 MAINTENANCE FACTOR OF OUTDOOR LED LIGHTING INSTALLATION

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Abstract

Today with the LED technology in outdoor lighting we can notice that it brings a new way of designing outdoor application in term of period and factor of maintenance.

Indeed LED do not behave like high discharge lamps and are not driven by the same factor; that is why we cannot realise a LED lighting application in the same way as a “standard” lighting application.

When calculating a lighting installation we should think about maintenance of the installation and not only to look at values at commissioning stage.

In order to optimize and well appreciate the energy efficiency of a LED lighting installation it is very important to evaluate correctly the maintenance factor in order to guaranty the required lighting level over one given period.

As today there are no norm regarding outdoor LED lighting application we propose to show the key parameters in term of maintenance of LED to take into account when designing an outdoor LED lighting installation and their influence. It will also show the real need to have norms in this area.

Keywords: LED, Maintenance factor, Lighting, Driving current, Pollution, Aging of material

1 Definition of maintenance factor for outdoor luminaires installations

During its life, an outdoor lighting installation performance will depreciate, meaning that the light coming out from it will progressively decrease. The parameters that will impact even influencing this depreciation can be of various origins: the environment, the luminaire construction and its components, the operations during its life [1].

The maintenance factor MF which is defined as:

$$MF=\frac{Em}{Ein}$$

where $Em=$ maintained luminance or illuminance produced by the lighting installation

$Ein=$ initial luminance or illuminance produced by the lighting installation

is the expression of this depreciation.

It allows to predict the light output of the lighting installation at the end of its life, and therefore to design appropriately the installation to fulfill the minimum lighting levels required by Standards [2] [3].

When designing such an installation, one should take into consideration those elements of depreciation, therefore choose the appropriate products, define maintenance operations during its lifetime and finally dimension the lighting installation according to those elements.

The parameters playing a major role in a lighting installation depreciation, are of three root causes:

- The source luminous flux depreciation
- The source survival
- The luminaire depreciation: the source dirtying and luminaire components dirtying and aging
2 Key parameters and difference between high intensity discharge and LED sources

2.1 The source luminous flux depreciation

Any electric light sources have their luminous flux diminishing with hours of operation.

There are various causes of this phenomenon. For example, for high intensity discharge lamps, blackening of the burner due to material loss of electrode during operation and ignition, degradation of the transmittance of burner material (quartz or ceramic) or change in radiated material composition may occur and be responsible for luminous flux losses.

For LED sources, main known parameters affecting strongly the flux depreciation is the driving current, the junction temperature, but also the ambient temperature or moisture environment; those elements causing for instance diode material degradation or impurities in encapsulant leading to light emission losses.

The industry-standard are using the term ‘lumen maintenance’, which is the converse of the luminous flux depreciation, to expressed the % of initial flux that a source maintain over time.

One of the main aspect differences of LED sources compared to high intensity discharge lamps or fluorescent lamps is the time scale of this luminous flux depreciation, which can be 5 or 6 times the lifetime of the latter.

Figure 1 shows an example of lumen maintenance curve for different lamps type.

![Lumen maintenance of lighting sources](image)

**Figure 1.** Lumen maintenance of different sources in function of burning hours

From lumen maintenance curve, one expressed lumen maintenance data in the form of the time Lx, the flux of a light source will fall at x % of the initial flux.

Example: L70 expressed in hours is the time the light source delivers 70% of its initial flux.

LED manufacturers are relying on the US standard IES LM-80-08 [4], for the testing and reporting of the lumen maintenance of single LED. It describes measurements and reporting on LED light sources for various operating conditions (temperature, driving current...), for a period of 6000 hrs, maximum 10 000hrs.

From it, LED manufacturers are applying their own models for extrapolation of the data on larger time period (> 50 000 hrs) and for more extensive operating conditions (driving current, junction temperature...).

Figure 2 shows an example of model prediction of LED lumen maintenance.
**Figure 2.** XLamp type models prediction for lumen maintenance in function of burning hours

(source CREE- July 2009)

Those models serve to give Lx data of one LED, under different conditions.

Figure 3 shows an example of LED lifetime prediction in function of junction temperature, for various driving currents.

**Figure 3.** L70 lifetime prediction graph, as a function of junction temperature

(source CREE- July 2009)

Those lifetime curves are given for an individual LED light source, and there is, for the moment, no validated models to derive into data for array of LED.

Also in the absence of real data on LED luminaire basis (measurements for every combination of all influencing parameters would be too complex, expensive and time costly), LED luminaire manufacturers must define their own models for the extrapolation of the lumen maintenance for the LED luminaire.

### 2.2 The source survival

Most of light sources burn out at their end of life (operational failure), with immediate effects like no ignition, or shift in colour, or effects that could be more difficult to detect like cycling.

Sources life is influenced by a lot of different factors.
The main cause of lamp failure, for e.g. a high pressure Sodium lamp, is the lamp voltage increase (gradual process) and becomes too high, and also the leakage of the discharge tube and/or the outer bulb. External factors also influence the lamp life: stability of the mains voltage, on-off switching cycle, ballast and ignitor type or cold-spot temperature of the discharge tube.

The source survival (or life expectancy) for a lamp is communicated by a curve, representing the % of survivals (this is defined as the average expected behaviour for this lamp) in relation with the burning hours.

Most commonly, manufacturers are given the Average Rated Life, which is defined as the number of hours, for which 50 % of a large population of a lamp type have failed.

For conventional lamps, it is based upon data under standardized controlled conditions according to IEC.

Besides, for lighting installations, one should consider also early failures, which are the failure of lamps before 100 burning hours. Causes are mainly external of lamps themselves, and can be of many various origins.

For LED sources, the rated life of a LED population is not well-known. Most of LED will not fail at the end of life, but their light output will be so much degraded, that it will fall under acceptable values for the application (typically below 70 % of the initial flux). However, luminous flux maintenance is not the only failure mode. LED can also fail catastrophically.

Therefore failure rate for LED sources is the combination of the probability of catastrophic failure and the % of LED which have their light output falling below useful luminous flux.

Figure 4 shows the graphical representation of the lifetime of a population, applicable for LED [6].

![The Bathtub Curve](image)

**Figure 4.** Failure rate mode for LED

Failure modes of LED have to be considered also at different levels, from bare die level through lighting installation level.

### 2.3 The source service lifetime

The service lifetime expresses the percentage of light output of the total installation in relation of the burning hours (therefore including % of failures).

It is defined as:

\[
\text{Service lifetime (hrs)} = \text{life expectancy (hrs)} \times \text{lumen maintenance (hrs)}, \text{ in relation with burning hours of the installation.}
\]

Figure 5 gives the service lifetime for various intensity discharge lamps.
For LED, failure rate of a single LED are often neglected or not communicated by LED manufacturers. And this is obviously the case for an array of LED in a luminaire. Therefore, by confusion, the luminous flux depreciation value for a single LED is often used as the LED installation service lifetime.

2.4 The luminaire depreciation

The third parameter playing an important role in the luminous output flux depreciation of an installation is the depreciation due to luminaire and its components dirtying and the luminaire components aging. Dirtying of luminaire components, like closing bowl, optical elements (aluminium reflectors or plastic diffusers and refractors) and lamps dirtying are the most critical parameters in the luminous output flux depreciation of a lighting installation. The accumulation of dust and greasy compounds significantly diminishes the reflection properties (of a reflector) and/or transmission properties of refractive components in a luminaire, therefore decreases significantly the light output ratio of the luminaire. The severity depends upon the environment of the lighting installation and the level of pollution.

Next to it, optical components can also have their reflection/transmission properties affected over time due their material aging, under specific conditions of high temperature and/or UV exposure.

Difference with LED installations can come from the components/luminaire parts that have different behavior regarding dirtying or aging (for instance, use of fan in a LED luminaire or some luminaire parts playing a role of heat sink).

The choice of a luminaire having a sufficient ingress protection, composed of robust materials over time and applying regular maintenance (cleaning/replace) period onto the luminaire and its components, are of importance in order to minimize the lighting installation depreciation.

The phenomena of the luminaire depreciation is the same, whether the lighting installation is using conventional lamps or LED sources, however it has to be considered differently, notably because of the significant longer lifetime of LED sources.

Today in lighting recommendations, there is nor value of pollution factor exposure neither ageing of optical cover after around three years of exposure. These values are suitable for high intensity discharge lighting installation but not for LED; as for LED lighting installation we would need values till at least 10 years as the LED lighting luminaires allow being use till approximately 60000 burning hours without changing source.

With conventional lamps, the cleaning period could be usefully combined with the replacement of the source. With LED sources, some maintenance aspects of the installation need to be dissociated from the source replacement, to maintain the minimum required illumination level onto the useful lit area.
3 Maintenance factor tool for outdoor LED lighting installation

By using given data of LED manufacturers and applying extrapolation of some data regarding aging of material and pollution factor it is possible to calculate a maintenance factor to apply when designing an outdoor lighting installation. But this maintenance factor will be calculated with some approximation as all data are extrapolated data.

The tool uses extrapolation of existing data and data of LED manufacturer to calculate the maintenance factor of a given outdoor lighting installation.

3.1 Principles of calculations of the maintenance factor

The formula below is used:

\[ MF = LLMF \times LSF \times LMF \]

![Graphs showing lumen depreciation and relative initial LED flux depending on ambient temperature.](image)

**Figure 6.** Methodology of calculation of the LLMF

The LLMF (LED Lumen Maintenance Factor) depends mainly on LED type, ambient temperature and driving current.
Today as failure rates are still unknown, we only consider in the maintenance factor tool failures link to LED only. It means that failures link to LED only have been taken into account and not failures which depend on solder joint or other causes. A value of LED failure of 5000 ppm (parts per million) have been chosen as a safe starting point before getting more precise data from LED manufacturers. For the luminaires used in the maintenance factor tool we have taken as hypothesis that we can accept to have three LED failures per module.

So it means at the end a value of LSF =1

Luminaires under outdoor ambient environment are exposed to pollution.

By extrapolating data from CIE 154:2003 [1] using linear extrapolation, we have defined pollution factor till 10 years for luminaires with IP6X.

Table 1. Luminaire maintenance factor (LMF) [1]

<table>
<thead>
<tr>
<th>Optical compartment IP Rating</th>
<th>Pollution Category</th>
<th>Exposure time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP6X</td>
<td>High</td>
<td>0.91 0.9 0.88 0.85 0.83</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>0.92 0.91 0.89 0.88 0.87</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>0.93 0.92 0.91 0.90 0.90</td>
</tr>
</tbody>
</table>

Figure 7. Extrapolated depreciation factor in function of time and pollution level
On top of the pollution factor, aging of optical cover plays also an important role in the LMF (Luminaire Maintenance Factor). The AFE (French association of lighting) gives value of aging of optical cover for closed luminaires till 12000 burning hours.

**Table 2. Aging of optical cover [5]**

<table>
<thead>
<tr>
<th>Burning hours</th>
<th>Type of luminaire</th>
<th>Closed Plastic cover</th>
<th>Closed Glass cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PMMA (Polymethyl metacrylate)</td>
<td>PC (polycarbonate)</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4000</td>
<td></td>
<td>1</td>
<td>0.98</td>
</tr>
<tr>
<td>8000</td>
<td></td>
<td>0.99</td>
<td>0.97</td>
</tr>
<tr>
<td>12000</td>
<td></td>
<td>0.99</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**Aging of optical cover in function of burning hours**

**Figure 8. Methodology of calculation of the LMF**
3.2 Example results of the tool

In the tool we can set different parameters to calculate the maintenance factor.

Figure 9 shows the interface where the user can adjust them.

The key parameters are:

- Driving current
- Reloading period (change of LED module)
- Ambient temperature
- Cleaning period
- Pollution level
- Type of optical cover material

![Maintenance factor calculation of Philips Outdoor LEDs luminaires](image)

**Solution 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminaire</td>
<td>CitySoul Leds</td>
</tr>
<tr>
<td>Driving current</td>
<td>350 mA</td>
</tr>
<tr>
<td>Burning hours per year</td>
<td>4000</td>
</tr>
<tr>
<td>Reloading period (year)</td>
<td>no reloading</td>
</tr>
<tr>
<td>Average night temperature over one year</td>
<td>10 °C</td>
</tr>
<tr>
<td>Cleaning period (year)</td>
<td>3</td>
</tr>
<tr>
<td>Pollution</td>
<td>low</td>
</tr>
<tr>
<td>CLO</td>
<td>no</td>
</tr>
<tr>
<td>Maintenance factor at</td>
<td>50000</td>
</tr>
<tr>
<td>MF for 50000 hours (12 years)</td>
<td>0.80</td>
</tr>
</tbody>
</table>

![Figure 9. Inputs for calculation of the maintenance factor](image)

As a result, the tool will give the maintenance factor value for the chosen period, which is the lowest light output value of the lighting installation over this period.

With this tool we can visualize what is the amount of light on the application depending on the time (Figure 10).
3.2.1 Influence of the different parameters

The tool allows the comparison of two different lighting installations having different key parameters. Therefore we can better see the influence of one parameter on the luminous output flux depreciation.

In the example below the only difference between solution 1 and solution 2 is that there is no cleaning of luminaires for solution 2 and a cleaning every three years for solution 1.

In this case we lose more than 22 % of light output if luminaires are not cleaned compared to a solution where luminaires are cleaned every three years.

The pollution level and ambient temperature are the less influencing parameters for the light output depreciation of LED outdoor lighting installations.

The pollution factor is for LED luminaires the parameter that most influences the maintenance factor.
**Table 3. Level of influence on light output depreciation of the different parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Level of influence on light output depreciation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (&lt;5 %)</td>
</tr>
<tr>
<td>Driving current of LED</td>
<td></td>
</tr>
<tr>
<td>Cleaning period</td>
<td></td>
</tr>
<tr>
<td>Pollution level</td>
<td></td>
</tr>
<tr>
<td>Optical cover material</td>
<td></td>
</tr>
<tr>
<td>Releading period</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusion**

The fast penetration of the LED technology into the lighting market has changed the consideration of this lighting installations maintenance.

Knowledge of the maintenance factor and behaviour of LED lighting installation is necessary to guaranty and maintain the required lighting levels over a given period.

Significantly affected by LED sources specificities in terms of luminous flux depreciation and failure modes, outdoor LED lighting installations overtime are on the other side still influenced by pollution factor and luminaire cleaning cycles, as conventional lighting installations.

But today we can notice a lack of data for LED and LED in luminaires, and it is important to develop standards for LED performance, for measurements conditions, reporting and use of reliable data concerning LED. Already Standard IEC PAS on performance requirements for LED luminaires and LED modules are ongoing and should be published in 2011.

By the help of tools and reliable data, we can better take into consideration the various factors influencing the luminous output flux depreciation of a LED lighting installation, which is mandatory for the knowledge of the LED lighting installations depreciation overtime in order to best dimension those installations.

This is the only way to guarantee the sustainability of a LED lighting installation, and to give confidence to the end-users for the success of this new technology.

On top of that, it will be useful for planning maintenance work and to use the right products combination in order to minimize power consumption of the lighting installation.

**References**

6. WILKINS, D.J. 2002 *The Bathtub curve and product failure behavior* Reliability HotWire eMagazine