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# Light and lighting — Maintenance factor determination — Way of working



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# Contents

# Foreword

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ISO collaborates closely with the International Commission on Illumination (CIE) on all matters of standardization for light and lighting.

This document was prepared by Technical Committee ISO/TC *274*, *Light and lighting*. The document has been jointly prepared with CIE JTC 11, *Light and Lighting — Maintenance factor — Way of working*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.



# Introduction

Continuous maintenance of lighting installations is essential as it ensures that the performance of a system stays within the design limits and promotes safety and efficient use of energy. In the design phase this is taken into account through the use of the maintenance factor. The maintenance factor combines several different factors such as the assumed product/installation behaviour, the environmental parameters and maintenance and cleaning schedules.

The methodology of determining the maintenance factor has been extensively documented by CIE (see Clause 2 and bibliography). However, as the focus of these technical reports was predominantly on incandescent and gas discharge light sources, more clarity is needed to ensure the proper use/translation of the existing methodology towards technologies such as light emitting diodes (LED).

Technologies such as LED distinguish themselves from other technologies by their long lifetime, low failure rate and their integration of components which were previously seen as separate components. As such the previous methods used to determine the depreciation and survival of luminaires might seem unusable and cause uncertainty. However, based on work by IEC (see Clause 2) the luminous flux depreciation and light source failure parameters have now been (re)established for LED-based light sources and allow for translation into an updated way of working to determine the maintenance factor using the existing CIE methodology and data for luminaire and surface dirt depreciation.

This document combines insights from IEC standards with regard to product performance of luminaires and light sources currently in the market with the existing determination methodology from CIE Technical Reports. Furthermore, it references the data in the CIE Technical Reports with regard to the impact of the environment on luminaires (accumulation of dirt on surfaces and luminaires).

This document provides the following:

— background information with respect to the principles of the maintenance factor and the relevant parameters for indoor and outdoor applications;

— a detailed way of working on how to apply the maintenance factor determination method (as described in CIE 154:2003 and CIE 097:2005) for outdoor and indoor lighting designs using the technologies available in the market;

— explanation and examples on how to apply the maintenance factor and how to ensure proper operation over time corresponding to the determined values.

# Light and lighting — Maintenance factor determination — Way of working

## 1 Scope

This document specifies a standardized way of working for determining the maintenance factor for both outdoor and indoor lighting installations using the methodology as described in CIE 154:2003 and CIE 097:2005.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE 097:2005, *Maintenance of Indoor Electric Lighting Systems*

CIE 154:2003, *Maintenance of Outdoor Lighting Systems*

CIE S 017, *ILV International Lighting Vocabulary*

IEC 62722-2-1, *Luminaire performance — Part 2-1: Particular requirements for LED luminaires*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

**3.1**
**abrupt failure value**
**AFV**
percentage of LED based products failing to operate at median useful life ($L_x$)

[SOURCE: IEC 62717:2014+AMD1:2015, modified — generalized to products]

**3.2**
**cleaning interval**
planned time between cleaning of (parts of) the products and/or components

**3.3**
**CLO lifetime**
time over which the *CLO* (3.5) feature ensures a constant luminous flux

**3.4**
**component replacement interval**
planned time between replacement of one or more specified luminaire component(s)

**3.5**
**CLO**
**constant light output**
functionality to constantly adjust the luminous flux of the light source based on the known or predicted depreciation behaviour of the light source to enable a constant luminous flux over time

**3.6**
**failure probability**
$p_f$
probability that the component (e.g. light source, luminaire) catastrophically fails

Note 1 to entry: Failure probability is expressed as a factor.

**3.7**
**installation lifetime**
time over which the installation is expected to function as designed

**3.8**
**maintenance period**
total time over which the maintenance is planned

Note 1 to entry: Within a single maintenance period different maintenance cycles can be planned for different activities (e.g. cleaning, light source replacement).

Note 2 to entry: The maintenance period is often expressed in years.

**3.9**
**median useful life**
$L_x$
length of time until 50 % of a population of operating LED products reaches gradual light output degradation of a percentage *x*

**3.10**
**surface refurbishment interval**
planned time between surface refurbishment instances where the reflecting properties of the room or area surfaces are restored to their original state, including cleaning or painting of interior surfaces such as walls and ceilings

Note 1 to entry: The concept 'surface refurbishment interval' does not refer to surfaces which are an integral part of the luminaire.

**3.11**
**survival probability**
$p_s$
probability that a component continues to operate at a certain point in time

Note 1 to entry: Survival probability is expressed as a factor.

Note 2 to entry: The component can be e.g. a light source, a luminaire.

Note 3 to entry: There is a distinct difference between the survival factor (see 6.3) and the survival probability. The survival probability describes the performance of an individual component whereas the survival factor describes the outcome of the determination process as described in 6.3.

**3.12**
**useful life**
$L_{x,By}$[1)]
<of LED luminaires> length of time until a percentage $y$ of a population of operating LED luminaires reaches gradual light output degradation of a percentage $x$, expressed in general in the '$L_{x,By}$' format

Note 1 to entry: Useful life can be specified on different product levels such as on individual LED, LED module or LED luminaire level. As for example luminaire design impacts thermal design, the useful life of the LED module might be different from the useful life of the luminaire.

[SOURCE: IEC 62717:2014+AMD1:2015, modified — specifier <of LED luminaires> and quantity symbol added to the term]

## 4 Symbols and units

The symbols and units in Table 1 apply.

**Table 1 — Symbols and units**

| Symbol | Term | Unit |
|---|---|---|
| $E_A$ | measured illuminance | lx |
| $E_{A,c}$ | corrected measured illuminance | lx |
| $E_m$ | maintained illuminance | lx |
| $E_{in}$ | initial illuminance | lx |
| $f_{LF}$ | luminous flux factor (see 6.2) | 1 |
| $f_{LLM}$ | lamp luminous flux maintenance factor | 1 |
| $f_{LM}$ | luminaire maintenance factor (see 6.4) | 1 |
| $f_m$ | maintenance factor (see 6.1)<br>NOTE In this document the term "maintenance factor" is used for luminaires either with integrated or separate light sources, in contrast to CIE 97 and CIE 154 where the light source is generally seen as separate from the luminaire. | 1 |
| $f_S$ | survival factor (see 6.3) | 1 |
| $f_{SM}$ | surface maintenance factor (see 6.5) | 1 |
| $\Phi_L$ | luminaire luminous flux | lm |
| $\Phi_{CLO}$ | CLO-corrected luminaire luminous flux | lm |
| $\Phi_S$ | standard luminaire luminous flux | lm |
| $\Phi_e$ | end-of-life luminaire luminous flux | lm |
| $\Phi_i$ | initial luminaire luminous flux | lm |
| $L_x$ | median useful life (see 3.8) for $x$ % remaining luminous flux | h |
| $L_{x,By}$ | useful life | h |
| $p_f$ | failure probability | 1 |
| $p_S$ | survival probability | 1 |

1) Note that in the source IEC 62717 the expression "$L_xB_y$" is incorrectly presented as a quantity symbol for the term "useful life". As such, this document introduces the symbol $L_{x,By}$ for the term "useful life" for use in this document and further usage.

# 5 Influencing factors

## 5.1 Luminaire and/or light source characteristics

Depreciation of the luminaire and/or light source due to regular ageing and/or product-related characteristics shall be taken into account. This includes the following components:

— luminous flux depreciation (either of the light source or the luminaire, depending on the luminaire design) (see 6.2);

— light source and/or luminaire catastrophic failure (depending on luminaire design) (see 6.3).

## 5.2 Recoverable external factors

Recoverable factors concern those external factors, causing depreciation of the lighting installation performance, of which the effects can be economically reversed or mitigated during service and/or routine maintenance. The following factors shall be taken into account:

— removable pollution in/on the luminaire (see 6.4);

— depreciation of room or area surface characteristics relevant to the lighting installation (i.e. reduction of reflectance due to degradation of walls or ceiling finishes) (see 6.5).

## 5.3 Non-recoverable external factors

Influencing external factors are classified as non-recoverable when they are caused by external (environmental) factors and cannot be reversed during normal maintenance or are uneconomical to restore. These factors include the ageing/fading of (non-replaceable) components due to the environmental conditions and/or the irreversible soiling of components in applications due to specific (aggressive) substances.

Although these factors should be taken into account during the design and maintenance planning phase, they are not included in the maintenance factor as described in this document.

## 5.4 Maintenance period, cleaning, replacement and surface refurbishment interval

The choice of maintenance period, cleaning and replacement interval has a large impact on the maintenance factor. Prior to determination of the maintenance factor, the following information shall be determined:

— maintenance period (often expressed in years);

— cleaning interval of luminaires (often expressed in years);

— component replacement interval (often expressed in burning hours) and

— surface refurbishment interval (often expressed in years).



# 6 Maintenance factor determination

## 6.1 Basic description of the method

The maintenance factor $f_m$ is determined using the Formula (1).

$$f_m = f_{LF} \cdot f_S \cdot f_{LM} \cdot f_{SM} \tag{1}$$

where

$f_{LF}$ is the luminous flux factor (see 6.2);

$f_S$ is the survival factor (see 6.3);

$f_{LM}$ is the luminaire maintenance factor (see 6.4);

$f_{SM}$ is the surface maintenance factor (see 6.5).

Annex A provides examples demonstrating the determination of these factors.

NOTE The methodology described in this document is a replacement of the methodology as described in CIE 097:2005 and CIE 154:2003. Terminology has been changed to suit a more generalized approach for luminaires either with integrated or separate light sources. Terminology changes are further specified in the relevant paragraphs.

## 6.2 Luminous flux factor

### 6.2.1 Luminous flux factor determination — General

The luminous flux factor, $f_{LF}$, expresses the depreciation of the luminous flux over time due to ageing of the light source or luminaire during regular operation (this excludes external factors). This is defined as the ratio of depreciated luminous flux to the initial luminous flux.

For luminaires with an integrated light source the luminous flux factor, $f_{LF}$, shall be determined for the (full) luminaire. For luminaires with a non-integrated light source the luminous flux factor, $f_{LF}$, shall be determined for the light source (i.e. lamp).

NOTE 1 In CIE 097:2005 and CIE 154:2003 the equivalent of the luminous flux factor, $f_{LF}$, is the lamp luminous flux maintenance factor ($f_{LLM}$, abbreviation: LLMF). See Note in 6.1 for further information.

NOTE 2 The luminous flux factor, $f_{LF}$, determined at luminaire level will better reflect reality as this includes all components and operating conditions. Therefore, this is the default method for all types of luminaires. However, for luminaires with non-integrated light sources it is often not possible to determine this for the full luminaire as data is only available for the light source and as such the luminous flux factor, $f_{LF}$, on light source level is accepted for luminaires with non-integrated light sources.

For LED-based luminaires the luminous flux factor, $f_{LF}$, shall be determined based upon the light source or luminaire replacement interval and shall be provided by the luminaire supplier according to the definitions in IEC 62722-2-1.

The replacement interval can correspond to the median useful life, $L_x$. In this case the luminous flux factor, $f_{LF}$, equals $x/100$.

EXAMPLE 1 $L_{80}$ = 50 000 h translates to 80 % remaining luminous flux at 50 000 h. If the luminaire or light source is also planned to be replaced at 50 000 h this would result in a luminous flux factor $f_{LF}$ = 0,80.



If the replacement interval is different from the published values, the correct luminous flux factor, $f_{LF}$, needs to be supplied by the manufacturer. Alternatively, the tables with example values provided in Annex B may be used as an approximation.

NOTE 3 In some cases the depreciation values are not individually stated, but can be obtained from the lifetime values which will be presented as the median useful life, $L_x$, or the useful life '$L_{x,By}$' value. In both cases, only the $x$ value of the $L_x$ value is relevant for the luminous flux factor determination, the $B_y$ element of '$L_{x,By}$' is not taken into account in the $f_{LF}$ and consequently the $f_m$ determination (e.g. the luminous flux factor $f_{LF}$ = 0,80 after 50 000 h for both $L_{80,B50}$ = 50 000 h and $L_{80,B10}$ = 50 000 h specifications).

NOTE 4 In some cases the depreciation values will be presented as '$L_xF_y$' values. The '$L_xF_y$' is a (no longer in use) indication of lifetime not just taking into account depreciation but takes into account multiple maintenance factor parameters (namely luminous flux depreciation and survival factor). As such, this value is not appropriate for the determination of the maintenance factor as it does not allow for separation of the luminous flux factor, $f_{LF}$, and the survival factor, $f_S$.

For light sources such as halogen lamps, high pressure sodium lamps, metal halide lamps or fluorescent lamps, the depreciation of the luminous flux is often provided as a separate characteristic for given lifetimes.

EXAMPLE 2 If the planned maintenance period is at 16 000 h and the rated lamp luminous flux maintenance factor $f_{LLM}$ provided by the manufacturer at 16 000 h is 0,90, then the luminous flux factor $f_{LF}$ is 0,90.

NOTE 5 Dimming and/or switching behaviour can have a positive or negative effect on the depreciation of the light source, but this depends upon the luminaire and/or light source design. Information on these effects can be requested from the manufacturer of the light source or luminaire.

### 6.2.2 Luminous flux factor determination — Special case: Constant light output (CLO)

Luminaires utilizing constant light output techniques constantly adjust the luminous flux based on the known or predicted depreciation behaviour of the light source to enable a constant luminous flux over time. This functionality needs to be captured in the determination of the luminous flux factor, $f_{LF}$.

The CLO feature is realized by initially dimming the light source to the predicted end-of-life luminous flux and steadily increasing the current (and as such the power consumption) over time to compensate for the depreciation in luminous flux due to ageing of the light source.

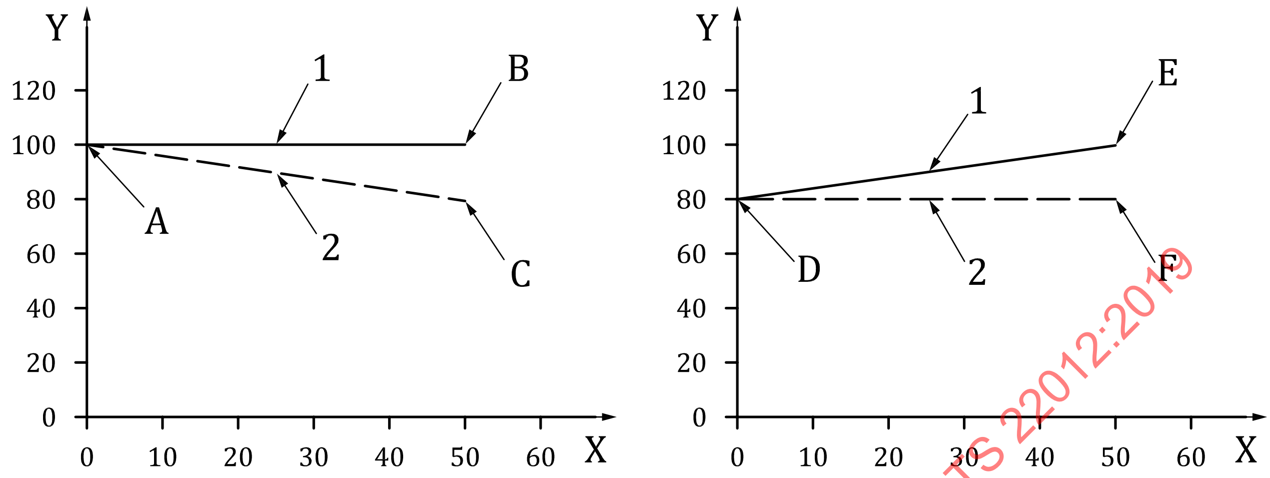
NOTE 1 The increasing power consumption over time also has an effect on the electrical design and energy calculations for the installation but is also a factor when comparing different CLO and non-CLO luminaires.

NOTE 2 In the context of this TS, CLO refers to the stand-alone feature based on known or predicted depreciation and does not include external input such as sensors. As such, it only applies to the luminous flux factor, $f_{LF}$. Other systems using external input to correct for depreciation exist but are not a part of this document.



EXAMPLE




**a) Standard, non-CLO luminaire behaviour (simplified)**

**b) CLO luminaire behaviour (simplified)**

**Key**

1 Relative power
2 Relative luminous flux
X time in 1 000 h
Y relative output in %
A rated power and luminaire luminous flux for luminaires without CLO, 100 %
B end of useful life power for luminaires without CLO
C end of useful life luminous flux for luminaires without CLO (e.g. for $L_{80}$ = 80 %)
D rated power and luminaire luminous flux for luminaires corrected for CLO (e.g. 80 % of maximum for $L_{80}$)
E end of useful life power for luminaires with CLO (100 %)
F end of useful life luminous flux for luminaires with CLO (e.g. 80 % of maximum for $L_{80}$)

**Figure 1 — Illustration of CLO principle using simplified graph representations**

Figure 1 a) shows a simplified representation of a standard product not using CLO, based on $L_{80}$ = 50 000 h (i.e. 20 % depreciation after 50 000 h). Both power and luminous flux are set to their maximum value (point A). Over time, power remains the same (line between point A and B) whereas the luminous flux for a luminaire without CLO depreciates to its end-of-life luminous flux (line between point A and C, 80 % of luminous flux).

Figure 1 b) shows a simplified representation of the same luminaire as on left side, but with CLO functionality. Both power and luminous flux start at 20 % below their maximum output at 0 h (based on standard operation where total luminous flux depreciation is 20 % at the end of life - point D). Over time, the luminous flux is kept constant (line between point D and F), by increasing the power (line between point D and E). Note that at the end of life, both the standard and the CLO product have the same power consumption (B versus E) and same luminous flux (C versus F).

Figure 1 illustrates the behaviour of a CLO luminaire during operation, however in practice, there are two ways CLO luminaires specifications are provided by manufacturers. Depending on which of the two options is used, the luminous flux factor, $f_{LF}$, shall be determined differently. The current known options are:

1. the standard (non-CLO) specifications are specified (in which case the CLO correction needs to be done in the maintenance factor using the luminous flux factor as specified below);

2. the corrected luminous flux is given (in which case no CLO correction is needed as this is already represented in the corrected luminous flux, $f_{LF}$ = 1,00).

For CLO luminaires, the luminous flux factor, $f_{LF}$, shall be determined according to Formula (2).

$$\text{If} \quad \Phi_L = \Phi_{CLO} \quad \text{then} \quad f_{LF} = 1{,}00$$
$$\text{If} \quad \Phi_L = \Phi_R \quad \text{then} \quad f_{LF} = \frac{\Phi_e}{\Phi_R} \qquad (2)$$

where

$\Phi_L$ is the specified luminaire luminous flux;

$\Phi_{CLO}$ is the CLO-corrected rated luminaire luminous flux (i.e. Figure 1, point D);

$\Phi_R$ is the rated luminaire luminous flux (i.e. Figure 1, point A);

$\Phi_e$ is the end-of-life luminaire luminous flux (i.e. Figure 1, point C).

If the replacement interval is longer than the given CLO lifetime, the manufacturer shall be consulted for the luminous flux factor, $f_{LF}$, at the time of replacement.

NOTE 3 Product specifications can include an indication of the CLO luminous flux, e.g. by specifying the dedicated CLO luminous flux, or by specifying the lifetime including the CLO feature (examples of such indications are $L_{CLO\ 80}$ = 50 000 h or $L_{con\ 80}$ = 50 000 h where either CLO or con (for constant) is added to the regular useful life indications).

NOTE 4 In CLO installations light source behaviour and driver behaviour are interlinked. The calculations assume that in the case of premature driver failure, the replaced components match the performance and behaviour of the original part prior to failure.

## 6.3 Survival factor

### 6.3.1 Survival factor description

The survival factor, $f_S$, expresses the probability of the light source and/or luminaire to continue to operate at a given time. This factor shall be based on the type of replacement regime (see 6.3.2, 6.3.3 and 6.3.4). In practice, the spot replacement regime is the default regime to ensure safety, however, this needs to be validated for each project. If the survival factor, $f_S$, is based on the light source or luminaire specifications, then the input parameters as used for the determination of the survival factor $f_S$, shall match the input parameters as used to determine the luminous flux factor, $f_{LF}$ (e.g. if a specific number of burning hours was used to determine the luminous flux factor, $f_{LF}$, the same number of burning hours shall be used for the survival factor, $f_S$, determination).

NOTE In CIE 097:2005 and CIE 154:2003 the equivalent of the survival factor, $f_S$, is the lamp survival factor ($f_{LS}$, abbreviation: LSF). See Note in 6.1 for further information.

### 6.3.2 Spot replacement regime

The spot replacement regime assumes that when luminaires or light sources fail, they are immediately replaced by a luminaire or light source with similar characteristics. In this case the corresponding survival factor, $f_S$ = 1,00.

NOTE In most cases there will be a slight delay in replacement of the failed luminaire or light source. However, there are no internationally established methods to determine the impact of this delay.

### 6.3.3 Group replacement regime

For the group replacement regime, failure of all components that have a direct impact on the luminaire's ability to provide light shall be taken into account, with the exception of component failures already accounted for in the luminous flux factor, $f_{LF}$ (e.g. failure of single LEDs as part of the regular luminous flux depreciation). The survival factor, $f_S$, shall be determined for the (relevant) component with the shortest replacement interval. If multiple components have the same replacement interval, the survival factor, $f_S$, will be determined based on the component with the lowest survival probability.

The survival factor, $f_S$, is calculated as according to Formula (3).

$$f_S = p_S \tag{3}$$

where

$f_S$ is the survival factor;

$p_S$ is the survival probability of the relevant component.

When a failure probability is given instead of the survival probability (e.g. the abrupt failure value AFV for LED-based products or percentage of failures) the survival probability is calculated according to Formula (4).

$$p_S = 1{,}00 - p_f \tag{4}$$

where

$p_S$ is the survival probability;

$p_f$ is the failure probability.

In case the failure probability is given in percentages, $p_f$ shall be calculated by dividing the failure probability percentage by 100.

If the survival probability of the driver and light source are given separately, then both are taken into account using the above rules (e.g. if the driver has a shorter replacement interval than the light source, the survival probability of the driver is used as the survival factor, $f_S$).

If the survival probability is presented as a single probability for the full luminaire (without specifying individual survival probabilities), then that survival probability is used to determine the survival factor, $f_S$.

NOTE In general, the survival factor does not compensate for the light loss of a single luminaire.

#### 6.3.4 Regime combinations

Combining the different maintenance regimes is quite common. In outdoor, the combination of spot and group replacement is commonly used (e.g. luminaires are replaced on the spot, and after a specified number of years the full installation is refurbished). As replacement of failed components is done immediately, the spot replacement regime rules apply for determination of the survival factor, $f_S$.

### 6.4 Luminaire maintenance factor

#### 6.4.1 Luminaire maintenance factor description

The luminaire maintenance factor, $f_{LM}$ (as also described in CIE 097:2005 and CIE 154:2003, abbreviation LMF) expresses the relative output of the luminaire due to dirt deposited on light sources, optical components or other components influencing the luminaire output. The luminaire maintenance factor, $f_{LM}$, shall be based upon the luminaire characteristics and environmental conditions according to the procedure as described in CIE 097:2005 for indoor luminaires and CIE 154:2003 for outdoor luminaires.

### 6.4.2 Indoor luminaires

The luminaire maintenance factor, $f_{LM}$, for indoor luminaires shall be based upon the combination of the luminaire design, environmental pollution category and cleaning interval.

Example tables containing the classification of luminaire designs, applications and example luminaire maintenance factors, $f_{LM}$, based upon the cleaning interval can be found in C.1.

For accurate data always consult the manufacturer.

### 6.4.3 Outdoor luminaires

The luminaire maintenance factor, $f_{LM}$, for outdoor luminaires shall be based upon the combination of luminaire design (rated according to IP classification) and the environmental pollution category and cleaning interval.

Example tables containing the classification of luminaire designs, environmental pollution category and example luminaire maintenance factors, $f_{LM}$, based upon the cleaning interval can be found in C.2.

For accurate data always consult the manufacturer.



## 6.5 Surface maintenance factor

Depreciation of surface reflection shall be taken into account via the surface maintenance factor $f_{SM}$. For indoor applications this relates to all relevant reflecting surfaces such as walls and ceilings whereas for outdoor this only refers to tunnels and underpass applications (not included in this document, more information on tunnels and underpasses can be found in CIE 088:2004). For outdoor lighting with the exception of tunnels and underpasses the surface maintenance factor, $f_{SM}$, is set to 1,00.

NOTE 1 In CIE 097:2005 the equivalent of the surface maintenance factor, $f_{SM}$, is the room surface maintenance factor ($f_{RSM}$, abbreviation: RSMF). See Note in 6.1 for further information.

NOTE 2 When, for tunnels and underpasses the walls and/or ceilings are not taken into account in the lighting design (i.e. reflections are not taken into account in the outcomes), the surface maintenance factor, $f_{SM}$, is usually set to 1,00.

The indoor surface maintenance factor, $f_{SM}$, (also called the room surface maintenance factor) shall be based on the principles as described in CIE 097:2005. This factor is based upon the luminaire distribution, reflectance of the major surfaces (ceiling/wall/floor), the environmental pollution category and the surface refurbishment interval.

Example tables for three different flux distributions, environmental pollution categories and reflectance values can be found in Annex D.

NOTE 3 Another commonly used definition of surface maintenance factor is the ratio of room surface reflectance at a given time to the initial reflectance value.

# 7 Use of the maintenance factor

## 7.1 Lighting design using the maintenance factor

The maintenance factor, $f_m$, shall be employed in lighting designs to ensure that the target requirements are met throughout the agreed life of the installation when the installation is maintained according to the defined maintenance schedule. The customer needs to be consulted to generate the required input parameters.

Generally, the maintenance schedule is a balance between the cost of compensating for loss of performance of the lighting installation compared with the cost of performing the maintenance operation(s).

The maintained illuminance, $E_m$, shall be calculated according to Formula (5)

$$E_m = E_{in} \cdot f_m \tag{5}$$

or for luminance-based designs according to Formula (6).

$$L_m = L_{in} \cdot f_m \tag{6}$$

where

$E_m$ is the maintained illuminance;

$E_{in}$ is the initial illuminance;

$L_m$ is the maintained luminance;

$L_{in}$ is the initial luminance.

When luminaires of different types are used in the same installation, but the input parameters for the maintenance factor vary significantly between luminaire types, the maintenance factor shall be determined per luminaire type and implemented in lighting design accordingly.

## 7.2 Documentation

### 7.2.1 Documentation of maintenance factor determination

In combination with the determined maintenance factor, $f_m$, clear documentation shall be provided on the conditions used to determine the maintenance factor, $f_m$.

This documentation shall include the individual factors that make up the maintenance factor, $f_m$ determination ($f_{LF}$, $f_S$, $f_{LM}$, $f_{SM}$) and the key values used in determining these (such as the used lifetime) and maintenance schedule.

### 7.2.2 Documentation of maintenance schedules

The maintenance schedule shall at least include the following information:

— installation lifetime;

— cleaning interval(s);

— component replacement interval(s);

— surface refurbishment interval.

## 7.3 Lighting verification using the maintenance factor

Illuminance (or luminance) measured by means of instruments at a given time represent the actual state of the lighting system. A common objective of the measurement is to verify whether the lighting system conforms to the target values set during the design phase.

To compare the measured value to the target-maintained illuminance value, $E_m$, it is necessary to correct the measured value to represent the value as projected for the end of the installation life.



Formula (7) shall be used to calculate the corrected measured illuminance:

$$E_{\mathrm{A,c}} = E_{\mathrm{A}} \cdot \frac{f_{\mathrm{m}}}{f_{\mathrm{m,I}}} \tag{7}$$

where

$E_{\mathrm{A,c}}$ is the corrected measured illuminance;

$E_{\mathrm{A}}$ is the actual measured illuminance

$F_{\mathrm{m,I}}$ is the interim maintenance factor reflecting the depreciation at the measurement time, calculated as if calculating a maintenance factor for the given time point;

$f_{\mathrm{m}}$ is the maintenance factor determined according to the end of life of the lighting system.

NOTE 1 The estimation of the interim maintenance factor using the regular maintenance factor determination procedure as described in Clause 6 is a worst-case scenario assuming the full (negative) effects of luminaire and surface depreciation for the cleaning cycles.

NOTE 2 The above procedure describes the basic principle. For more complex designs using separate maintenance factors for different luminaire types, the above principle can be used in conjunction with lighting simulations to determine the proper $E_{\mathrm{A,c}}$.



# Annex A
(informative)

# Maintenance factor determination examples

## A.1 Example 1: Parking area project 100 000 h, using spot replacement



Project information:

— Installation lifetime: 100 000 h;

— Burning hours per year: 4 000 h;

— Repair strategy: Spot replacement;

— Luminaire cleaning interval: 3 years;

— Pollution category: Low.

Luminaire information:

— Luminaire type: Flood lighting LED luminaire with integrated driver;

— Median useful life $L_{80}$: 100 000 h (no CLO);

— IP Class: IP66;

— Driver failure rate: 0,5 % per 5 000 h.

Determination:

1. Luminous flux factor: Installation lifetime is equal to the given median useful life at $L_{80}$. As such, the luminous flux factor $f_{LF}$ =0,80;

2. Survival factor: Project employs a spot replacement strategy. As such, the mentioned failure rate is not relevant, the survival factor $f_S$ = 1,00;

3. Luminaire maintenance factor: Based on Table C.5, an IP6X luminaire, with pollution category "low", with a 3 years cleaning interval results in a luminaire maintenance factor $f_{LM}$ = 0,90;

4. Surface maintenance factor: Only relevant for indoor installations and outdoor tunnels and underpasses. Not applicable for this situation, $f_{SM}$ = 1,00.

Maintenance factor $f_m$ = 0,80 × 1,00 × 0,90 × 1,00 = 0,72.

## A.2 Example 2: Urban street project 100 000 h, with CLO, using spot replacement

Project information:

— Installation lifetime: 100 000 h;

— Burning hours per year: 4 000 h;

— Repair strategy: Spot replacement;

— Luminaire cleaning interval: 3 years;

— Pollution category: Low.

Luminaire information:

— Luminaire type: LED luminaire with integrated CLO driver;

— Luminous flux: 6 000 lm non-CLO/4 800 lm CLO;

— Median useful life $L_{80}$: 100 000 h using CLO based on $L_{80}$;

— Luminaire flux given as both non-CLO luminous flux (case A) and CLO luminous flux (case B);

— IP Class: IP66;

— Driver failure rate: 0,5 % per 5 000 h.

Determination:

1. Luminous flux factor: Installation lifetime is equal to the given median useful lifetime at $L_{80}$. However, as this is a CLO luminaire, this warrants further investigation. Depending on how the luminaire is specified, there are two options:

   a) Luminous flux is specified as if no CLO is used. This means that the luminous flux depreciation needs to be taken into account in the maintenance factor. As such: The installation lifetime is similar to the given median useful life at $L_{80}$. As such, the luminous flux factor $f_{LF}$ = 0,80.

   b) Flux is specified with the CLO correction already applied. As such, depreciation is already accounted for in the luminaire and is not taken into account in the maintenance factor. Luminous flux factor $f_{LF}$ = 1,00.

2. Survival factor: Project employs a spot replacement strategy. As such driver failure rate is not relevant, survival factor $f_S$ = 1,00.

3. Luminaire maintenance factor: Based on Table C.5, an IP6X luminaire, with pollution category "low", with a 3 years cleaning interval results in a luminaire maintenance factor $f_{LM}$ = 0,90.

4. Surface maintenance factor: Only relevant for indoor installations and outdoor tunnels and underpasses. Not applicable for this situation, $f_{SM}$ = 1,00.

Case A maintenance factor $f_m$ = 0,80 × 1,00 × 0,90 × 1,00 = 0,72.

Case B maintenance factor $f_m$ = 1,00 × 1,00 × 0,90 × 1,00 = 0,90.

Both case A and case B should result in the same light level. To illustrate this, the effect can be observed when applying the maintenance factor as if it were a correction on the luminous flux.

| | |
|---|---|
| Case A: Luminaire/photometry is not corrected for CLO: | 6 000 lm × 0,72 = 4 320 lm |
| Case B: Luminaire/photometry is corrected for CLO: | 4 800 lm × 0,90 = 4 320 lm |

It should be kept in mind, that in the case of CLO luminaires, the power will increase over time to ensure the flux stays constant. This is not a part of the maintenance factor determination, but does warrant attention during the lighting and installation design.

## A.3 Example 3: Office project 25 000 h, using spot replacement

Project information:

— Installation lifetime: 25 000 h;

— Repair strategy: Spot replacement;

— Luminaire cleaning interval: 3 years;



— Surface cleaning/painting interval: 5 years;

— Surface reflections: 0,70/0,50/0,20 (ceiling/wall/floor).

Luminaire information:

— Luminaire type: LED recessed luminaire with integrated driver, closed design;

— Distribution type: Direct;

— Median useful life $L_{90}$: 25 000 h;

— Median useful life $L_{80}$: 50 000 h;

— Driver failure rate: 1 % per 5 000 h.

Determination:

— Luminous flux factor: Installation lifetime is similar to the given useful lifetime at $L_{90}$. As such, the luminous flux factor $f_{LF}$ = 0,90.

— Survival factor: Project employs a spot replacement strategy. As such driver failure rate is not relevant, survival factor $f_S$ = 1,00.

— Luminaire maintenance factor: Based on Table C.1, C.2 and C.3, offices fall in pollution category "clean", and a luminaire with an enclosed design in luminaire category D with a 3 years cleaning interval which results in a luminaire maintenance factor $f_{LM}$ = 0,79 (Table C.4).

— Surface maintenance factor: As this example uses a direct flux distribution, refer to Table D.1. Based on the given reflectance values (0,70/0,50/0,20), and surface refurbishment interval (5 years) in a clean environment, surface maintenance factor $f_{SM}$ = 0,94.

Maintenance factor $f_m$ = 0,90 × 1,00 × 0,79 × 0,94 = 0,67.

## A.4 Example 4: Warehouse project, 10 years, using group replacement

Project information:

— Installation lifetime: 10 years;

— Burning hours per year: 4 000 h;

— Repair strategy: Group replacement;

— Cleaning interval: 3 years;

— Surface cleaning/painting interval: 5 years;

— Surface reflections: 0,50/0,30/0,20 (ceiling/wall/floor).

Luminaire information:

— Luminaire type: LED highbay luminaire with integrated driver, IP65;

— Distribution type: Direct;

— Median useful life $L_{80}$: 50 000 h;

— Light source failure: abrupt failure value AFV = 1 % at 50 000 h;

— Driver failure rate: 1 % per 5 000 h.

Determination:

1. Luminous flux factor: Installation lifetime is 10 years with 4 000 burning hours per year. This results in a total of 40 000 burning hours for the full project. As the provide specifications only provide the depreciation for 50 000 h, the depreciation after 40 000 h can be estimated based on Table B.2. Using the reference specification of $L_{80}$ = 50 000 h, the estimated luminous flux factor $f_{LF}$ = 0,84.

2. Survival factor: As the project uses group replacement, the individual components need to be checked. The light source has a failure of 1 % over the lifetime of the luminaire, which corresponds to 0,8 % for 40 000 h (failure probability $p_f$ = 0,8/100 = 0,008) over the installation lifetime, which corresponds to a survival probability $p_s$ of 0,992 ($p_s$ = 1,0 – 0,008). The driver has a failure rate of 1 % per 5 000 h which corresponds to a total of 8 % for 40 000 h (failure probability $p_f$ = 8/100 = 0,08). This corresponds to a survival probability $p_s$ of 0,92 ($p_s$ = 1,00 – 0,08) over the installation lifetime. As the driver has the lowest survival probability, survival factor $f_S$ = 0,92.

3. Luminaire maintenance factor: Based on Tables C.1, C.2 and C.3, warehouses fall in pollution category "normal", and a luminaire with an IP over 5X in luminaire category E. With a 3 years cleaning interval this results in a luminaire maintenance factor $f_{LM}$ = 0,84 (Table C.4).

4. Surface maintenance factor: As this example uses a direct flux distribution, we need to look at Table D.1. Based on the given reflectance values (0,50/0,30/0,20), and surface refurbishment interval (5 years) in a normal environment, surface maintenance factor $f_{SM}$ = 0,95.

Maintenance factor $f_m$ = 0,84 × 0,92 × 0,84 × 0,95 = 0,62.



# Annex B
(informative)

# Luminous flux factor $f_{LF}$ tables (Typical examples)

To be used with 6.2.1 for approximation of the luminous flux factor at intermediate time points. For accurate information always consult the manufacturer.

**Table B.1 — Typical examples of luminous flux factor $f_{LF}$ per 5 000 burning hours — Values based on IES TM-21-11 calculation method**
**Part 1: from 0 h to 30 000 h**

| Median useful life $L_x$[a] | | Luminous flux factor $f_{LF}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **hours** | ***x*** | **0** | **5 000** | **10 000** | **15 000** | **20 000** | **25 000** | **30 000** |
| 35 000 | 70 | 1,00 | 0,95 | 0,90 | 0,86 | 0,82 | 0,78 | 0,74 |
| | 75 | 1,00 | 0,96 | 0,92 | 0,88 | 0,85 | 0,81 | 0,78 |
| | 80 | 1,00 | 0,97 | 0,94 | 0,91 | 0,88 | 0,85 | 0,83 |
| | 85 | 1,00 | 0,98 | 0,95 | 0,93 | 0,91 | 0,89 | 0,87 |
| | 90 | 1,00 | 0,99 | 0,97 | 0,96 | 0,94 | 0,93 | 0,91 |
| 50 000 | 70 | 1,00 | 0,96 | 0,93 | 0,90 | 0,87 | 0,84 | 0,81 |
| | 75 | 1,00 | 0,97 | 0,94 | 0,92 | 0,89 | 0,87 | 0,84 |
| | 80 | 1,00 | 0,98 | 0,96 | 0,94 | 0,91 | 0,89 | 0,87 |
| | 85 | 1,00 | 0,98 | 0,97 | 0,95 | 0,94 | 0,92 | 0,91 |
| | 90 | 1,00 | 0,99 | 0,98 | 0,97 | 0,96 | 0,95 | 0,94 |
| 70 000 | 70 | 1,00 | 0,97 | 0,95 | 0,93 | 0,90 | 0,88 | 0,86 |
| | 75 | 1,00 | 0,98 | 0,96 | 0,94 | 0,92 | 0,90 | 0,88 |
| | 80 | 1,00 | 0,98 | 0,97 | 0,95 | 0,94 | 0,92 | 0,91 |
| | 85 | 1,00 | 0,99 | 0,98 | 0,97 | 0,95 | 0,94 | 0,93 |
| | 90 | 1,00 | 0,99 | 0,99 | 0,98 | 0,97 | 0,96 | 0,96 |
| 100 000 | 70 | 1,00 | 0,98 | 0,96 | 0,95 | 0,93 | 0,91 | 0,90 |
| | 75 | 1,00 | 0,99 | 0,97 | 0,96 | 0,94 | 0,93 | 0,92 |
| | 80 | 1,00 | 0,99 | 0,98 | 0,97 | 0,96 | 0,95 | 0,94 |
| | 85 | 1,00 | 0,99 | 0,98 | 0,98 | 0,97 | 0,96 | 0,95 |
| | 90 | 1,00 | 0,99 | 0,99 | 0,98 | 0,98 | 0,97 | 0,97 |

[a] Note that $B_y$ is not taken into account for maintenance factor determination purposes.

**Table B.2 — Typical examples of luminous flux factor $f_{LF}$ per 5 000 burning hours — Values based on IES TM-21-11 calculation method Part 2: from 35 000 h to 65 000 h**

| Median useful life $L_x$[a] | | Luminous flux factor $f_{LF}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| hours | $x$ | 35 000 | 40 000 | 45 000 | 50 000 | 55 000 | 60 000 | 65 000 |
| 35 000 | 70 | 0,70 | | | | | | |
| | 75 | 0,75 | | | | | | |
| | 80 | 0,80 | | | | | | |
| | 85 | 0,85 | | | | | | |
| | 90 | 0,90 | | | | | | |
| 50 000 | 70 | 0,78 | 0,75 | 0,73 | 0,70 | | | |
| | 75 | 0,82 | 0,79 | 0,77 | 0,75 | | | |
| | 80 | 0,86 | 0,84 | 0,82 | 0,80 | | | |
| | 85 | 0,89 | 0,88 | 0,86 | 0,85 | | | |
| | 90 | 0,93 | 0,92 | 0,91 | 0,90 | | | |
| 70 000 | 70 | 0,84 | 0,82 | 0,80 | 0,78 | 0,76 | 0,74 | 0,72 |
| | 75 | 0,87 | 0,85 | 0,83 | 0,81 | 0,80 | 0,78 | 0,77 |
| | 80 | 0,89 | 0,88 | 0,87 | 0,85 | 0,84 | 0,83 | 0,81 |
| | 85 | 0,92 | 0,91 | 0,90 | 0,89 | 0,88 | 0,87 | 0,86 |
| | 90 | 0,95 | 0,94 | 0,93 | 0,93 | 0,92 | 0,91 | 0,91 |
| 100 000 | 70 | 0,88 | 0,87 | 0,85 | 0,84 | 0,82 | 0,81 | 0,79 |
| | 75 | 0,90 | 0,89 | 0,88 | 0,87 | 0,85 | 0,84 | 0,83 |
| | 80 | 0,92 | 0,91 | 0,90 | 0,89 | 0,88 | 0,87 | 0,86 |
| | 85 | 0,94 | 0,94 | 0,93 | 0,92 | 0,91 | 0,91 | 0,90 |
| | 90 | 0,96 | 0,96 | 0,95 | 0,95 | 0,94 | 0,94 | 0,93 |

[a] Note that $B_y$ is not taken into account for maintenance factor determination purposes.

**Table B.3 — Typical examples of luminous flux factor $f_{LF}$ per 5 000 burning hours — Values based on IES TM-21-11 calculation method Part 3: from 70 000 h to 100 000 h**

| Median useful life $L_x$[a] | | Luminous flux factor $f_{LF}$ | | | | | | |
|---|---|---|---|---|---|---|---|---|
| hours | $x$ | 70 000 | 75 000 | 80 000 | 85 000 | 90 000 | 95 000 | 100 000 |
| 70 000 | 70 | 0,70 | | | | | | |
| | 75 | 0,75 | | | | | | |
| | 80 | 0,80 | | | | | | |
| | 85 | 0,85 | | | | | | |
| | 90 | 0,90 | | | | | | |
| 100 000 | 70 | 0,78 | 0,77 | 0,75 | 0,74 | 0,73 | 0,71 | 0,70 |
| | 75 | 0,82 | 0,81 | 0,79 | 0,78 | 0,77 | 0,76 | 0,75 |
| | 80 | 0,86 | 0,85 | 0,84 | 0,83 | 0,82 | 0,81 | 0,80 |
| | 85 | 0,89 | 0,89 | 0,88 | 0,87 | 0,86 | 0,86 | 0,85 |
| | 90 | 0,93 | 0,92 | 0,92 | 0,91 | 0,91 | 0,90 | 0,90 |

[a] Note that $B_y$ is not taken into account for maintenance factor determination purposes.



# Annex C
(informative)

# Luminaire maintenance factor $f_{LM}$ determination examples

## C.1 Indoor luminaires

**Table C.1 — Recommended inspection intervals of lighting systems in different working environments (from CIE 097:2005, Table 2.1)**

| Inspection interval | Environment | Activity or task area |
|---|---|---|
| 3 years | Very Clean (VC) | Clean rooms, semiconductor plants, hospital clinical areas[a], computer centres |
| | Clean (C) | Offices, schools, hospital wards |
| 2 years | Normal (N) | Shops, laboratories, restaurants, warehouses, assembly areas, workshops |
| 1 year | Dirty (D) | Steelworks, chemical works, foundries, welding, polishing, woodwork |

[a] For reason of hygiene control, more frequent inspection may be required.

**Table C.2 — Approximate cleaning intervals (marked X) for luminaires used in various environments (VC, C, N or D, see Table C.1) (from CIE 097:2005, Table 2.2, modified — symbols adjusted)**

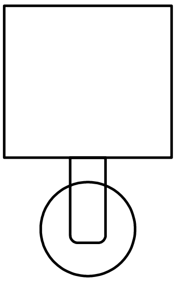
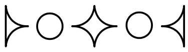
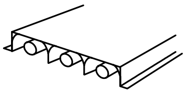
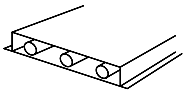
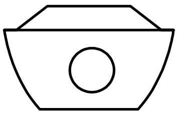
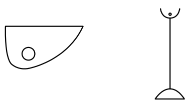
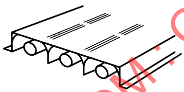
| Luminaire type | Cleaning intervals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3 years | | | 2 years | | | 1 year | | |
| | VC C | N | D | VC C | N | D | VC C | N | D |
| A, Bare batten  | X | | | | X | | | | X |
| B, Open top housing (natural ventilated)  | X | | | | X | | | | X |
| C, Closed top housing (unventilated)  | X | | | (X) | | | | X | |
| D, Enclosed IP2X  | X | | | (X) | | | | X | |
| E, Dust proof IP5X  | X | X | | | | X | | | |
| F, Enclosed indirect (uplight)  | | | | X | | | (X) | X | |
| G, Air handling, forced ventilated  | X | X | | | | X | | | |

**Table C.3 — Examples of luminaire types (CIE 097:2005, Table 2.3)**

| Type | Luminaire types in Table C.2 | Luminaire descriptions |
|---|---|---|
| A | Bare batten | Bare lamp luminaires |
| B | Open top housing (natural ventilated and so called "self cleaning" types) | Direct-indirect luminaires without cover<br>Direct-indirect luminaires with indirect reflector and closed optical device<br>Wall washing luminaires (vertical opening)<br>Wall mounted luminaires open top and base<br>Downlights with open top |
| C | Closed top housing (unventilated) | Recessed and surface mounted luminaires (e.g. with louvers)<br>Downlights, spotlights |
| D | Enclosed IP2X | General purpose luminaires with closed covers and optics |
| E | Dust proof IP5X | Dust proof IP5X (protected, clean room luminaires) |
| F | Indirect lighting and uplight | Free standing, pendent, wall mounted uplighters with closed base, cove lights |
| G | Air handling and forced ventilated | Air handling body and optic used with air-conditioning or ventilation systems |

**Table C.4 — Example of indoor luminaire maintenance factors $f_{LM}$ (CIE 097:2005, Table 3.4)**

| Luminaire type (see Table C.2) | Elapsed time between cleanings years | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0,5 | | | | 1,0 | | | | 1,5 | | | | 2,0 | | | | 2,5 | | | | 3,0 | | | | |
| | Environment | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Any | VC | C | N | D | VC | C | N | D | VC | C | N | D | VC | C | N | D | VC | C | N | D | VC | C | N | D |
| A | 1 | 0,98 | 0,95 | 0,92 | 0,88 | 0,96 | 0,93 | 0,89 | 0,83 | 0,95 | 0,91 | 0,87 | 0,80 | 0,94 | 0,89 | 0,84 | 0,78 | 0,93 | 0,87 | 0,82 | 0,75 | 0,92 | 0,85 | 0,79 | 0,73 |
| B | 1 | 0,96 | 0,95 | 0,91 | 0,88 | 0,95 | 0,90 | 0,86 | 0,83 | 0,94 | 0,87 | 0,83 | 0,79 | 0,92 | 0,84 | 0,80 | 0,75 | 0,91 | 0,82 | 0,76 | 0,71 | 0,89 | 0,79 | 0,74 | 0,68 |
| C | 1 | 0,95 | 0,93 | 0,89 | 0,85 | 0,94 | 0,89 | 0,81 | 0,75 | 0,93 | 0,84 | 0,74 | 0,66 | 0,91 | 0,80 | 0,69 | 0,59 | 0,89 | 0,77 | 0,64 | 0,54 | 0,87 | 0,74 | 0,61 | 0,52 |
| D | 1 | 0,94 | 0,92 | 0,87 | 0,83 | 0,94 | 0,88 | 0,82 | 0,77 | 0,93 | 0,85 | 0,79 | 0,73 | 0,91 | 0,83 | 0,77 | 0,71 | 0,90 | 0,81 | 0,75 | 0,68 | 0,89 | 0,79 | 0,73 | 0,65 |
| E | 1 | 0,96 | 0,94 | 0,93 | 0,91 | 0,96 | 0,94 | 0,90 | 0,86 | 0,92 | 0,92 | 0,88 | 0,83 | 0,93 | 0,91 | 0,86 | 0,81 | 0,92 | 0,90 | 0,85 | 0,80 | 0,92 | 0,90 | 0,84 | 0,79 |
| F | 1 | 0,94 | 0,92 | 0,89 | 0,85 | 0,93 | 0,86 | 0,81 | 0,74 | 0,91 | 0,81 | 0,73 | 0,65 | 0,88 | 0,77 | 0,66 | 0,57 | 0,86 | 0,73 | 0,60 | 0,51 | 0,85 | 0,70 | 0,55 | 0,45 |
| G | 1 | 1,00 | 1,00 | 0,99 | 0,98 | 1,00 | 0,99 | 0,96 | 0,93 | 0,99 | 0,97 | 0,94 | 0,89 | 0,99 | 0,96 | 0,92 | 0,87 | 0,98 | 0,95 | 0,91 | 0,86 | 0,98 | 0,95 | 0,90 | 0,85 |
| For accurate data always consult the manufacturer. | | | | | | | | | | | | | | | | | | | | | | | | | | |