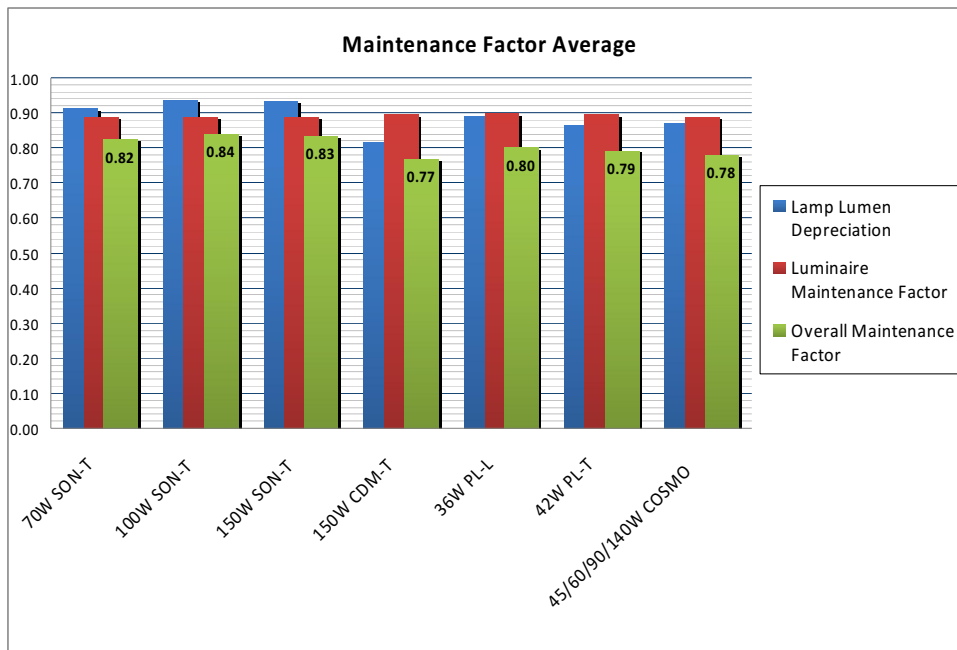


3 b) What is your current re-lamping policy for each lamp type?



The significant finding was that 41% of authorities are re-lamping 4 year lamps every three years, the same percentage as re-lamp every 4 years. The results show that 6% of authorities have extended the re-lamp period to 5 years, and 12 % burn to extinction.

4. What value of Maintenance Factor do you use for the following situations?



When Local Authorities were asked about the Maintenance Factor used, the significant finding was that the average value for SON lamps seemed to be lower than expected, whilst the opposite was true for white light sources (COSMO).

5 Conclusions and Comments on current practice

There are a number of conclusions that can be drawn from the returns from the Local Authority questionnaires.

Cleaning policy – There are large variations in luminaire cleaning policies between authorities, ranging from 12 monthly up to 48 monthly. It makes sense for cleaning policies to be extended if there is not too much of a detrimental effect on MF values. Cleaning cycles should coincide with re-lamping.

Pollution Category – The High pollution category is rarely used, which suggests that the method is too subjective. The vast majority of Authorities suggested that Medium Pollution category was used for their area.

Re-lamping policy for 4Year lamps – The significant finding here was that lamps designed for a 4 year life were not necessarily re-lamped at 4 years. 41% were re-lamped at 3 years, the same number as for 4 years. This suggests that Maintenance regimes are not flexible enough to adapt to improving technologies.

Lamp lumen depreciation – The values of lamp lumen depreciation used by Authorities did not necessarily reflect the latest data from lamp manufacturers. This may be due to the difficulty in obtaining up-to-date information from manufacturers, or the fact that there may be historical trends being applied within different Authorities.

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6 Effect of Different Maintenance Factor values and whole life cost

Maintenance Factors (MFs) are utilised in street lighting design calculations as a factor which is multiplied by the average illuminance or luminance in order to obtain a maintained figure. Thus where the limiting factor for a calculation is the average level, then a reduction in MF will lead to a reduction in optimum spacing.

A number of sample calculations have been performed to illustrate this effect.

Typical calculations are done for subsidiary roads and for traffic routes.

To see what effect a reduction or increase in maintenance factor would have a variety of calculations were carried out for both Luminance and Illuminance lighting classes.

Traffic Routes

For traffic routes ME3c, ME3a and ME2 calculations were carried out using different luminaires and a variety of road layouts and column arrangements. In each set of calculations all variables were fixed apart from the maintenance factor, this was altered from 0.80 – 0.95 in 0.05 increments. By using the L_{av} min as the limiting factor and altering the maintenance factor as stated the following results were found.

Each time the maintenance factor was increased by 0.05 the spacing was increased by either 2.0 or 2.5 metres. (See Fig 1)

Maintenance Factor	Max. Spacing (m)
0.95	43.0
0.90	40.5
0.85	38.0
0.80	36.0

(Fig 1 - ME3c/Single Sided)

On all occasions the U_o varied by a maximum of 3% (Fig 2) but the U_L varied by as little as 1% or as much as 12% (Fig 3).

U_o	U_L
59	70
59	71
57	71
56	71

(Fig 2 - ME3a/Opposite)

U_o	U_L
42	54
45	58
44	61
45	66

(Fig 3 - ME3c/Single Sided)

As part of the calculations estimates were produced on the amount of columns per km, wattage per km and approximate power saving per km. The amount of columns saved per km only varied by 1 or 2 metres per MF variation. The saving in power was around 200 – 350 Watts each time the MF was altered.

Residential Roads

For Residential roads S4 and S3 calculations were carried out on the same basis as the traffic routes. Again for each set of calculations all main variables were kept the same with only the column arrangement and MF being varied. For these calculations the MFs used were between 0.70 and 0.85 and were varied by 0.05 increments. In these calculations the limiting factor that was used was the E_{Min} .

For both the S3 and S4 calculations the column spacing varied by 1–2 metres each time the MF was altered. The amount of columns used per km varied by 3 -4 metres per set of calculations and the saving in wattage per km was around 50-125 Watts.

Conflict Area

An Area calculation was carried out on a typical roundabout to see what effect the reduction or increase in MF would have on the results. The MFs used were between 0.80 and 0.95 and varied in 0.05 increments. Using the E_{Ave} as the limiting factor only this figure altered with the MF the U_0 did not alter.

Maintenance Factor (MF)	E_{Min} (lx)	E_{Ave} (lx)	U_0
0.80	13.12	32.32	41
0.85	13.94	34.35	41
0.90	14.76	36.37	41
0.95	15.58	38.39	41

(Fig 4 – Conflict Area)

The main thing to be noted from the results above (Fig 4) is as the E_{Ave} increases there is a scope to be able to decrease the wattage and still be able to achieve the required levels. This may not lead to a decrease in column numbers but would give you a decrease in total wattage used to light the roundabout.

Summary

A key point that has been determined from the calculations carried out is that not only can a potential saving in columns be made but also a saving in the amount of wattage consumed for a given installation.

7 Luminaire Testing

7.1 Selection Criteria

7.1.1 Introduction

As part of the research project into Luminaire Maintenance Factors (LMF's), luminaires from the field were removed and tested in a photometric laboratory. The objective of this was to measure the reduction in light output from a luminaire with time, or alternatively the improvement in light output following a luminaire clean. The option of testing luminaires in-situ was rejected as it was thought that there would be too many variables which would create inaccuracies in the results.

7.1.2 Selection of Luminaires

The following key criteria with respect to selecting luminaires were identified in order to limit the scope of the testing:

- The research and the testing are required to look primarily at the LMF and not the Lamp Luminous Flux Maintenance Factor (LLFMF).
- The main objective is to identify the reduction in output due to dirt and pollution and not due to deterioration of the protector (for instance due to UV degradation of polycarbonate). Thus luminaires should have been installed within the previous 5 years. The ideal scenario is to obtain luminaires just prior to the first scheduled bulk clean and re-lamp.
- The luminaires selected for testing include a range of protectors from flat glass; shallow bowl; vertical glazing; self-cleaning glass.
- The luminaires selected should have an IP rating of IP65 or better.
- The date of the installation and, if applicable, of the last bulk clean and lamp change is documented. It is preferable to use luminaires that are approaching their first clean.
- Ranges of cleaning cycles are chosen between 1 year and 3 years.

7.1.3 Identification of suitable sites

The sites identified covered a number of different options so that a spread of conditions is obtained. There are a number of factors which are thought to be important in determining the amount of dirt that a luminaire will attract.

- The sites chosen were open sites away from trees, tunnels, overbridges etc.
- The sites included low and medium pollution areas and some high pollution areas where possible, although this measure is often used in a subjective way.
- The sites included rural and urban locations.

-
- One variable which seems to make a large difference to the amount of dirt on a luminaire is the mounting height. A mixture of luminaires from traffic routes at 8m, 10 & 12m height and residential roads at 5m & 6m height were investigated.
 - The sites included coastal and inland locations.

With the above criteria, there were a large number of test options. To test all options would be beyond the scope of this project, so a representative sample was identified.

7.2 Test Strategy and Procedure

7.2.1 Testing in a photometric laboratory

In order to get a high level of accuracy in test measurements, luminaires were removed from site and taken to a test laboratory to obtain photometric measurements under test conditions.

Ideally at least two luminaires were tested from each site so that individual anomalies were avoided, and a good feel for typical levels of depreciation was obtained.

Luminaires of known age with a quantified lamp change and cleaning record were taken from site and detailed measurements taken in the laboratory to confirm:

- amount of degradation of performance compared with a new luminaire;
- amount of lamp depreciation.
- the change in shape of the light distribution between clean and dirty protectors. If there is an effect it could be the most important factor, as it could alter minimum point values and uniformities of illuminance or luminance.

Within the timescale and scope of the current brief the lamp lumen depreciation will not be investigated for accuracy. The project concentrated on LMF's only.

A number of manufacturers participated in the research and offered laboratory facilities. These include Philips, Urbis, Thorn, and DW Windsor. Each participating manufacturer provided testing for approximately 5 - 10 samples. I

7.2.2 Removal from site

The below procedure represents a typical methodology for removing luminaires for testing.

- a) Identify suitable site based on the criteria above for Site Selection and Luminaire Selection.
- b) Photograph site.
- c) Remove the luminaires from the column without touching the protector or removing the lamp.
- d) Protect the luminaire by supporting in a box and packing in order to protect the protector from any contact with other surfaces or any other pressure which may affect the dirt deposits.

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- e) Ensure adequate packaging and labelling of the sample to ensure that the luminaire is not inadvertently touched or cleaned.
 - f) Arrange for the luminaires to be transported to the laboratory or test centre.

7.2.3 Assessment in the laboratory

The below procedure represents a typical methodology for testing the luminaires.

- a) Visual examination of the luminaire to ensure that it has no dirt inside the protector. (A preliminary examination of the luminaire would have been carried out on site prior to removal)
- b) Test the luminaire in accordance with BS EN 13202-1:2004
- c) The luminaire should be tested with a laboratory test lamp prior to cleaning.
- d) The luminaire exterior surface of the protector should be cleaned with detergent in accordance with the procedure detailed in 7.2.4 below.
- e) The luminaire should be re-tested with the same test lamp after it has been cleaned.
- f) If possible, the luminaire should be tested for a third time but with a new protector in order to determine the non-recoverable losses due to degradation of the protector.

The reason for doing a full measurement of luminaires is to determine whether the shape of the light distribution is affected by the deposition of dirt. If after testing a few representative samples, it is determined that the change in shape of the distribution is insignificant, then the testing can be simplified for further tests.

If the change in shape is significant, then this has implications for the way that Maintenance Factors are applied as the current assumption is based on a global reduction percentage due to dirt etc.

7.2.4 Cleaning of Luminaires

ILE Technical Report 19 Chapter 3 entitled “Practical Aspects of Cleaning” provides guidance on the cleaning technique that should be adopted by each laboratory and this is summarised below.

- It is essential that any detergent used and that any cleaning process does not affect the integrity of the protector surface.
- The manufacturer’s recommendations should be followed regarding the diluting of the detergent and the mixing and storing of the solution.
- TR 19 recommended a concentration of 1:100 for lightly soiled luminaires and 1:10 for excessively dirty luminaires.
- A slightly better cleaning result will generally be obtained by using higher temperature water, so warm water is recommended.

-
- The cleaning solution can be applied either by cloth or by spray. If cloth is used, then it must be soft, clean and contain no abrasive particles which could damage the surface of the protector.
 - It is important that when cleaned, the protectors are dried with a clean soft non-abrasive cloth.

7.2.5 Interpretation of Results

It was anticipated that the results from the above laboratory tests and site tests would show a relationship between some of the many variables including mounting height and environmental zone. This coupled with the time since last clean and reduction in light output should enable the creation of a table of LMF's for different luminaire clean cycles.

7.3 Variables

Many variables were identified in order to obtain a strategy for the luminaire testing. In addition some of the criteria were fixed so that the testing would be better equipped to produce meaningful results.

The following criteria were set:

- Street Lighting luminaires were tested
- The IP rating was IP65 or higher.
- The luminaires were less than 5 years old.
- The sites were not close to trees, bridges or other locations which could adversely affect the result.

The variables include:

- Age of installation
- Time since last bulk change and clean
- Protector Type
- Rural or Urban (Environmental Zone)
- Road Hierarchy (As defined in Well Maintained Highways)
- Special circumstances including being adjacent to the coast or on a salting route

8 Results of Testing

The methodology for the calculation of a comprehensive maintenance factor for outdoor lighting installations is well established and formalised in document CIE 154:2003.

However, with increasing legislation on clean air and the reduction of air-borne pollutants it is possible that the table of values being applied to calculate the LMF is no longer valid, and a new table needs to be produced.

As an initial step a number of manufacturers in cooperation with BSI are measuring the performance of street luminaires recovered from outdoor installations to verify the decline in performance due to dirt on the luminaire.

Some of the results received from the independent results have been discounted due to irregular results (i.e. depreciation greater than 1) or the voltage supply of the test equipment not being stabilised during the test.

8.1 Test Results

8.2 Statistical Analysis

A majority of the luminaires were sent to their respective manufacturers to enable them to conduct their own tests to the methodology previously supplied, as well as some of the luminaires being tested independently. The depreciation of each of the luminaires was plotted onto the graph, each showing a smaller depreciation than that shown in the current BS 5489 table.



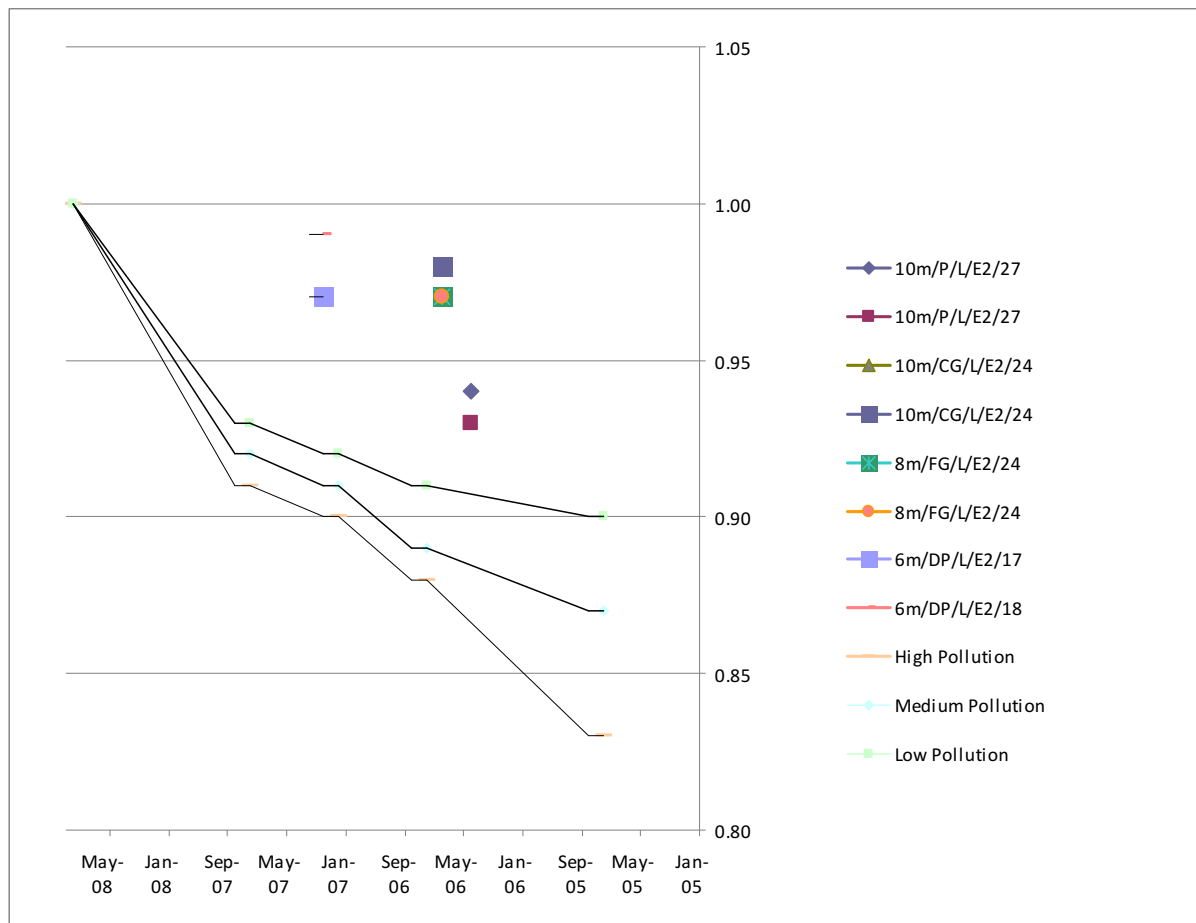
Although the results proved the current recommendations were too low, the result were sporadic and further analysis was required to determine the individual factors affecting the depreciation. The individual factors analysed were pollution, column height and environmental zones.

8.3 Results by Pollution Category

The current British Standard uses the pollution categories to define the level of depreciation. All the luminaires removed from site were grouped into low, medium or high pollution. These results have then been individually plotted to a graph.

8.3.1 Low Pollution

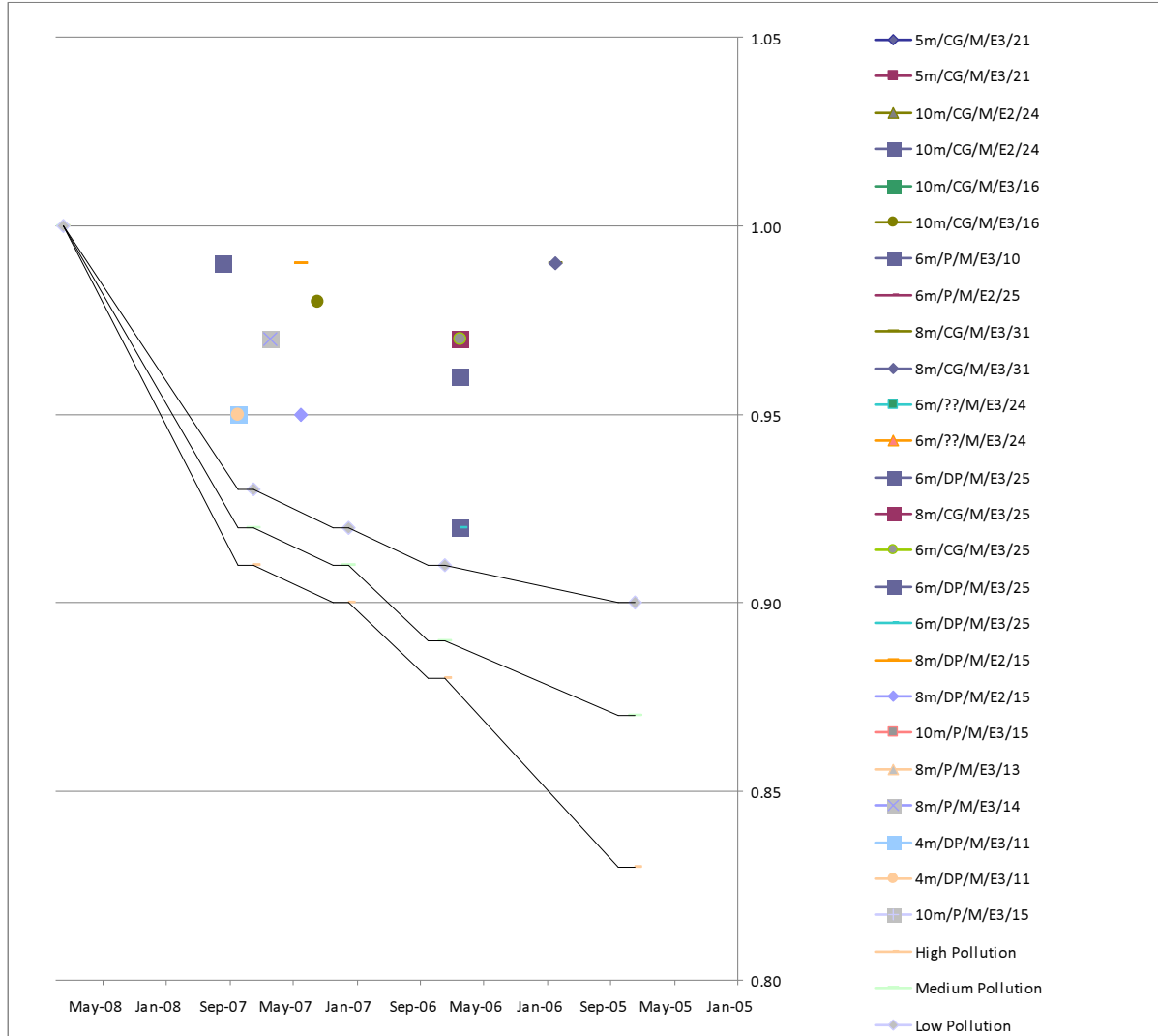
All the results suffered a depreciation level much less than that recommended in the current British Standards.



The results are clustering between 0.97 to 0.99 at approximately 1 year and 0.93 to 0.98 at 2 years.

8.3.2 Medium Pollution

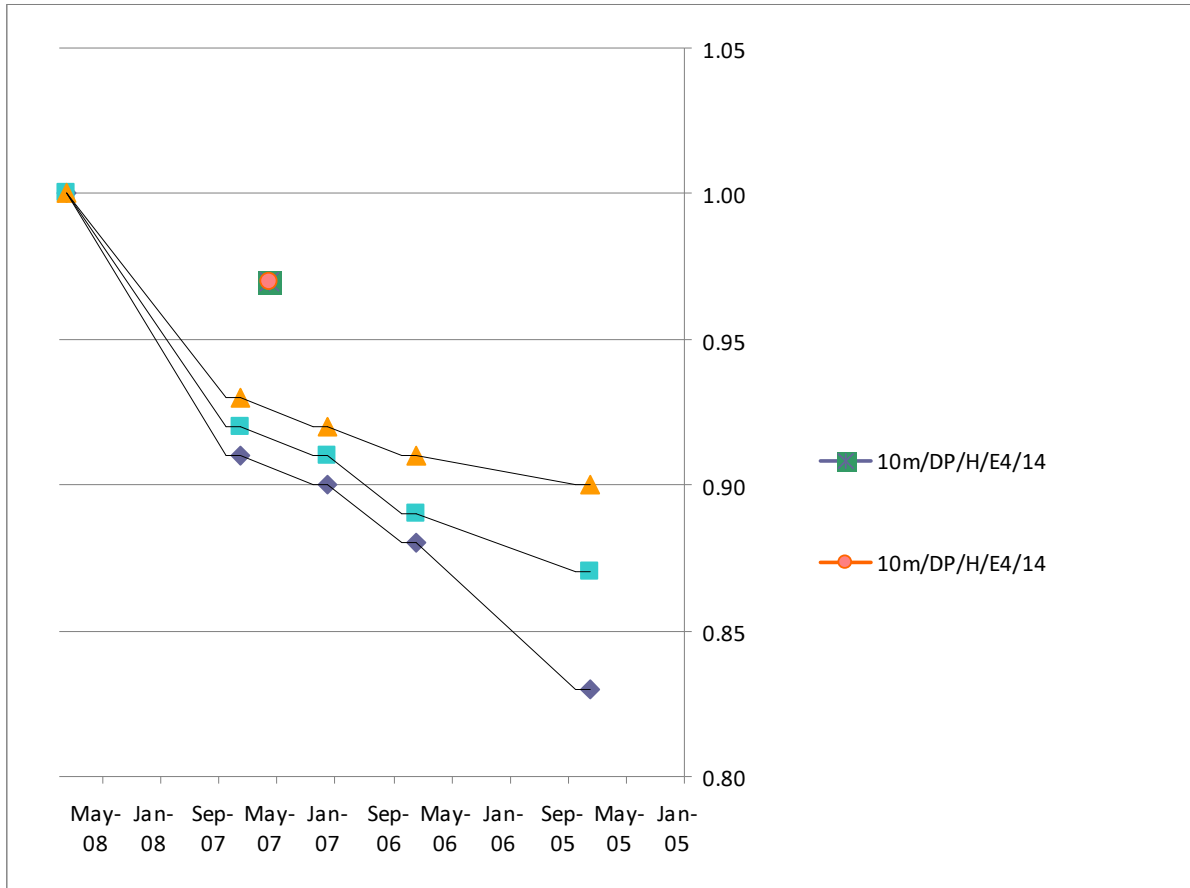
All the results suffered a depreciation level less than that recommended in the current British Standards.



The results are more sporadic than that seen in the low pollution category, and do not define any particular trend. Variations between sites can explain why the results are so different. Although they are all in a medium pollution zone, the shorter columns suffered from spider infestations, which significantly reduced the output of the luminaire.

8.3.3 High Pollution

All the results suffered a depreciation level less than that recommended in the current British Standards. However, only two luminaires were categorized as high pollution, therefore, any meaningful analysis of the results is impossible.

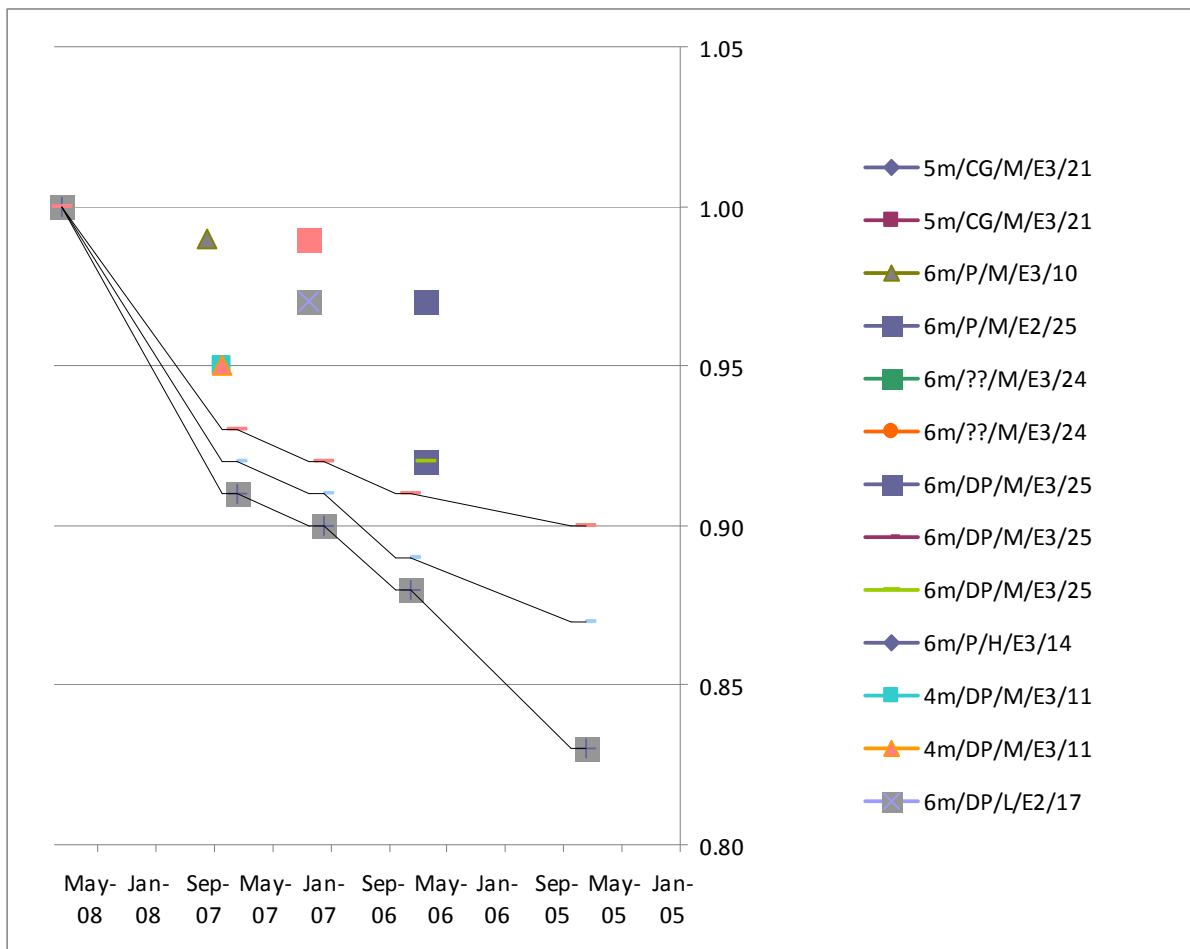


8.4 Results by Column Height

All the luminaires removed from site had their heights noted and these have been plotted onto graphs of 6 metres or less and greater than 6 metres.

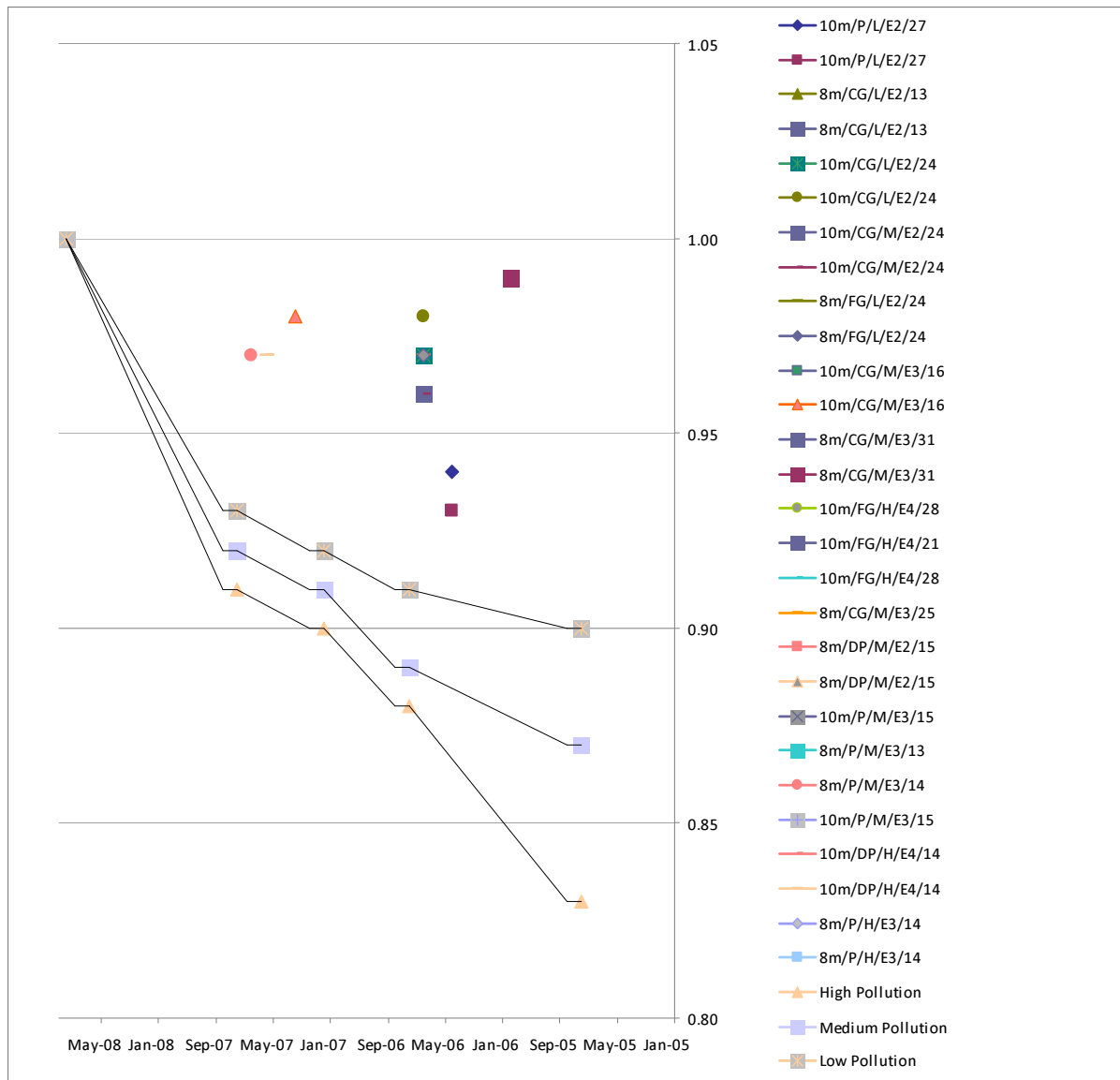
It is considered that columns of a lower mounting height suffer from more degradation as any debris from the road is thrown upwards on to the protectors. Whereas columns of a greater mounting height are out with the debris zone and therefore remain cleaner.

8.4.1 Columns less than 6 metres ($\leq 6m$)



8.4.2 Columns greater than 6 metres (>6m)

When comparing the two graphs it can be seen that although both sets of results achieve a higher value than that recommended, the taller columns achieve a lower and more consistent level of depreciation than shorter columns.

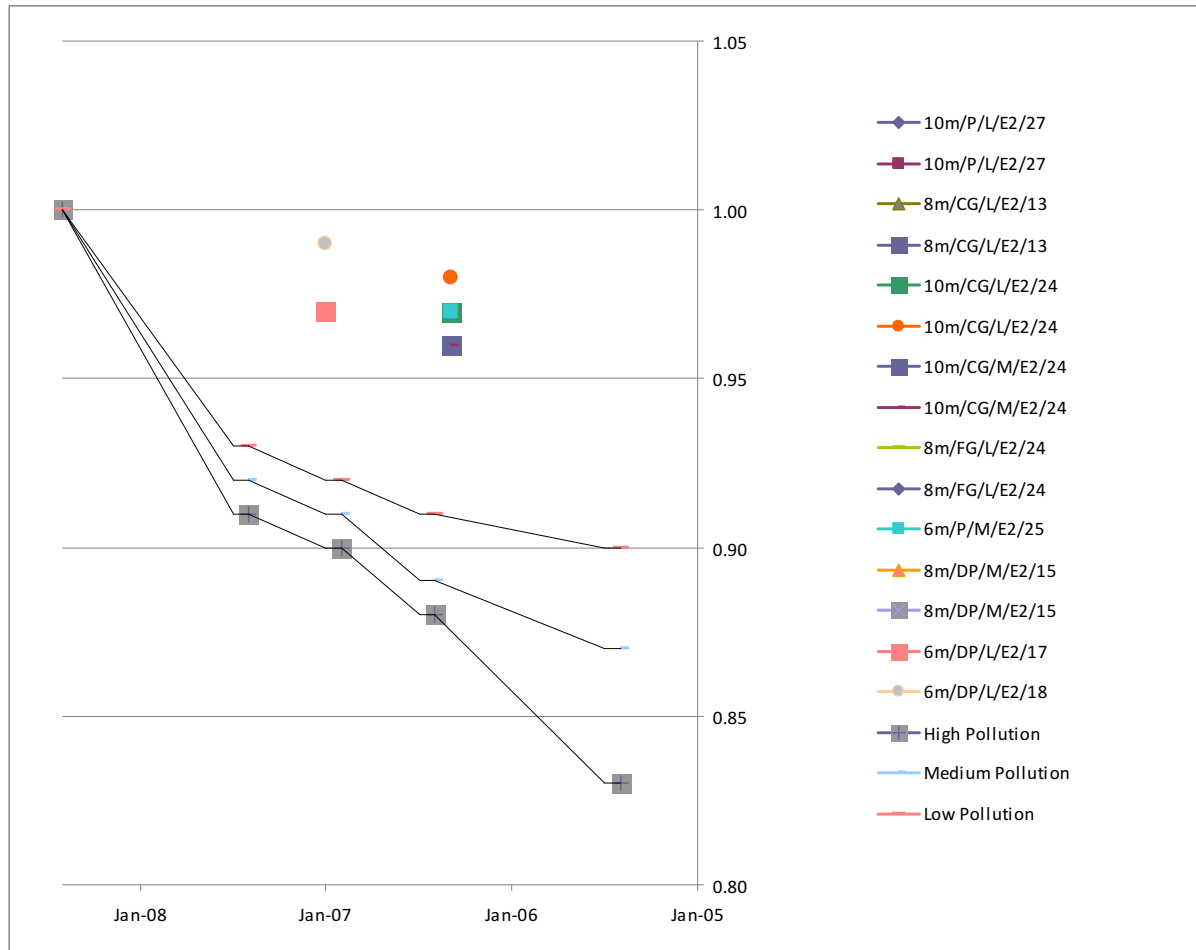


8.5 Results by Environmental Zone

Again, all the results achieved are greater than the BS5489 recommendations.

8.5.1 Environmental Zones E1/E2

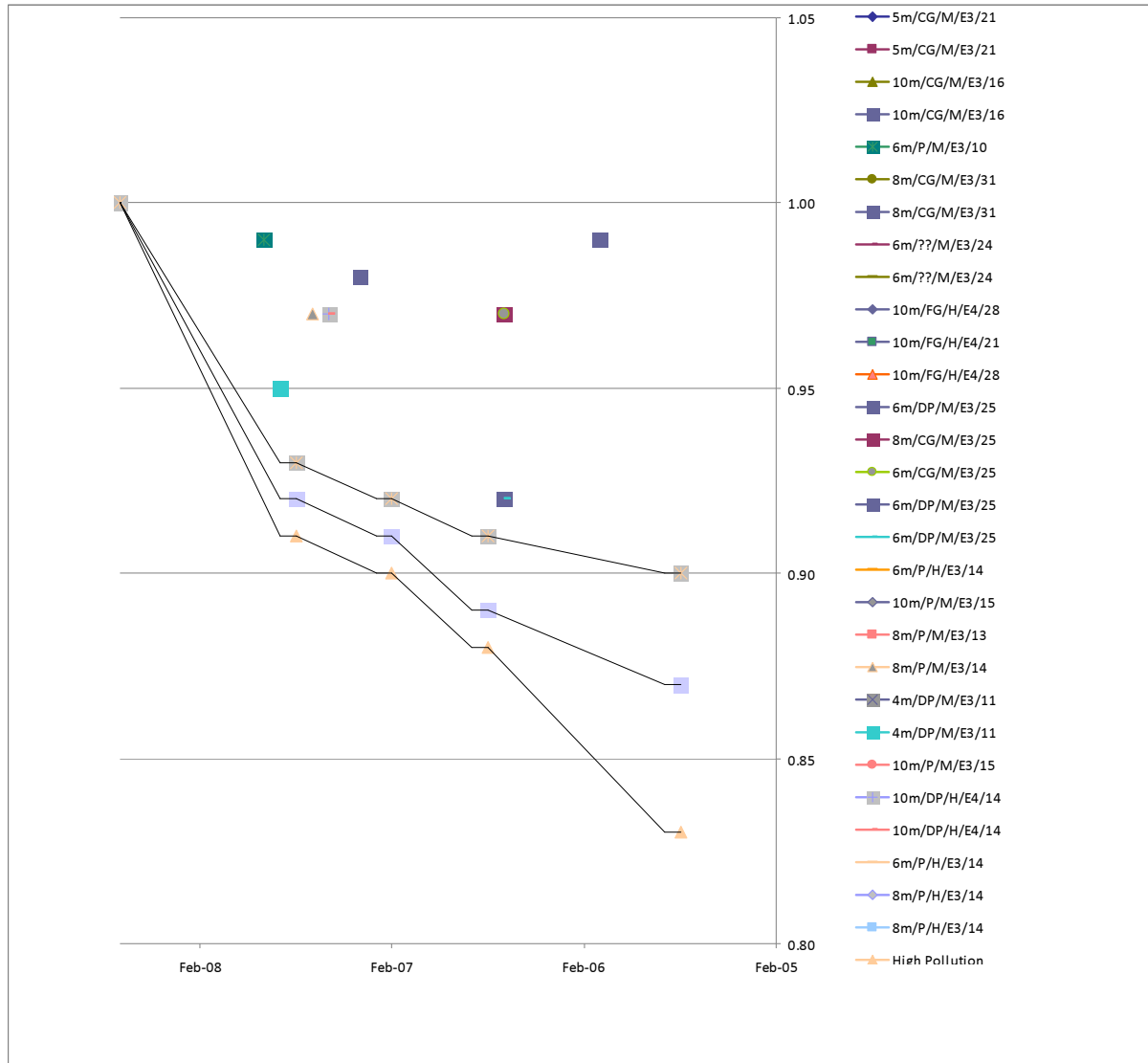
The E1 and E2 environmental zone results are more irregular, but further analysis shows that the results depreciating more are the columns of a lower mounting height (i.e. $\leq 6\text{m}$).



The results provide a very close set of results for approximately 1 and 2 years, showing only 0.02 differences between the best and worst results. Both areas achieve results 5 percent greater than the current recommendations

8.5.2 Environmental Zones E3/E4

The E3 and E4 environmental zones are closely linked to the pollution levels, however, the results are more consistent than the low pollution results.



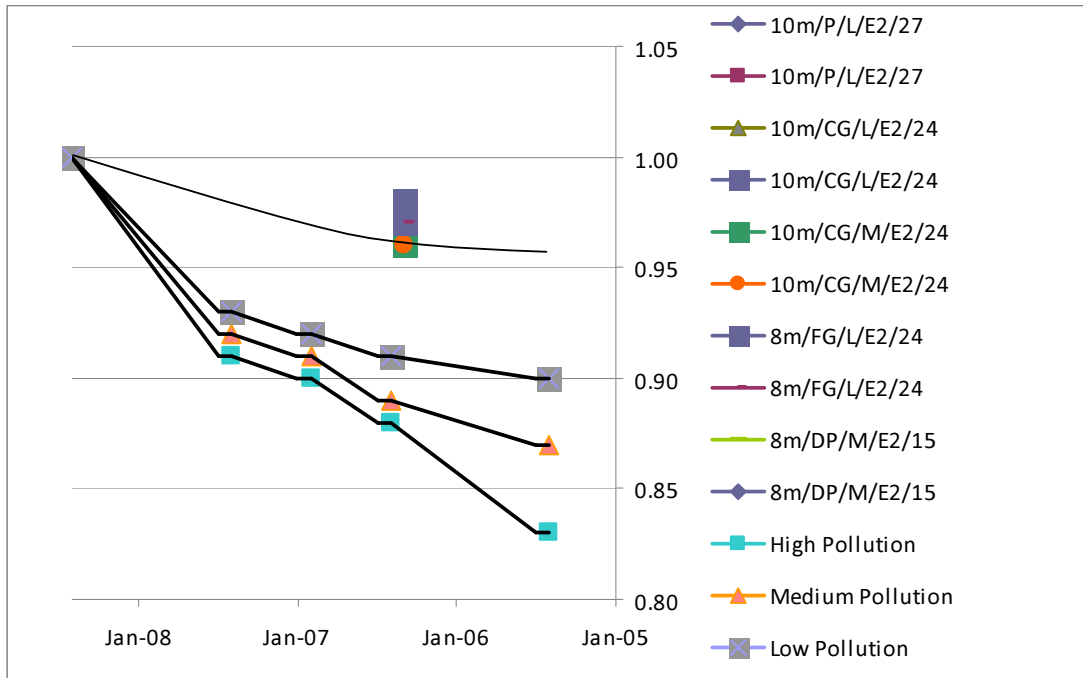
The results are very similar to the medium pollution table.

The results are less consistent; however, the lowest results are from the shorter columns, two of which were heavily infested with spiders.

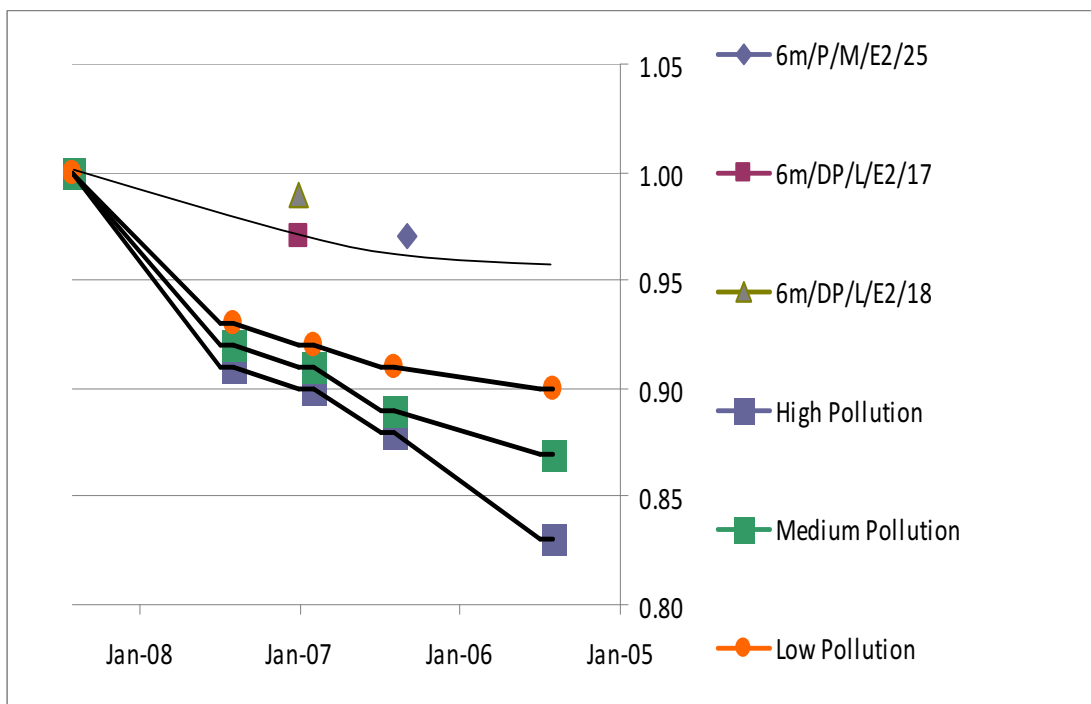
8.6 Results by Height & Environmental Zone

8.6.1 E1/E2 Environmental Zone

≥8m columns – E1/E2



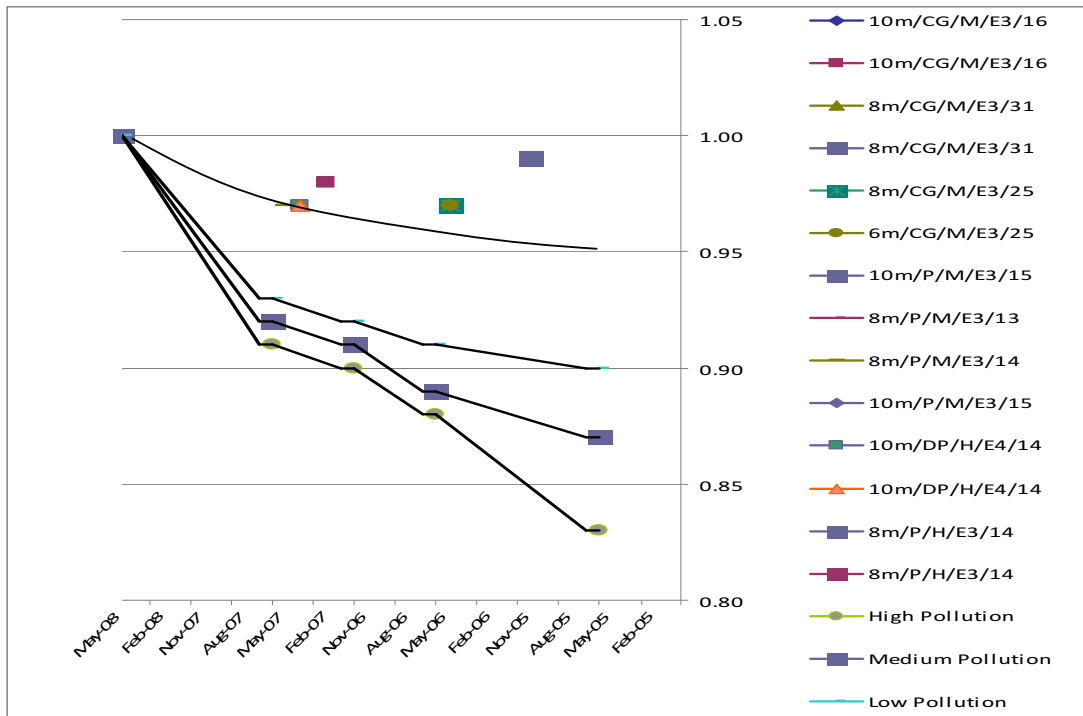
≤6m columns E1/E2



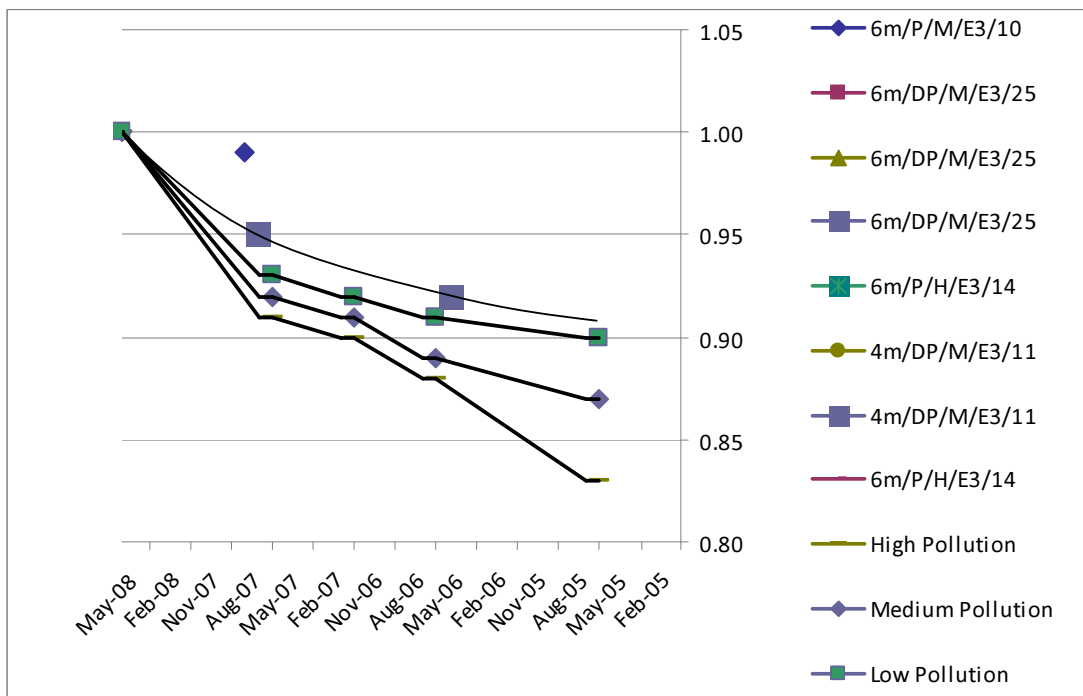
The above results show that there is no a similar curve for all mounting heights tested in an E1/E2 environmental zone.

8.6.2 E3/E4 Environmental Zone

≥8m columns – E3/E4



≤6m columns E3/E4



The above graphs show that the LMF in urban areas is affected by the mounting height and that lower mounting height luminaires attract greater amounts of dirt than those at 8m or above.

9 Conclusions

The major conclusion that was reached from analysing all of the test results is that the Luminaire Maintenance Factor defined by BS5489 is a conservative estimate, and all luminaires had a higher output than the BS5489 predictions.

Across all the tables, it is clear that the current recommendations within BS5489 are not a true reflection of the findings found on site.

The pollution categories are often misused, with authorities designating one pollution category for the whole county. This may mean individual areas are using depreciation factors not relevant to the area, and therefore more power is used to light the road, thus increasing expenditure on energy.

The results for the pollution categories do not provide a clear line between low and medium pollution (High pollution has not been considered due to the lack of results as suitable sites were not found). The medium pollution results vary significantly and encompass the same areas of the graph as the low pollution, therefore the traditional method of relating pollution category to LMF would seem to be unsuitable.

The mounting height analysis shows a more definite split between columns of height 6m or less and those greater than 6 metres height. The taller columns suffer from very little degradation over the first two years. The shorter columns, especially the 4-metre columns suffer considerably from spider infestation. The infestation may be due to the low mounting height and the area the luminaires were positioned as it was particularly overgrown.

The environmental zone analysis also shows a more definite split between E1/E2 and E3/E4 zones. The E1/E2 results show a very compact set of results, indicating a maximum drop of 4 percent of the first two years. The E3/E4 results appear to be more irregular, however, the results providing a higher level of degradation confirms the summary of the mounting heights, in which the shorter columns suffer from more degradation.

The major problem with the current BS5489 recommendation is the initial drop in performance in the first year which can be anywhere from 0.91 (high pollution) to 0.93 (low pollution). The results from this project show that the actual drop off after the first year is more reserved. Currently it is estimated that the initial drop is 3 to 4 percent.

There is the possibility that bowl type could affect the level of dirt build up. Dirt particles carried in crosswinds are more likely to stick to luminaires with a bowl rather than one with a flat glass protector. In this project, results were obtained for only two luminaires tested with Flat Glass protectors.

A new method for calculating the MF could include more than one factor to calculate the depreciation. For example, the combining of pollution categories, road heights and environmental zones to calculate LMF's.

The table below represents the results of testing based upon the mounting height and the environmental zone. This differentiation seemed to provide the best consistency of results, although further targeted testing would assist to verify the findings.

Table of LMF's based upon test results for different environmental zones and mounting heights.

E Zone / MH	12 months	24 months	36 months	48 months
E1/E2 6m or less	0.98	0.96	0.95	0.94
E1/E2 >7m	0.98	0.96	0.95	0.94
E3/E4 6m or less	0.94	0.92	0.90	0.89
E3/E4 >7m	0.97	0.96	0.95	0.94

The table shows a significant increase in the LMF recommended for any given situation. All of the individual test results showed a higher LMF than recommended in BS5489-1.

Effect of improving the Maintenance Factor by 5 percentage points:

A calculation was performed to show the effect energy consumption would have on whole life costing. Clearly this depends on the installation and solution proposed, but the illustration below indicates the type of saving that could be achieved for a typical Local Authority road.

Maintenance	Columns/km	Wattage/km	Power Saving/ km	Whole Life Costs	Savings	Percentage
0.75	24	2160	-	£39.2K	-	-
0.80	22	1980	180	£35.9K	£3.3K	9.47%

10 Determining the Luminaire Maintenance Factor

The relevant factors which can affect the Luminaire Maintenance Factor (LMF) include:

- Cleaning Frequency
- Environmental Zone (E1 – E4)
- Road Hierarchy
- Mounting Heights (6,8,10m)
- Protector Type
- Other influence (coastal location, salting route etc.)

11 Further Testing

It is recommended that further testing be carried out to create a larger and wider cross section of results, sampling luminaires from each of the factors that may affect the results (environmental zone, pollution category and column height) to analyse for any trends. This should enable the production of a specific table of LMF's.

12 Acknowledgements

Questionnaire respondents

Project Steering Group

Local Authorities:

Bournemouth BC

Hampshire

Surrey CC

Wiltshire

London Borough of Sutton

City of Westminster

Organisations assisting with luminaire removal:

BBISL

SEC Contracting

T Cartledge

Transerv

Organisations assisting with luminaire testing:

Luxonic

DW Windsor

Philips

Thorn Lighting

Urbis Lighting

13 References / Bibliography

BSI & CEN Standards

BS 5489-1:2003	Code of Practice for design of road lighting
BS EN 13201:2003	Road Lighting
EN 12464-2	Outdoor Work Places

ILE Technical Reports

Outdoor Lighting Guide

TR19	The Effectiveness of Lantern Cleaning (1989)
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CIE Publications

CIE 154:2003	The Maintenance of Outdoor Lighting Systems
CIE 33.1:1996	Depreciation of Installations and their Maintenance

Roads Liaison Group / CSS / UK Lighting Board

Well-lit Highways

Well-Maintained Highways

HA Design Manual for Roads & Bridges

TD34	Design of Road Lighting for the Strategic Motorway and All-Purpose Trunk Road Network
TD23/99	Inspection and Maintenance of Road Lighting
TRRL	Lab report 367 "Marshall Committee Recommendation"

Appendix A Maintenance Factor Questionnaire for Local Authorities

A questionnaire was created with the objective of obtaining information from local authorities on current practice for calculating Maintenance Factors and for obtaining information regarding the thoughts of the industry on how this subject should develop in the future.

The questionnaire was sent to a sample of County Councils, Unitary Authorities, Metropolitan Boroughs, London Boroughs, Scottish Local Authorities and a good response has been received to date.

The results are analysed to see if there are any trends.

The questionnaire is reproduced below:

Review of Luminaire Maintenance Factors

The CSS have commissioned Mott MacDonald to review Luminaire Maintenance Factors in order to create a strategy which will assist local authorities with their policy on Maintenance Factors

The benefits of having a more realistic Maintenance Factor is that it will provide a more accurate prediction to achieving the lighting levels that you are seeking and it may result in fewer columns required and therefore lower energy consumption.

In order to obtain a realistic assessment of current policy, we would appreciate a few minutes of your time to complete this questionnaire.

Local Authority.....

Engineer.....

Contact info: Tel or e-mail.....

1 What is your current luminaire cleaning policy for IP 6X luminaires?

Mounting Height	12 month	18 month	24 month	36 month	48 month	Other
5/6m						
8/10/12m						

2 What pollution category do you use predominantly?

Pollution Category	% of installations
High	
Medium	
Low	
	100

3 Please complete the table below to indicate:

- What lamps are most prevalent in your inventory?
- What is your current re-lamping policy for each lamp type?

(note BTE is burn to extinction)

Lamp Type	% of lamp type in inventory	Re-lamp regime (years)						
		1	2	3	4	5	6	BTE
SOX								
SON								
SON (PIA or 4Y)								
CDO-TT								
CDM-T								
CPO-T								
PL-L Outdoor								
PL-T								
Other								
	100							

4. What value of Maintenance Factor do you use for the following situations?

Lamp Type	Lamp Luminous Flux Maintenance Factor	Luminaire Maintenance Factor	Overall Maintenance Factor
70W SON-T	0.	0.	0.
100W SON-T	0.	0.	0.
150W SON-T	0.	0.	0.
150W CDM-T	0.	0.	0.
36W PL-L	0.	0.	0.
42W PL-T	0.	0.	0.
45/60/90/140W Cosmo	0.	0.	0.

5. Do you obtain the MF value from the design software package?

Lighting Reality Y/N

Philips Calculux Y/N

Urbis TURBO Light Y/N

Other ... (please specify)..... Y/N

6. How accurate do you believe the current method of deriving Maintenance Factors is?

a) very accurate

b) very inaccurate

c) about right

c) unsure

7. How would you like to see the method change for the future?

a) Do you think the value you use is

a) too high

b) about right

c) too low

b) Please make comments on alternative methods

8. Would you be prepared to assist with measurements of a selection of your luminaires either on site, or with removal of the luminaires for laboratory measurement?

Y / N

Appendix B Typical Maintenance Factor Calculation

The current process for deriving the Maintenance Factor (MF) for a lighting design is as follows:

Calculate MF – BS5489-1 Method

1. Obtain the Pollution Category of the installation site (High, Medium or Low)
2. Obtain the Cleaning Cycle of the luminaire (from the Term Maintenance Contract or the Contractor)
3. Obtain the IP rating of the optical compartment of the luminaire as defined in BS EN 60529. (From the manufacturer or the luminaire data sheet)
4. Obtain the Luminaire Maintenance Factor (LMF) from BS5489-1 Table D for the IP rating, cleaning cycle and pollution category.
5. Obtain the Lamp Luminous Flux Maintenance factor (LLFMF) from lamp manufacturers data for the re-lamp period defined. This is generally provided in the form of a graph showing percentage lumen maintenance against lamp burning hours and using the annual burning hours for the location.
6. The calculation for MF is the product of the LLFMF and the LMF.

$$MF = LLFMF * LMF$$

Example

1. Low Pollution
2. Cleaning cycle = 2 years
3. Luminaire = IP6X tightness
4. LMF = 0.91 from Table D.1 of BS5489-1:2003
5. Lamp = 150W SON-T

Re-lamp Period = 4 years

From the lamp manufacturers data for the lamp; the LLFMF = 0.95

6. $MF = LLFMF * LMF = 0.95 * 0.91$

Hence MF = 0.86

Appendix C Site Reports

Maintenance Factor Study – Site Report

On-site Procedure

Safety Equipment and Risk Assessment

Before setting off, the contractor ensures the appropriate PPE (Personal Protective Equipment) is obtained. This includes:

- High Visibility Clothing
- Safety Helmet (Falling Objects)
- Safety Boots (Falling Objects / Poor ground conditions)
- Harness (Working from Height)
- Cones (Traffic Management [if necessary])
- Signage (Traffic Management [if necessary])

Onsite, once the selected luminaire has been found the vehicle is parked and the appropriate traffic management provided, cordon off the area and divert traffic around the vehicle providing a safe area of work.



Before touching any part of the column, the column is tested with a neon tester to ensure it is not live. The door to the column is opened and the luminaire is then isolated and the fuse removed to allow safe working at the top of the column.



With the van stabilised and the traffic diverted, the contractor enters the bucket, and proceeds to raise the bucket until in line with the luminaire.

Once in-line with the luminaire, the canopy is opened and the wire disconnected. This allows for the gear to be removed (and possibly the lamp depending on the luminaire manufacturer). The grub screws are released and the luminaire removed from the bracket, without touching the protector, and placed upside down in the bucket. The gear and lamp are re-fitted before being boxed.



A replacement luminaire is placed onto the column and the test luminaire placed into the box. The new luminaire is re-connected and tested once the fuse is replaced, to ensure the luminaire works correctly.



With the test luminaire removed any traffic management is removed, and the site to be left as found.

The luminaire is supported in a box and packed in order to protect the protector from any contact with other surfaces or any other pressure which may affect the dirt deposits. Finally, each box is labelled with the column number and road name.

Each site is photographed to determine its surroundings.

Although great care was taken to avoid touching the protector, there may be fingerprints on the protectors from when the luminaire was previously cleaned or installed.

Wiltshire

Street Scene

Sites 1 & 2

Beverbrook Road is a traffic route running from the A4 to the west of Calne to the north of the village. It is predominantly surrounded by open fields, but new housing developments are appearing along the southern section of the road, and to the north Beverbrook Road services a large industrial estate.

Sites 3 & 4

The High Street is part of the A4 traffic route, and is the main route in and out of Calne.

Sites 5 & 6

Cocklebury Road is situated in the centre of Chippenham. The road itself is an access road to an industrial estate, a large car park and housing estate. The road is tree lined and has a train line running along side much of its length.

Expected Pollution Category

Sites 1 & 2

The large open fields, minimal subsidiary roads, reduce number of trees, and suggest a low pollution area.

Sites 3 & 4

Are situated on the High Street and as busy traffic route (A4) in the village surrounded by properties and businesses it would be considered to be low/medium pollution

Sites 5 & 6

Cocklebury Road is adjacent to a railway and an industrial estate. This would be considered a medium pollution area.

Environmental Category

Sites 1&2	Rural, small village, or relatively dark urban locations	E2
Sites 3&4	Rural, small village, or relatively dark urban locations	E2
Sites 5&6	Rural, small village, or relatively dark urban locations / Small town centre's or urban locations	E2/E3



Sites 1 & 2



Sites 3 & 4



Sites 5 & 6

Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Lamp Source	Last Clean	Testing Facility	Date Sent
1	Calne - Beversbrook Road	10m	Thorn Rivera	P	103	N/C	SON	March 2005	Thorn	20/05/08
2	Calne - Beversbrook Road	10m	Thorn Rivera	P	134D	N/C	SON	March 2005	Thorn	20/05/08
3	Calne - A4 – High Street	8m	Philips Iridium	CG	?? (Before Arrow Garage)	N/C	SON	May 2007	Philips	20/05/08
4	Calne - A4 – High Street	8m	Philips Iridium	CG	?? (Outside Arrow Garage)	N/C	SON	May 2007	Philips	20/05/08



Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Lamp Source	Last Clean	Testing Facility	Date Sent
5	Chippenham - Cocklebury Road	5m	Philips Iridium	CG	20	N/C	SON	September 2006	Philips	20/05/08
6	Chippenham - Cocklebury Road	5m	Philips Iridium	CG	21	N/C	SON	September 2006	Philips	20/05/08



Surrey

Street Scene

Sites 1 & 2

Upper Chobham Road is a tree lined minor traffic route from West End to Lightwater. The luminaires have many trees in close proximity, and some tree debris may affect the degradation of the protectors.

Sites 3 & 4

The A325 (Portsmouth Road) is a major traffic route with many trees surrounding it.

Sites 5 & 6

Mytchett Road is also a minor traffic route running through the centre of Mytchett Village.

Expected Pollution Category

Sites 1 & 2

The aerial photography indicates a mainly suburban area, segregated by small open spaces and regular trees. This would indicate a low/medium pollution category.

Sites 3 & 4

The A325 is a medium traffic route and adjacent to the M3 motorway. Therefore, a pollution category of medium to high would be expected.

Sites 5 & 6

The area benefits from large open spaces and a significant number of surrounding trees and open spaces. This would indicate a pollution category of low to medium.

Environmental Category

Sites 1&2	Rural, small village, or relatively dark urban locations	E2
Sites 3&4	Rural, small village, or relatively dark urban locations	E2
Sites 5&6	Rural, small village, or relatively dark urban locations / Small town centres or urban locations	E2/E3



Sites 1 & 2



Sites 3 & 4



Sites 5 & 6

Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
1	Camberley – Upper Chobham Road	10m	WRTL Arc	CG	40	N/C	Spring 2006		
2	Camberley – Upper Chobham Road	10m	WRTL Arc	CG	44	N/C	Spring 2006		
3	Camberley – Portsmouth Road	10m	WRTL Arc	CG	107	N/C	Spring 2006		
4	Camberley – Portsmouth Road	10m	WRTL Arc	CG	185	N/C	Spring 2006		



Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
5	Mytchett – Mytchett Road	8m	WRTL Arc	FG	55	N/C	Spring 2006		
6	Mytchett – Mytchett Road	8m	WRTL Arc	FG	69	N/C	Spring 2006		



Bournemouth

Street Scene

Sites 1 - 9

All routes are servicing residential properties in Boscombe, some of which are traffic routes taking users to the coastal roads.

Sites 10 - 12

The Triangle is in Bournemouth City Centre, with no trees, but a considerable volume of traffic.

Expected Pollution Category

Site 1 - 9

With all the roads in close proximity to each other, and being situated next to the coast, it is expected that the pollution is likely to be medium.

Sites 10 - 12

The city centre location would suggest this to be a medium to high pollution area.

Environmental Category

Sites 1 - 9	Small town centre's or urban locations	E3
Sites 10-12	Small town or urban locations/ Town & city with high levels of night time activity	E3/E4

Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
1	Beechwood Avenue	10m	WRTL Arc 150W	CG	166	15/10/04	Feb '07		
2	Beechwood Avenue	10m	WRTL Arc 150W	CG	167	15/10/04	Feb '07	Not Sent	
3	Penrith Road	6m	CU P567	P	1	N/C	23/08/07	Not Sent	
4	Boscombe Overcliffe Rd	6m	CU P567	P	27	19/01/06	24/05/06	Not Sent	
5	Boscombe Overcliffe Rd	6m	WRTL 2015	P	28	19/01/06	24/05/06	Not Sent	
6	Sea Road (Boscombe)	8m	Thorn Triumph	CG	65	18/09/02	16/11/05		
7	Sea Road (Boscombe)	8m	Thorn Triumph	CG	64	18/09/02	16/11/05		
8	Cecil Road	6m	Urbis Sapphire 2 70W CDM		2	N/C	29/06/06		
9	Cecil Road	6m	Urbis Sapphire 2 70W CDM		3	N/C	28/06/06		



Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
10	The Triangle	10m	Philips SGS306	FG	161	N/C	02/02/06	Philips	19/05/08
11	The Triangle	10m	Philips SGS306	FG	163	N/C	10/09/06	Philips	19/05/08
12	The Triangle	10m	Philips SGS306	FG	157	N/C	07/02/06	Philips	19/05/08



Hampshire

Street Scene

Site 1

Canterbury Road runs through a leafy suburb in Farnborough, segregated by small open spaces and regular trees.

Sites 2 & 3

Queens Road is a minor traffic route servicing the local community shops.

Sites 4 & 5

The end of Queens Road is predominantly residential, but there is still a lack of open spaces and trees.

Expected Pollution Category

Site 1

The high density of properties and residential roads, and number of trees is likely this would be a low/medium pollution category.

Sites 2 & 3

The higher levels of traffic and lack of open space surrounding the area is likely to result in a medium level of pollution.

Sites 4 & 5

Due to the close proximity, to sites 2 & 3, the pollution category is still considered to be medium.



Site 1



Sites 2 & 3



Sites 4 & 5

Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
1	Canterbury Road	6m	Urbis ZX1	DP	5	29/05/03	05/05/06	Urbis	
2	Queens Road	8m	Urbis ZX3	CG	6	02/07/04	May '06	Urbis	
3	Queens Road	8m	Urbis ZX3	CG	8	19/05/04	May '06	Urbis	
4	Queens Road	6m	Urbis ZX1	DP	21	1999	May '06	Urbis	
5	Queens Road	6m	Urbis ZX1	DP	23	18/08/04	May '06	Urbis	



Gosport

Street Scene

Site 1

This road is the A32 and the main route from Gosport to Fareham and approximately 0.75 miles from the coast. The road is fairly open with few trees.

Site 2

This is a small but busy roundabout on the A32. The area is open with some trees.

Sites 3 & 4

For the first half of this road on one side, are a variety of military buildings and on the other where allotments, the road has trees on both sides of the road for the majority of its length.

Sites 5 & 6

This is a typical residential road which seemed fairly quiet, there were few open spaces and some trees. There were also some parking bays for residents and visitors.

Expected Pollution Category

Site 1 & 2

The pollution category for these two sites would probably be medium. The road is fairly open with few trees, there is a constant flow of traffic and gets fairly congested during rush hour.

Sites 3 & 4

This is a fairly main road linking between the A32 and the B3333 and would be considered a medium pollution category.

Sites 5 & 6

This road is in a more residential area of Gosport, is fairly quiet and could be considered as a low/medium pollution category.

Environmental Category

Sites 1 & 2	Small town centres or urban locations	E2
Sites 3 & 4	Small town centres or urban locations	E2
Sites 5 & 6	Urban locations	E2



Site 1



Sites 2



Sites 3 & 4



Sites 5 & 6

Site	Road Name	Height	Luminaire	Bowl	Column Number	Installation Date	Last Clean	Testing Facility	Date Sent
1	Roundabout with Gunners Way / Elson Road	10 metres	ZX3	Deep Bowl	LC121	Not Known	15 Months ago	LUXONIC	11/06/08
2	Roundabout with Rowner Road / Fareham road	10 metres	ZX3	Deep Bowl	LC125	Not Known	15 Months ago	LUXONIC	11/06/08
3	Military Road	8 metres	ZX3	Shallow Bowl	LC06	Not Known	15 Months ago	LUXONIC	11/06/08
4	Military Road	8 metres	ZX3	Shallow Bowl	LC23	Not Known	15 Months ago	LUXONIC	11/06/08
5	The Curve	6 metres	ZX1	DP	LC02	Not Known	17 Months ago	LUXONIC	11/06/08
6	The Curve	6 metres	ZX1	DP	LC07	Not Known	17 Months ago	LUXONIC	11/06/08



Westminster

Street Scene

Sites 1/2

Orchardson Street is a residential road with low-rise blocks of flats, located just off and to the north of Edgware Road. It is lightly trafficked with most traffic being for access to on street parking. The road is lightly tree lines

Sites 3/4

Capland Street is an access route to parking for flats. Both sites are located outside a school and low-rise flats. The road has a small number recently pruned London plane trees.

Sites 5/6

Penfold Street is a residential street which meets a main road/market street. (photo below shown looking towards market street and up Penfold Street). The road is moderately heavily trafficked for a residential road due to parking/access for people using shops and market.

Expected Pollution Category

Sites 1/2

Being situated in central London on a small residential/access road but close to the main road (Edgware Road) would suggest a pollution category of medium/high

Sites 3/4 are located on a residential road with a small number of offices away from major traffic routes and industry. This site would be considered as medium pollution category.

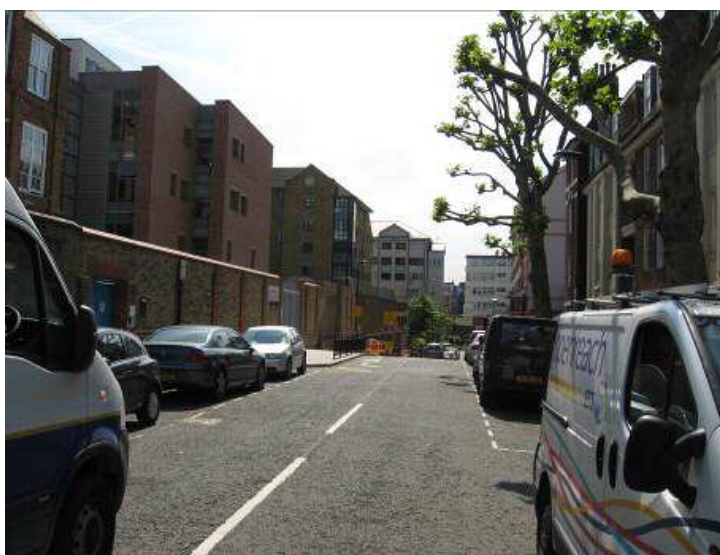
Site 5/6 are located either side of a junction between a subsidiary road and a main road (which doubles up as a market street) joining Edgware road. Due to the proximity to Edgware Road and the amount of traffic this site would be considered as medium/high pollution category

Environmental Category

Sites 1/2	Small town centres or urban locations	E3
Sites 3/4	Small town centres or urban locations	E3
Sites 5/6	Town/city centres with high levels of night time activity	E4



Sites 1 & 2

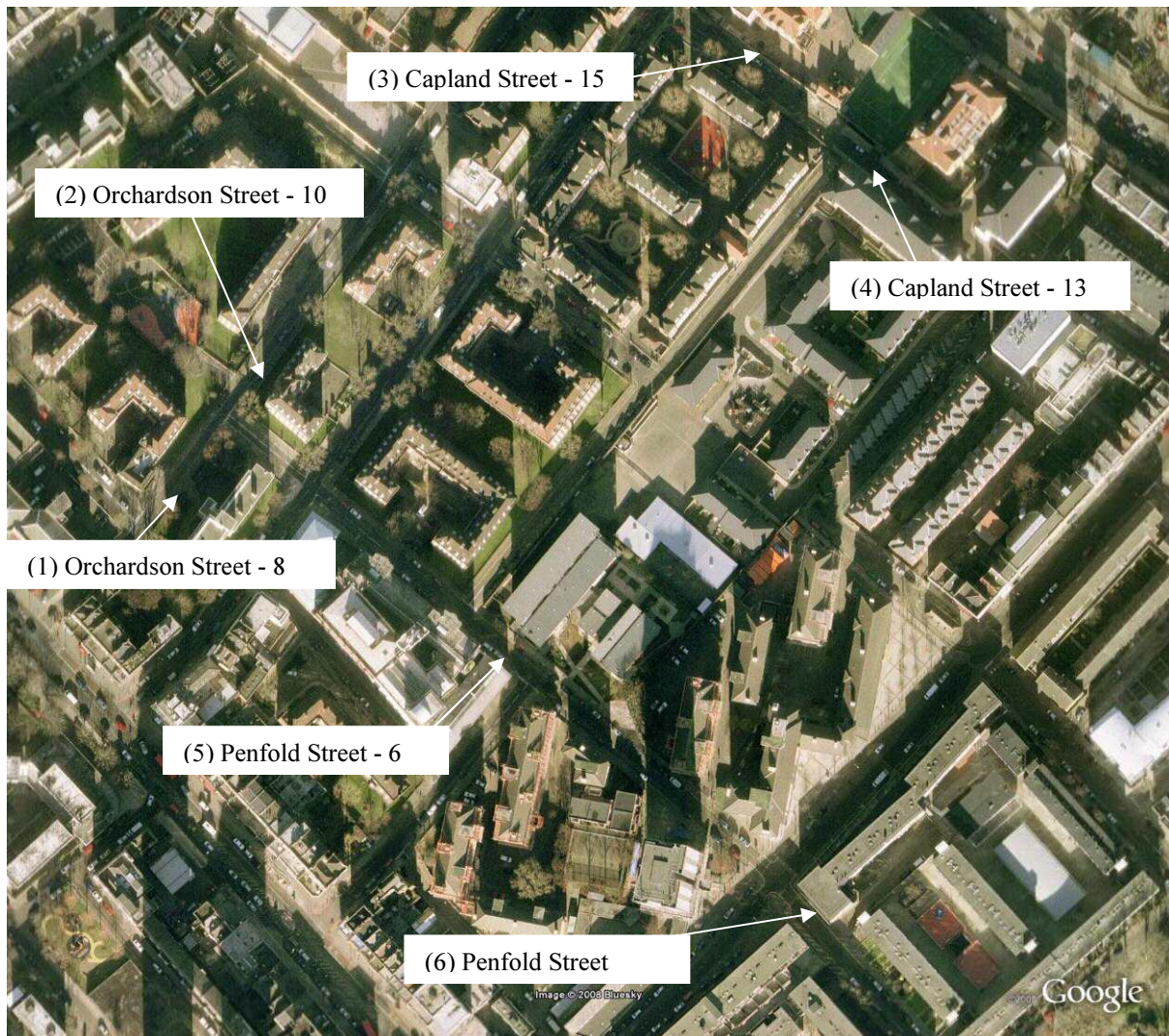


Site 3 & 4



Sites 5 & 6

Site	Road name	Height	Luminaire	Bowl	Column Number	Installation date	Last clean	Testing facility	Date sent
1	Orchardson Street	6	Philips SGS252	PC	8	??	Spring '07	Luxonic	09/05/2008
2	Orchardson Street	6	Philips SGS252	PC	10	??	Spring '07	Luxonic	09/05/2008
3	Capland Street	8	Philips SGS252	PC	15	??	Spring '07	Luxonic	09/05/2008
4	Capland Street	8	Philips SGS252	PC	13	??	Spring '07	Luxonic	09/05/2008
5	Penfold	10	Philips SGS252	PC	6	??	Spring '07	Luxonic	09/05/2008
6	Penfold	10	Philips SGS252	PC	?? (south east of x-road)	??	Spring '07	Luxonic	09/05/2008



Review of luminaire maintenance factors

This report describes a review of luminaire maintenance factors, which together with lamp luminous flux maintenance factors produce the maintenance factor to be used with a particular lamp and luminaire combination in the design of street lighting. Current methods were found to be based on research carried out in the 1970s, since when pollution levels and equipment designs have changed. Most documents refer to the current British Standard, BS 5489:2003.

The review comprised desktop research of relevant publications and standards, questionnaires to local authorities on their current practice, and the testing of luminaires removed from site to measure the actual light reduction over a period in service. The questionnaire results revealed a generally unscientific approach to setting pollution categories, often resulting in excessive conservatism. For the experimental work, luminaires with different bowl types and mounting heights were taken from locations in different environmental zones with varying pollution and traffic levels. All of the luminaire measurements revealed that loss of light output was less severe than predicted by the current standard.

Based on these findings, it is proposed that higher factors should be adopted. A revised table of “worst-case” maintenance factors for the different environmental zones, and four cleaning intervals is given. However it is considered that, in order to give greater confidence in the proposed factors, further work is required to create a wider range of results. The adoption of the proposed higher maintenance factors will result in designs requiring lower initial luminous flux, thus saving energy and cost and reducing typical CO₂ emissions.

Other titles in this series

- SL1** Review of the class and quality of street lighting. G I Crabb, R Beaumont and D Webster. TRL Published Project Report PPR380. 2009
- SL2** Invest to save – sustainable street lighting. P Fox. Mouchel. 2009
- SL4** The use of passively safe signposts and lighting columns. G L Williams, J V Kennedy, J A Carroll and R Beesley. TRL Published Project Report PPR342. 2009
- SL5a** Review of the lighting requirement for traffic signs and bollards. J Cooper, K Stafford, P Owlett and J Mitchell. TRL Published Project Report PPR382. 2009
- SL5b** Guidance on the lighting requirement for traffic signs and bollards. J Cooper and J Mitchell. TRL Published Project Report PPR383. 2009

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SL3